**Supplementary Material**

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

Melanie L. Bateman1, Roger K. Day2, Belinda Luke3, Steve Edgington3, Ulrich Kuhlmann1, Matthew J.W. Cock3

1CABI, Rue des Grillons 1, CH-2800 Delémont, Switzerland  
2CABI, 673 Limuru Road, PO Box 633-00621 Nairobi, Kenya  
3CABI, Bakeham Lane, Egham, Surrey, TW20 9TY, UK

Correspondence  
Melanie L. Bateman, CABI, Rue des Grillons 1, CH-2800 Delémont, Switzerland.  
Email: [m.bateman@cabi.org](mailto:m.bateman@cabi.org)

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# Supplementary Table 1 National lists of registered pesticides and biopesticides for the 30 study countries

| Country | References for the national lists of registered pesticides |
| --- | --- |
| 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>. Accessed July 2017.  Servicio Nacional de Sanidad y Calidad Agroalimentaria - Argentina. *LMR de principios activos por cultivo.* Accessed July 2017. |
| Benin | Liste des produits phytopharmaceutiques. December 2016. |
| Bolivia | <http://www.senasag.gob.bo/egp/productossv4.html> |
| 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 July 2017.  Bettiol, W., Boechat Morandi, M. A., Vegette Pinto, Z., de Paula Júnior, T. J., Barbosa Corrêa, É., Bittencourt Moura, A., Mantovanello Lucon, C. M., de Cássia do Bomfim Costa, J., & J. L. Bezerra. (2012). *Produtos Comerciais à Base de Agentes de Biocontrole de Doenças de Plantas*. EMBRAPA Meio Ambiente. Documentos 88. Jaguariúna, SP. |
| Burkina Faso | Pesticide Liste Globale. May 2017. |
| Cameroon | Liste Grand Publique. March 2017. |
| Chile | <http://www.sag.cl/ambitos-de-accion/plaguicidas-y-fertilizantes/78/registros> |
| Colombia | Instituto Colombiano Agropecuario – ICA. *Listado de Registros nacionales de plaguicidas quimicos de uso agrícola*. <http://www.ica.gov.co/Areas/Agricola/Servicios/Regulacion-y-Control-de-Plaguicidas-Quimicos.aspx>. Accessed July 2017.  Instituto Colombiano Agropecuario – ICA. *Listado de Productos Bioinsumos registrados.* <http://www.ica.gov.co/getdoc/a5c149c5-8ec8-4fed-9c22-62f31a68ae49/Fertilizantes-y-Bio-insumos-Agricolas.aspx>. Accessed July 2017. |
| DR Congo | DR Congo Registered Pesticides 2014 |
| Costa Rica | <http://www.sfe.go.cr/SitePages/Registrodesustancias/Estado-de-sustancias-en-registro.aspx> |
| Ecuador | AGROCALIDAD - Agencia Ecuatoriana de Aseguramiento de la Calidad del Agro. *Listados oficiales Plaguicidas Agrícolas.* <http://www.agrocalidad.gob.ec/listados-oficiales-plaguicidas-agricolas/>. March 2017. |
| Ethiopia | List of Registered Pesticides. 2017. |
| Ghana | Environmental Protection Agency. (2017). Revised Register of Pesticides as at January 2017 under Part II of the Environmental Protection Agency Act, 1994 (Act 490). Accra, Ghana. |
| Kenya | Kenyan Pesticide Control Board. *Products Registered for Use on Crops.* <http://pcpb.or.ke/cropproductsviewform.php>. Accessed December 2017. |
| Malawi | Pesticides Control Board. 2015. List of Pesticides Registered In Malawi. |
| Mali | Pesticide Liste Globale. May 2017. |
| Mexico | Servicio Nacional de Sanidad, Inocuidad y Calidad Agroalimentaria - Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación - Mexico. *Lista de Plaguicidas de uso agrícola autorizados.* <http://189.254.115.252/Resoluciones/Consultas/ConWebRegPlaguicida.asp?TipoRegPlafest=1&TxtBuscar=TAB&button=Buscar&MM_Buscar=FrmBuscar&offset=0>.Accessed August 2017. |
| Mozambique | Ministério da Agricultura, Direcção Nacional de Serviços Agrários. 2017. *Lista Dos Pesticidas Registados Em Moçambique*., Departamento de Sanidade Vegetal, Repartição de Registo e Controle De Agroquímicos. |
| Nigeria | National Agency for Food & Drug Administration and Control. Directorate of Registration & Regulatory Affairs – Lagos. *Approved pesticides*. Undated. |
| Panama | *Agroquímicos - Productos registrados en Panamá*. [http://www.mida.gob.pa/direcciones/direcciones\_nacionales/direccion-de-sanidad-vegetal/agroquimicos.html](http://www.mida.gob.pa/direcciones/direcciones_nacionales/direccion-de-sanidad-vegetal/agroquimicos.html%20) |
| Peru | <http://200.60.104.77/SIGIAWeb/sigia_consulta_producto.html> |
| Rwanda | Official Gazette nᵒ 30 of 25/07/2016 |
| Sierra Leone | 2012 List of AI recommended by Ministry of Agriculture, Forestry and Food Security |
| South Africa | <http://www.croplife.co.za/index.php/croplife-sa-initiatives?layout=edit&id=15>  <http://www.nda.agric.za/doaDev/sideMenu/Food%20Import%20&%20Export%20Standard/docs/Guideline%20for%20registered%20agrochemicals%20to%20control%20Fall%20armyworm%20in%20South%20Africa.pdf> |
| Tanzania | Tropical Pesticides Research Institute. 2011. *List of Registered Pesticides in Tanzania.* <http://tpri.or.tz/>; <http://tpri.or.tz/news/Pesticides_Gazette_2011.pdf>. Accessed March 2017. |
| Togo | Liste des produits phytopharmaceutiques homologues. July 2017. |
| Tunisia | Liste des pesticides homologués en Tunisie. September 2016. |
| Uganda | Ministry of Agriculture Animal Industry and Fisheries. 2017. Register of Agricultural Chemical Registered Under Section 4 of the Agricultural Chemicals (Control) Act, 2006. |
| 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 July 2017.  *Pesticides Chemical Search*. Office of Pesticide Programs. United States Environmental Protection Agency. <https://iaspub.epa.gov/apex/pesticides/f?p=CHEMICALSEARCH:1>: Accessed July 2017.  United States Government Publishing Office. *Govinfo.* <https://www.govinfo.gov>. Accessed July 2017. |
| Zambia | List, Undated. |

# Supplementary Table 2 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? | * 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? Is use realistic given farmers’ time and labour constraints? Are there appropriate application equipment and storage facilities available? Is the biopesticide compatible with other crop protection measures that are applied in the production system? 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 proceed to the next point * 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 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. 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, 2015) 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; **-** = 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 Pesticide Action Network (2016). PAN International List of Highly Hazardous Pesticides (PAN, 2016).

Y = Listed; N = Not listed

6 AI is permitted for use in in the EU.

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

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

| **Active ingredient**  **(in alphabetical order)** | **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** |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| (z)-11-hexadecenyl acetate | Semiochemical | Beet armyworm, FAW | Low hazard | U | N | N | N | N | N | N | N | N | Y | Y |
| (z,e)-9,12-tetradecadien-1-yl acetate | Semiochemical | Lepidoptera, *Spodoptera litura* | Warning | N | N | N | N | N | N | N | N | N | N | Y |
| 2-phenylethyl propionate | Botanical | Armyworms (*Spodoptera* spp.) | Missing data | - | - | - | - | N | N | N | N | N | N | N |
| Allyl isothiocyanate (see also “mustard oil”) | Botanical | Armyworm, caterpillars, FAW, southern armyworm, yellowstriped armyworm (*S.* *ornithogalli*) | Danger | N | N | N | N | N | N | N | N | N | N | N |
| Anagrapha falcifera multi-nuclear polyhedrosis virus polyhedral inclusion bodies in aqueous suspension | Microbial | Armyworm, beet armyworm, caterpillars, FAW, southern armyworm, western yellowstriped armyworm (*S.praefica*), yellowstriped armyworm | Low hazard | N | N | N | N | N | N | N | N | N | N | N |
| Azadirachtin (neem products) | Botanical | Armyworm, beet armyworm, caterpillars | Warning | U | N | N | N | N | N | N | N | N | Y | Y |
| *Bacillus thuringiensis* | Microbial | FAW | Danger | N | N | N | N | N | N | N | N | N | - | - |
| *Bacillus thuringiensis* subsp. *aizawai* | Microbial | Beet armyworm, Lepidoptera, armyworm | Danger | N | N | N | N | N | N | N | N | N | Y | Y |
| *Bacillus thuringiensis* subsp. *kurstaki* | Microbial | Lepidoptera, armyworm, beet armyworm, FAW, yellowstriped armyworm, *S. litura* | Danger | N | N | N | N | N | N | N | N | N | Y | Y |
| *Beauveria bassiana* | Microbial | Lepidoptera, armyworm | Low hazard | U | N | N | N | N | N | N | N | N | Y | Y |
| Beet armyworm nuclear polyhedrosis virus | Microbial | Beet armyworm | Missing data | N | - | - | - | N | N | N | N | N | N | N |
| Borax | Inorganic compounds / minerals | Armyworm, beet armyworm | HHP | N | N | N | Y | N | N | N | N | Y | N | N |
| Canola oil (Rape seed oil) | Botanical | Caterpillars, FAW, armyworm, beet armyworm | Low hazard | N | N | N | N | N | N | N | N | N | Y | Y |
| Capsaicin | Botanical | Armyworm, caterpillars, FAW, southern armyworm, yellowstriped armyworm | Danger | N | N | N | N | N | N | N | N | N | N | N |
| Chromobacterium subtsugae strain praa4-1 cells and spent fermentation media | Microbial | Armyworm, beet armyworm, FAW, yellowstriped armyworm | Missing data | U | - | - | - | N | N | N | N | N | Y | Y |
| Cinnamaldehyde | Botanical | Armyworm, Lepidoptera | Warning | N | N | N | N | N | N | N | N | N | N | N |
| Citric acid | Botanical | Wide range of insects including ants, aphids, beetles, mealybugs and mites; fungi | HHP | N | Y | Y | Y | N | N | N | N | N | N | N |
| Cryolite | Inorganic compounds / minerals | Armyworm, beet armyworm, caterpillars | Danger | N | N | N | N | N | N | N | N | N | N | N |
| d-glucitol, octanoate | Botanical | Caterpillars | Low hazard | N | N | N | N | N | N | N | N | N | N | N |
| *Dysphania ambrosioides* | Botanical | Caterpillars | Danger | N | N | N | N | N | N | N | N | N | N | N |
| Emamectin benzoate | Microbial extracts / fermentation products / enzymes | Beet armyworm, FAW | Danger | N | N | N | N | N | N | N | N | N | Y | N |
| Ethyl palmitate | Botanical | Spider mites | Low hazard | N | N | N | N | N | N | N | N | N | N | N |
| Ethyl (z)-7-dodecenyl acetate | Semiochemical | FAW | Low hazard | - | - | - | - | N | N | N | N | N | - | N |
| Ethyl (z)-9-tetradecenyl | Semiochemical | FAW | Low hazard | N | N | N | N | N | N | N | N | N | ? | N |
| Eugenol | Semiochemical | Armyworm | Low hazard | N | N | N | N | N | N | N | N | N | Y | Y |
| Garlic oil | Botanical | Armyworm, caterpillars | Warning | N | N | N | N | N | N | N | N | N | N | N |
| gs-omega/kappa-hxtx-hv1a | Other | Armyworm, Lepidoptera | Missing data | - | - | - | - | N | N | N | N | N | N | N |
| Helicoverpa zea single capsid nucleopolyhedrovirus (vpn-hzsnpv) (baculovírus) | Microbial | FAW | Missing data | - | - | - | - | N | N | N | N | N | N | N |
| Kaolin clay | Inorganic compounds / minerals | Aphids, armyworm, cutworms, earwigs, faw, grasshoppers, japanese beetle, june beetles, loopers, mites, onion thrips, powdery mildew, stink bugs, tarnished plant bug, thrips, whiteflies Plant regulator (growth enhancer), plant regulator (increase yield), | Danger | N | N | N | N | N | N | N | N | N | Y | N |
| Lufenuron | Insect growth regulators | Biting and sucking insects, e.g. caterpillars and beetle larvae | Warning | N | N | N | N | N | N | N | N | Y | Y | N |
| Maltodextrin | Inorganic compounds / minerals | Spider mites, aphids and whiteflies | Missing data | N | - | - | - | N | N | N | N | N | Y | Y |
| Matrine | Botanical | Caterpillars | Warning | N | N | N | N | N | N | N | N | N | N | N |
| *Metarhizium anisopliae* | Microbial | Lepidoptera | Missing data | N | - | - | - | N | N | N | N | N | Y | Y |
| Methoxyfenozide | Insect growth regulators | Lepidoptera eggs | Low hazard | N | N | N | N | N | N | N | N | N | Y | N |
| Mustard oil | Botanical | Armyworm, southern armyworm, FAW | Danger | N | N | N | N | N | N | N | N | N | N | N |
| Orange oil | Botanical |  | Missing data | U | - | - | - | N | N | N | N | N | N | Y |
| Oxymatrine | Botanical |  | Warning | N | N | N | N | N | N | N | N | N | N | N |
| *Isaria fumosorosea* apopka 97 (*Paecilomyces fumosoroseus* fe9901) | Microbial | Caterpillars | Missing data | U | - | - | - | N | N | N | N | N | Y | Y |
| Potassium salts of fatty acids | Inorganic compounds / minerals | Caterpillars, armyworm | Danger | N | N | N | N | N | N | N | N | N | Y | Y |
| Pyrethrins | Botanical | Armyworm, beet armyworm, caterpillars, lawn armyworm (*S. mauritia)*, southern armyworm, western yellowstriped armyworm, white grubs, whiteflies, yellowstriped armyworm | Warning | N | N | N | N | N | N | N | N | N | Y | Y |
| Spodoptera frugiperda nucleopolyhedrovirus (SfMNPV) | Microbial | FAW, beet armyworm | Missing data | - | - | - | - | N | N | N | N | N | N | N |
| Silicon dioxide (diatomaceous earth) | Inorganic compounds / minerals | Armyworm, beet armyworm, caterpillars | Warning | N | N | N | N | N | N | N | N | N | Y | N |
| s-methoprene | Insect growth regulators | Armyworm | Warning | U | N | N | N | N | N | N | N | N | N | N |
| Soybean oil | Botanical | Caterpillars, FAW | Low hazard | N | N | N | N | N | N | N | N | N | N | N |
| Spinetoram | Microbial extracts / fermentation products / enzymes | Armyworm, FAW, beet armyworm, true armyworm (*Pseudaletia unipuncta*), caterpillars, southern armyworm | Warning | U | N | N | N | N | N | N | N | Y | Y | N |
| Spinosad | Microbial extracts / fermentation products / enzymes | Armyworm, beet armyworm, FAW, caterpillars, true armyworm, southern armyworm | Warning | N | N | N | N | N | N | N | N | Y | Y | N |
| *Steinernema carpocapsae* | Macrobials - entomopathogenic nematodes |  | Low hazard | U | - | - | - | N | N | N | N | - | - | - |
| *Steinernema feltiae* | Macrobials - Entomopathogenic nematodes |  | Low hazard | U | - | - | - | N | N | N | N | - | - | - |
| Sucrose octanoate | Botanical | Caterpillars | Missing data | - | - | - | - | N | N | N | N | N | - | N |
| Sulphur | Inorganic compounds / minerals | Caterpillars | Warning | N | N | N | N | N | N | N | N | N | Y | Y |
| *Trichogramma* spp. | Macrobials - parasitoids | FAW | Low hazard | U | - | - | - | N | N | N | N | 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 (Y / N)** | | | | | | | | | | | **Active Ingredients registered for use in its countries  where FAW is spreading in Africa (Y / N)** | | | | | | | | | | | | | | | | | | |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Active ingredient**  **(shortened names / details)** | 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 | Countries with registrations | Products registered |
| (z)-11-hexadecenyl acetate | 0 | 0 | 1 | 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 | 2 | 2 |
| (z,e)-9,12-tetradecadien-1-yl acetate | 0 | 0 | 1 | 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 | 2 | 4 |
| 2-phenylethyl propionate | 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 | 1 | 2 |
| Allyl isothiocyanate (mustard oil) | 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 | 1 | 0 | 0 | 2 | 2 |
| Anagrapha falcifera MNPV | 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 | 1 | 1 |
| Azadirachtin | 1 | 0 | 0 | 0 | 0 | 6 | 3 | 1 | 6 | 0 | 110 | 0 | 0 | 0 | 0 | 1 | 0 | 10 | 1 | 0 | 0 | 0 | 1 | 0 | 3 | 5 | 0 | 22 | 0 | 1 | 14 | 171 |
| *Bacillus thuringiensis* | 0 | 0 | 11 | 0 | 0 | 0 | 0 | 112 | 4 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 2 | 0 | 9 | 0 | 1 | 11 | 144 |
| *B. thuringiensis* subsp. *aizawai* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 3 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 5 | 10 |
| *B. thuringiensis* subsp. *kurstaki* | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 8 | 41 | 0 | 1 | 0 | 0 | 0 | 0 | 8 | 0 | 1 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 8 | 68 |
| *Beauveria bassiana* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 6 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 1 | 4 | 0 | 0 | 2 | 0 | 1 | 0 | 5 | 1 | 0 | 0 | 1 | 0 | 9 | 25 |
| Borax | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 5 | 0 | 3 | 5 | 15 |
| Canola oil (rape seed oil) | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 19 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 2 | 22 |
| Capsaicin | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 12 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 | 15 |
| Chromo-bacterium subtsugae | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 10 |
| Cinnamaldehyde | 0 | 0 | 0 | 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 | 1 | 3 |
| Citric acid | 0 | 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 | 1 | 1 |
| Cryolite | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 7 |
| d-glucitol, octanoate | 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 | 1 | 1 |
| *Dysphania ambrosioides* | 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 | 1 | 2 |
| Emamectin benzoate | 3 | 3 | 0 | 0 | 1 | 0 | 0 | 0 | 2 | 5 | 9 | 1 | 22 | 11 | 0 | 0 | 5 | 9 | 0 | 22 | 4 | 0 | 0 | 0 | 7 | 0 | 4 | 3 | 2 | 1 | 18 | 114 |
| Ethyl (z)-7-dodecenyl acetate | 0 | 0 | 1 | 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 | 1 | 1 |
| Ethyl (z)-9-tetradecenyl | 0 | 0 | 1 | 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 | 1 | 1 |
| Ethyl palmitate | 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 | 0 | 0 |
| Eugenol | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 3 |
| Garlic oil | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 2 | 7 |
| 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 | 1 | 1 |
| Helicoverpa zea NPV | 0 | 0 | 3 | 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 | 1 | 3 |
| Kaolin clay | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 7 |
| Lufenuron | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 7 | 0 | 0 | 4 | 2 | 0 | 0 | 0 | 6 | 1 | 4 | 3 | 0 | 0 | 0 | 4 | 0 | 1 | 3 | 0 | 0 | 11 | 37 |
| 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 | 1 | 1 |
| Matrine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 |
| *Metarhizium anisopliae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 5 | 9 |
| Methoxyfenozide | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 1 | 0 | 0 | 5 | 9 |
| Orange oil | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 4 | 7 |
| Oxymatrine | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 2 |
| *Isaria fumosorosea* | 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 | 1 | 1 |
| Beet armyworm NPV | 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 | 1 | 2 |
| Potassium salts of fatty acids | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 15 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 2 | 16 |
| Pyrethrins | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 171 | 0 | 0 | 0 | 0 | 0 | 1 | 10 | 4 | 0 | 0 | 0 | 1 | 0 | 3 | 1 | 0 | 0 | 0 | 0 | 8 | 193 |
| Sex pheromones | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 2 | 11 |
| Spodoptera frugiperda NPV | 0 | 0 | 1 | 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 | 2 | 2 |
| Silicon dioxide | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 6 |
| s-methoprene | 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 | 1 | 1 |
| Soybean oil | 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 | 1 | 4 |
| Spinetoram | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 3 | 1 | 22 | 0 | 2 | 0 | 0 | 1 | 0 | 2 | 1 | 2 | 0 | 0 | 0 | 0 | 2 | 0 | 2 | 1 | 0 | 0 | 12 | 43 |
| Spinosad | 5 | 3 | 0 | 0 | 0 | 0 | 0 | 0 | 7 | 4 | 70 | 1 | 4 | 1 | 0 | 2 | 1 | 3 | 2 | 4 | 3 | 1 | 1 | 0 | 4 | 1 | 1 | 4 | 0 | 1 | 21 | 123 |
| *Steinernema carpocapsae* | 0 | 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 | 1 | 1 |
| *Steinernema feltiae* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 2 | 3 |
| Sucrose octanoate | 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 | 1 | 1 |
| Sulphur | 14 | 0 | 0 | 0 | 0 | 0 | 36 | 0 | 0 | 0 | 5 | 0 | 0 | 0 | 0 | 0 | 0 | 14 | 2 | 0 | 1 | 0 | 0 | 0 | 15 | 0 | 0 | 20 | 2 | 2 | 10 | 111 |
| *Trichogramma* spp. | 0 | 0 | 2 | 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 | 1 | 2 |

# 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 |

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) | Recommendation and next steps |
| --- | --- | --- | --- | --- | --- | --- |
| 2-phenylethyl propionate | N | Missing data | NP**[[1]](#footnote-1)** | Y | N | Not recommended for further action |
| Allyl isothiocyanate (mustard oil) | YSpLe | Y | NMAP | Y | N | Allyl isothiocyanate is the active ingredient in mustard oil, so it is potentially a candidate for local production. Bioassays should be performed. |
| Anagrapha falcifera multi-nuclear polyhedrosis virus polyhedral inclusion bodies in aqueous suspension | N | Y | Y | Y | N | Not recommended for further action |
| Azadirachtin (neem products) | YfaNr | Y | Y | Y | Y | To better understand the potential for azadirachtin-based products as a means of FAW control in the local context, field trials could be conducted. 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* | YFaNr/  YLeNr | Y | Y | Y | Y | 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* | YFN | Y | Y | Y | Y |
| *Bacillus thuringiensis* subsp. *kurstaki* | YSN | Y | Y | Y | Y |
| *Beauveria bassiana* | YFaLa | Y | Y | Y | Y | Take forward for lab/field trials to determine which isolates are most suitable for FAW control. |
| Beet armyworm nuclear polyhedrosis virus | YSpNr | Y | Y | Y | N | Not registered in any of the 19 African countries, so no further action is recommended. |
| Borax | YFaLa | N | Y | Y | Y | Not recommended for further action |
| Canola oil (rape seed oil) | N | Y | Y | Y | N | Not recommended for further action |
| Capsaicin | YFaLa | Y | Y | Y | N | Capsaicin is the active ingredient in chili peppers, so it is potentially a candidate for local production. Field trials should be performed. |
| Chromobacterium subtsugae strain praa4-1 cells and spent fermentation media | YSpNr | Y | Y | Y | N | Not registered for use in any of the reviewed countries in Africa. Therefore, no further action is recommendedI. |
| Cinnamaldehyde | N | Y | Y | N | N | Not recommended for further action |
| Citric acid | N | N | NMA | No data | Y | Not recommended for further action |
| Cryolite | N | Y | NMA | Y | N | Not recommended for further action |
| d-glucitol, octanoate | N | Y | No data | Y | Y | Not recommended for further action |
| *Dysphania ambrosioides* | YFaLa | Y | NMI | Y | N | 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. |
| Emamectin benzoate | YSpAf | Y | N | Y | Y | Not recommended for further action |
| Ethyl palmitate | N | Y | Y | Y | Y | Not recommended for further action |
| Eugenol | N | Y | Y | Y | Y | Not recommended for further action |
| Garlic oil | YSpAf | Y | Y | Y | N | Candidate for local production. Further tests in the laboratory should be conducted prior to considering registration. |
| gs-omega/kappa-hxtx-hv1a | N | Missing data | Y | Y | N | No further action recommended. This AI would seem to be too early in its development |
| Helicoverpa zea single capsid nucleopolyhedrovirus (vpn-hzsnpv) (baculovírus) | YSpNr | Y | Y | N | N | 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. |
| Kaolin clay | YSpAf | Y | Y | Y | Y | Carry out bioassays in countries where it is registered |
| Lufenuron | YFaNr | Y | NMA | Y | Y | Carry out field trials in countries where it is registered |
| Maltodextrin | YLeLa | Y | N | Y | Y | 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 | YFaLa | Y | No data | No data | Y | Carry out field trials in countries where it is registered to determine efficacy against FAW, agronomic sustainability, and practicality for use. |
| *Metarhizium anisopliae* | YFaNr | Y | Y | Y | Y | Three countries have *Metarhizium* registered. However they do not appear to have been tested on FAW. Field trials on FAW are recommended. |
| Methoxyfenozide | YFaNr | Y | Y | Y | Y | Conduct field trials in countries where it is registered |
| Orange oil | YFaLa | Y | Y | Y | Y | Conduct field trials in countries where it is registered |
| Oxymatrine | YLeAf | Y | No data | No data | Y | Given that oxymatrine is registered for use in Ghana, 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. |
| Isaria fumosorosea apopka 97 (Paecilomyces fumosoroseus fe9901) | YSpLa | Y | Y | Y | N | *Isaria fumosorosea* is not registered in any of the 19 countries, so further action is not recommended. |
| Potassium salts of fatty acids | N | Y | Y | Y | Y | No further follow-up action recommended. |
| Pyrethrins | YFaNr | Y | NMAP | Y | Y | Field trials to assess efficacy should be conducted in countries where pyrethrins are registered. |
| Sex pheromones | YFaAf | Y | Y | N | Y | Develop for monitoring rather than control. |
| Silicon dioxide (diatomaceous earth) | YFaLa | Y | Y | Y | Y | Field trials to assess efficacy should be conducted in countries where registered. |
| s-methoprene | N | Y | NMA | Y | N | No further follow-up action recommended. |
| Soybean oil | N | Y | Y | N | N | No further follow-up action recommended. |
| Spinetoram | YFaNr | Y | NMP | Y | Y | Field trials to assess efficacy should be conducted in countries where registered. |
| Spinosad | YFaNr | Y | NMPR | Y | Y | Field trials to assess efficacy should be conducted in countries where registered. |
| Spodoptera frugiperda nucleopolyhedrovirus (SfMNPV) | YFaNr | Y | Y | Y | N | Not availablein Africa. However worth testing in bioassays |
| *Steinernema carpocapsae* | YSpNr | Y | Y | N | Y | There are issues regarding efficacy, shelf-life and cost |
| *Steinernema feltiae* | YFaNr | Y | Y | N | Y | There are issues regarding efficacy, shelf-life and cost |
| Sucrose octanoate | YLeLa | Y | Y | Y | N | Bioassays to determine its efficacy against FAW are recommended. |
| Sulphur | N | Y | Y | Y | Y | No evidence to merit further work |
| *Trichogramma* spp. | YFaNr | Y | Y | N | Y | Test whether native species parasitise FAW. Explore local production and distribution. |

# Supplementary data. Efficacy, agronomic sustainability, practicality and affordability of the biopesticide active ingredients registered for use against fall armyworm in at least one of the 30 study countries

[2-phenylethyl propionate 20](#_Toc515355325)

[Allyl isothiocyanate (mustard oil) 20](#_Toc515355326)

[Anagrapha falcifera nuclear polyhedrosis virus (AFNPV) 21](#_Toc515355327)

[Azadirachtin (neem products) 21](#_Toc515355328)

[*Bacillus* *thuringiensis* 22](#_Toc515355329)

[*Beauveria* *bassiana* 23](#_Toc515355330)

[Beet armyworm nuclear polyhedrosis virus 24](#_Toc515355331)

[Borax 24](#_Toc515355332)

[Canola oil (rape seed oil) 25](#_Toc515355333)

[Capsaicin 26](#_Toc515355334)

[*Chromobacterium subtsugae* strain praa4-1 cells and spent fermentation media 26](#_Toc515355335)

[Cinnamaldehyde 27](#_Toc515355336)

[Citric acid 27](#_Toc515355337)

[Cryolite 28](#_Toc515355338)

[d-glucitol, octanoate 29](#_Toc515355339)

[*Dysphania ambrosioides* (Mexican tea) 29](#_Toc515355340)

[Emamectin benzoate 30](#_Toc515355341)

[Ethyl palmitate 30](#_Toc515355342)

[Eugenol 31](#_Toc515355343)

[Garlic oil 31](#_Toc515355344)

[GS-omega/kappa-Hxtx-Hv1a 32](#_Toc515355345)

[Helicoverpa zea single capsid nucleopolyhedrovirus (vpn-hzsnpv)(baculovírus) 32](#_Toc515355346)

[*Isaria fumosorosea* apopka 97 (*Paecilomyces fumosoroseus* fe9901) 33](#_Toc515355347)

[Kaolin clay 33](#_Toc515355348)

[Lufenuron 34](#_Toc515355349)

[Maltodextrin 34](#_Toc515355350)

[Matrine 35](#_Toc515355351)

[*Metarhizium* *anisopliae* 35](#_Toc515355352)

[Methoxyfenozide 36](#_Toc515355353)

[Orange oil 36](#_Toc515355354)

[Oxymatrine 37](#_Toc515355355)

[Potassium salts of fatty acids 37](#_Toc515355356)

[Pyrethrins 38](#_Toc515355357)

[Sex pheromones 38](#_Toc515355358)

[Spodoptera frugiperda nucleopolyhedrovirus (SfMNPV) 40](#_Toc515355359)

[Silicon dioxide (diatomaceous earth) 40](#_Toc515355360)

[S-methoprene 41](#_Toc515355361)

[Soybean oil 42](#_Toc515355362)

[Spinetoram 42](#_Toc515355363)

[Spinosad 42](#_Toc515355364)

[*Steinernema carpocapsae* and *S. feltiae* 43](#_Toc515355365)

[Sucrose octanoate 43](#_Toc515355366)

[Sulphur 44](#_Toc515355367)

[*Trichogramma* spp. 45](#_Toc515355368)

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 (NCBI, 2017a). It also attracts Japanese beetles and kills insects, spiders and mites (US EPA, 2000a). Products containing 2-phenylethyl propionate are typically registered for use against wasps, spiders and storage pests (including some Lepidoptera). It is used in domestic settings and in warehouses. Products often contain other AI such as pyrethrins or piperonyl butoxide.

1. *Efficacy:* Review 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:* For some of the HHP criteria (1-4), data were not available (NCBI, 2017a), so a full assessment of human health hazards is not possible. 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. Because of the missing hazard data, it is not possible to say whether the human health and environmental risks are acceptable or not.
3. *Agronomic sustainability:* No cautions regarding pollinators were listed on the labels assessed, but Hymenoptera such as wasps, hornets and yellow jackets are listed as targets, suggesting that it may be toxic to bees.
4. *Practicality:* No special requirements for PPE, application equipment, storage or disposal were listed.
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.

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

Allyl isothiocyanate (mustard oil)

Allyl isothiocyanate is an organosulfur compound which is a constituent of certain cruciferous vegetables such as mustard, horseradish and wasabi (NCBI, 2017b). It is responsible for the pungent taste of foods derived from these plants (Zviely, 2011). The commercial products *Bugitol* and *Nemitol* (Champon Millennium Chemicals, Inc.) containing allyl isothiocyanate that were identified through analysis of the lists of registered pesticides are derived from the essential oil of mustard. These commercial products also contain capsaicin derived from *Capsicum spp.* Bugitol is registered for use on a wide range of crops, including maize and other grains, whereas Nemitol is only registered for use against armyworm in landscaping and golf courses. Bugitol is applied to the plants whereas Nemitol is also applied as a soil treatment.

1. *Efficacy:* There was laboratory evidence of efficacy of allyl isothiocyanate against other *Spodoptera* species. One study assessed the toxicity of allyl isothiocyanate on its own and in formulation with other pesticides against *Spodoptera litura* when applied as a spray or fumigant (Eltayeb, Zhang, Xie, & Mi, 2010). The study found that *S. litura* was susceptible to allyl isothiocyanate, and they suggested that it could be an alternative to the fumigant phosphine. In another study, artificial diets containing allyl isothiocyanate were lethally toxic to neonates of *Spodoptera eridania* (Li, Eigenbrode, Stringam, & Thiagarajah, 2000). The above mentioned product Bugitol is registered for use against armyworm, including FAW, in the USA. The product label states that Bugitol “repels and controls” pests such as armyworm.
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria, 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); fatal or 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; NCBI 2017b). 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. 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 commercial product containing allyl isothiocyanate kills and repels bees, so it should not be applied prior to or during pollination.
4. *Practicality:* The product label for Bugitol states that it should be applied preventively at foliar emergence. Applications should be repeated at 10- to 14-day intervals to maintain the repellent effect. The required elements of PPE are as follows: chemical resistant gloves, protective eyewear, long-sleeved shirt and trousers, and shoes plus socks. No extraordinary equipment, storage or disposal requirements were listed on the label. Overall, the product seems reasonably practical to use.
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.

**Recommendation:** Allyl isothiocyanate is the active ingredient in mustard oil, so it is potentially a candidate for local production. Bioassays should be performed. To mitigate harmful effects to pollinators, mustard oil should not be applied immediately prior to or during pollination. Given that it is very toxic to aquatic organisms, care should be taken to avoid contaminating waterways.

Anagrapha falcifera nuclear polyhedrosis virus (AFNPV)

This nuclear polyhedrosis virus originally isolated from the celery looper, *Anagrapha falcifera* [*Syngrapha falcifera*]. With more than 30 Lepidoptera species from ten different families showing susceptibility to AFNPV (Hostetter and Puttler, 1991), this Nuclear Polyhedrosis Viruses (NPV) has a relatively broad host range for a Baculovirius (Grewal, Webb, Beek, Dimock, & Georgis, 1998).

1. *Efficacy:* There is no evidence to suggest that nuclear polyhedrosis virus of *Anagrapha falcifera* is effective (Farrar & Ridgway, 1999). A study comparing virulence of AFNPV to various Lepidoptera species concluded that AFNPV could provide effective control to *H. zea*, *H. virescens*, and *S. exigua* in field but not FAW (Grewal et al., 1998). However, more generally NPV have been shown to be effective in controlling *Spodoptera* (Moscardi, 1999; Redman, Wilson, Gryzywacz, & Cory, 2010).
2. *Human health and environmental hazards:* The risks to human health and the environment are low. It is not a cholinesterase inhibitor. It can cause mild eye irritation and is harmful if inhaled. There are insufficient data on ground water contamination, or whether it is a carcinogen, a developmental or reproductive toxin or an endochrine disruptor. According to the International Organisation for Biological Control (IOBC) data on pesticide selectivity there is no influence of granulosis virus on benefical organisms. The European Food Safety Authority (EFSA, 2012) peer review of Cydia pomonella granulovirus (CpGV) indicated that there is low toxicity towards bees.
3. *Agronomic sustainability:* It appears to be safe to benefical organisms.
4. *Practicality:* The product label examined for nuclear polyhedrosis virus 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). Nuclear polyhedrosis virus 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

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

Azadirachtin (neem products)

Azadirachtin, derived from the tree *Azadirachta indica*, is one of the most widely used botanical biopesticides. Azadirachtin extracts are used by both commercial farmers and small scale farmers, and they are produced both as commercial products and by the farmers themselves. Most commercial neem products are oil-based, emulsifiable concentrates containing azadirachtin at various concentrations. Azadirachtin disrupts or inhibits the normal development of eggs, larvae or pupae by preventing normal hormone releases that trigger growth and maturation. It also acts as a repellent, a feeding and ovipositional deterrent, and a mating disruptor (Ghewande, Desai, Narayan, & Ingle, 1993).

1. *Efficacy:* Plant material (leaves, seeds, seed cake, seed kernels and oil) from *A. indica* has been successfully used for the control of a wide range of insect pests in field application, and there is consistent evidence for the control of lepidopteran pests (J. Dougoud, S. Toepfer, & W. Jenner, pers. comm. (in prep.)).There is evidence from the lab and the field (in the Americas), for the efficacy of azadirachtin against FAW. In the field in Brazil, azadirachtin reduced damage by FAW to the maize variety "José Lucena" (Azevedo, Moura, Júnior, Silva, & Oliveira, 2013). Crocker and Wei (2001) found that 2.5-7.50 kg/ha of azadirachtin 3% ME (microencapsulated) applied to newly hatched larvae can cause high rates of FAW mortality and they observed dosage-related reductions in larval weight gain. Azadirachtin showed ovicidal activity in concentrations up to 1000 mg L-1, which caused mortalities between 12 and 31% (Zamora, Martínez, Nieto, Schneider, Figueroa, & Pineda, 2008) and it also significantly reduced the larval weight of third instars of FAW. Four- and 6-day-old FAW caterpillars showed mortality after exposure to neem oil (83.33±0.83 and 89.58±0.90%, respectively) whereas it caused comparatively low larval mortality of the FAW predator *Eriopsis connexa* (25.00±0.33% versus 91.66±1.22% for lufenuron) (Tavares, Costa, Cruz, Silveira, Serrão, & Zanuncio, 2010). In a laboratory study, maize leaf disks treated with neem extracts repelled feeding by FAW (Mazzonetto, Coradini, Corbani, & Dalri, 2013). Meanwhile, in some field studies in crops like collards and pearl millet, there was no evidence for efficacy; azadirachtin was not effective at controlling FAW in pearl millet under field conditions in the USA (Buntin, Hanna, Wilson, & Ni, 2007). Similarly, azadirachtin was inconsistent in its performance against Lepidopteran pests including FAW in collards under field conditions in Virginia (Cordero et al., 2006).
2. *Human health and environmental hazards:* Azadirachtin does not meet any of the HHP criteria (NCBI, 2017c), 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:* Azadirachtin is moderately toxic to bees (University of Hertfordshire, 2017a). *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 Ghana and Kenya (CABI 2017a). Thus, the potential for invasiveness should assessed when considering local production of neem extracts.
4. *Practicality:* In order to assess practicality of use, the labels for two products were reviewed: Azatin XL, which is registered in Tunisia and the USA, and Neemazal, which is registered in South Africa and the USA. Products containing azadirachtin should be applied when infestation is expected or soon after the pest appears. The products can be applied at any time up to the day of harvest. The spray should be applied to the whole surface of the plant to ensure complete coverage, or as a soil drench. The spray mixture should be kept at a pH between 5.5 and 7 for optimal performance. Likewise, it should be used promptly after mixing with water. According to the product labels reviewed, they are compatible with most commonly used pesticides and fertilizers, though a jar test is recommended. An exception is highly alkaline products like captan and Bordeaux mixture; mixing with these products can cause phytotoxicity or reduce efficacy. The required elements of PPE are as follows: protective eyewear, long-sleeved shirt and trousers, and shoes plus socks. The two products differed in the chemical resistance requirements for the gloves: Neemazal requires the use of chemical resistant gloves whereas Azatin XL further specifies that the gloves should be made of barrier laminate or viton. No extraordinary equipment, storage or disposal requirements were listed on the label. Overall, products containing azadirachtin seem practical to use.
5. *Availability:* Several products containing azadirachtin are registered for use against armyworm, including FAW, in the Americas. Azadirachtin is registered in six of the 19 countries assessed in Africa: Ethiopia, Kenya, Rwanda, South Africa, Tanzania and Tunisia.
6. *Affordability:* No data available.

**Recommendation:** To better understand the potential for azadirachtin-based products as a means of FAW control in the local context, field trials could be conducted. 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*

*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. aizawi* 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 bepend on the subspecies and strain. Hardke, Leonard, Huang, & Jackson (2011) reported that Cry1f was effective against *Spodoptera frugiperda*. However, Cry1a(b) has been reported as showing signs of resistence (Vilella, Waquil, Vilela, Siegfried, & Foster, 2002). *Bt aizawai* HD 68 and *Bt thuringiensis* 4412 showed 100% and 80% control respectively against *Spodoptera frugiperda* (Polanczyk, Silva, & Fiuza, 2000). *Bacillus thuringiensis* subsp. *kurstaki* (product name DiPel strain ABTS – 351) is effective against *Spodoptera* spp., however other strains are better (Hernandez, 1988). The XenTari product is effective against black cutworm (Mashtoly, Abolmaaty, El-Zemaity, Hussien, & Alm, 2011).
2. *Human health and environmental hazards:* For human health XenTari (*Bt* subsp. *aizawai*) is harmful if inhaled or absorbed through the skin. It also causes moderate eye irritation. Hence the following must be worn; long-sleeved shirt and long trousers, water proof gloves, shoes and socks and a dust/mist mask meeting the NIOSH stardards of at least N-95, R-95 or P-95. XenTari is toxic to aquatic invertebrates as well as the green lacewing and the predatory mite *Metaseiulus occidentalis*. The toxicity of *Bt* subsp. *kurstaki* is classified as WHO U – unlikely to present acute hazard except for flower bugs (*Anthocoris nemoralis*) where it is moderately harmful (reduction field, semi-field 50-75%, lab 30-79%) (IOBC Pesticide Selectivity).
3. *Agronomic sustainability:* Due to toxicity to 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.
4. *Practicality:* There are three different formulations of *Bt* subsp. *kurstaki*: dry flowable granules (Registered in Kenya), emulsifiable suspension and wettable powder. The products should be stored in a cool dry place as high temperatures will damage spores. The application rate is 25-100g/100 ml water or 1kg/ha. XenTari (*Bt* subsp. *aizawai*) has an application rate of 0.5-2 pounds/acre in a water application. Generally *Bt* is stable at room temperature with a maximum temperature of 32oC.
5. *Availability: Bt* products are registered in 10 African coutries ; Kenya is the only one of these where *Bt* subsp. *aizawai* is registered, and *Bt* subsp. *kurstaki* is registered in five African countries (See Supplementary Table 5 for more registration information regarding countries and products)*.*
6. Affordability: No data.

**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, Waturu, Mureithi, Muriuki, Kamau, & Munene, 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. On a more general note Petlamul & Prasertsan (2012) concluded that *Beauveria bassiana* was pathogenic to *Spodoptera litura* larvae.
2. *Human health and environmental hazards:* 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. The usual safety equipment is recommended, including dust masks (NIOSH/MSHA approved respirator), overalls and gloves. As the product contains an oil it is classified under Section 311 or the Clean Water Act and/or under the Oil Pollution Act. Naturalis-L is not classified as dangerous according to Regulations (EC) No. 1272/2008 (CLP). It has precautionary statements P261 (avoid breathing spray), P262 (do not get in eyes, on skin or on clothing), P271 (use outdoors or in a well ventilated area), P280 (wear protective gloves) and P309+P311 (if exposed or feeling unwell contact a doctor). It also has three supplementary statements: EUH401 (to avoid risks to human health and the environment, comply with the instructions for use); SP1 (do not contaminate water with the product or its contrainer); and EUH208 (contains *Beauveria bassiana*, strain ATCC 74040). Micro-organisms may have the potential to provoke sensitising reactions.
3. *Agronomic sustainability:* BotaniGard 22WP has the potential to be pathogenic to honey bees. 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:* BioPower has the following application rate: powder: 4kg/ha in 500 l water for foliar spray and 3 l/ha for liquid. It has a shelf life of two years for the liquid formulation and 1 year for the powder formulation. Naturalis-L has an application rate of 0.3% v/v (i.e. 3 litres in 1000 l water). The shelf life is one year at room temperature. However, ideally the product should be stored at 4-5oC to retain maximum spore viability.
5. *Availability:* There are 11 products of *B. bassiana* registered in 7 African countries and a further 10 products registered in the Americas.
6. Affordability: No data

**Recommendation:** Take forward for lab/field trials to determine which isolates are most suitable for FAW control.

Beet armyworm nuclear polyhedrosis virus

Beet armyworm nuclear polyhedrosis virus or Spodoptera exigua nuclear polyhedrosis virus (SeNPV) is a baculovirus which infects beet armyworm (*S. exigua*) (Smits, 1987; CABI, 2017f).

1. *Efficacy*: A commercial preparation of this virus was first registered in the US (Spod-X®, produced by Certis USA); products have since been registered in Europe and Thailand. Preparations of this virus can be used on a range of crops but is specific to larvae of beet armyworm (*S. exigua*). However the genome of this virus is strikingly similar to that of the S. frugiperda multiple nucleopolyhedrovirus (SeMNPV) and was also found to replicate in FAW in the presence of SeMNPV (Serrano, Williams, Simón, López-Ferberc, Caballero, & Muñoz, 2013). In Spain local *S. exigua* were significantly more susceptible to a local strain of this virus compared to the Spod-X® preparation (Lasa, Pagola, Ibañez, Belda, Williams, & Caballero, 2007).
2. *Human health and environmental hazards*: This AI is not listed as a PAN bad actor chemical or listed by WHO for acute toxicity. 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.
3. *Agronomic sustainability*: Do not apply directly to water bodies or to areas where surface water is present. Do not contaminate water bodies when cleaning spray equipment or when disposing of leftover material.
4. *Practicality*: Commercial preparations can be applied using conventional ground or aerial application equipment. The quantities of water used should provide thorough coverage of infested plants without runoff. The amount of water used depends on weather, equipment and local experience but is generally between 200-1200L/ha for ground spraying and 60L/ha aerial spraying. 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 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.

Borax

Borax, also known as boric acid or sodium tetraborohydrate decahydrate, is a naturally-occurring mineral produced by the repeated evaporation of seasonal lakes. Products containing borax have been registered for use in the United States since 1948 and can be used to manage insects, mites, fungi and weeds. Borax works by desiccating the soft body stage of arthropods. In particular, borax products have been used indoors to manage pests such as silverfish, ants and cockroaches. There are also some products for use in the field in agriculture settings, which are registered against a wide range of diseases and insects, including armyworm.

1. *Efficacy:* A review of the literature failed to identify any references that demonstrated the efficacy of borax against FAW or any other Lepidoptera in agricultural settings. Numerous publications indicate, however, 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 (NCBI, 2017d), thus it is considered to be an HHP (NCBI, 2017d). 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. 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:* No non-target effects were found.
4. *Practicality:* Borax should not be tank-mixed with surfactant adjuvants or copper-containing products. The required elements of PPE are as follows: protective eyewear, long-sleeved shirt and trousers, waterproof gloves and shoes plus socks. No extraordinary equipment, storage or disposal requirements were listed on the label.
5. *Availability:* Products containing borax are registered in Tunisia
6. *Affordability:* No data available.

**Recommendation:** Given that borax is an HHP, no further action is recommended.

Canola oil (rape seed oil)

Canola oil is an edible vegetable oil extracted from four species of rape plants, *Brassica napus, Brassica juncea, Brassica rapa* and *B. campestris* of the family Brassicaceae (mustard family) that can be used to control insects on a wide variety of crops (US EPA, 1998). Canola oil repels insects by altering the outer layer of the leaf surface or by acting as an insect irritant (US EPA, 1998).

1. *Efficacy:* 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. No studies were found regarding its efficacy against FAW. Some products containing canola oil and pyrethrins (e.g. Pyrol-O) are registered for use against *Spodoptera spp.* in the USA. One product reviewed, which contained only canola oil as an active ingredient, was not registered for use against armyworm.
2. *Human health and environmental hazards:* According to the majority of notifications provided by companies to ECHA in CLP notifications, no hazards have been classified, thus canola oil appears to have low toxicity with no adverse effects on humans or the environment (ECHA, 2017a). 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. While canola oil has a low toxicity to honeybees, one of the products reviewed, Pyrol-O, was listed as being highly toxic to bees. This could be due to the fact that the product also contains pyrethrins as an extra AI.
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 the USA. It is not registered in any of the 19 countries assessed in Africa.
6. Affordability: No data.

**Recommendation:** While one product on the market in the USA is labelled for use against armyworm, there is little evidence in the literature for efficacy. These products are said to be repellents, which may not be the most effective approach for managing FAW in the field. Not recommended for further action.

Capsaicin

Capsaicin is the active ingredient in chilli peppers. It is extracted by grinding dried, ripe chili peppers (*Capsicum* *spp.*) into a fine powder. The powder is then distilled in a solvent and the solvent is evaporated in order to obtain the highly concentrated oleoresin. This liquid has little odor but has an extremely pungent taste. Capsaicin is used as a bird, animal and insect repellent (US EPA, 1992a). Capsaicin also has some insecticidal activity and can be applied to crops with low levels of insect infestation (CABI, 2017b). Once applied to the plant surface, the capsaicin induces Lepidopteran larvae to move from the plant to the soil surface. Treatment with capsaicin-based products may also reduce adult egg-laying. Capsaicin is claimed to disrupt insect metabolism and to affect the insect central nervous system. It also damages insect cell membranes, causing holes to form. The review of the lists of registered pesticides identified some products for which capsaicin was the only AI, as well as products with capsaicin in formulation with other AI such as azadirachtin, garlic oil and soybean oil.

1. *Efficacy:* Chilli pepper extracts have been used to control a wide range of insect pests with some level of success in field trials (J. Dougoud, S. Toepfer, & W. Jenner, pers. comm. (in prep.)).Some laboratory studies reported slower growth rates of *Spodoptera frugiperda* feeding on an artificial diet spiked with capsaicin (Ahn, Badenes-Pérez, & Heckel, 2011), no studies were found to document the effects of capsaicin on larvae in the field in Africa or elsewhere. Some of the products reviewed are registered against beet armyworm (*Spodoptera exigua*).
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) (NCBI, 2017e). 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:* Capsaicin rapidly degrades in the environment, and it is toxic to honeybees (CABI, 2017b).
4. *Practicality:* Some product labels recommend using capsaicin-based products in combination with a sticker. The required elements of PPE are as follows: long-sleeved shirt and long trousers, socks and shoes. Some products’ labels also indicate that protective eyewear and waterproof or chemical resistant gloves should be worn when using products containing capsaicin. No extraordinary equipment, storage or disposal requirements were listed on the labels reviewed. Overall, products containing capsaicin seem practical to use.
5. *Availability:* This AI is not registered in any of the 19 countries assessed in Africa. Extracts of *Capsicum spp.* are prepared by farmers and used as an insect control in many countries.
6. *Affordability:* No data available.

**Recommendation:** Capsaicin is the active ingredient in chili peppers, so it is potentially a candidate for local production. Bioassays should be performed.

*Chromobacterium subtsugae* strain praa4-1 cells and spent fermentation media

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

1. *Efficacy: Chromobacterium subtsugae* is effective against armyworms, hornworms, loopers, saltmash caterpillar, tomato fruitworm, tomato pinworm and variegated cutworm in pepper production (Ozores-Hampton, Boyd, McAvoy, Miller, Noling, & Vallad, 2014).
2. *Human health and environmental hazards:* The productGrandevo does not meet the hazard criteria set by the 2012 Occupational Safety and Health Administration (OSHA) Hazard Communication Standard (29 CFR 1910.1200). However, this product is potentially irritating to the respiratory tract, eyes and skin (Marrone Bio Innovations 2013). It has the following hazard statements: H317 (may cause an allergic skin reaction) and H335 (may cause respiratory irritation). It has the following precautionary statements: P261 (avoid breathing fume/gas/mist/vapors/spray); P281 (use personal protective equipment as required); and P284 (wear respiratory protection). It is recommended that a dust/mist respirator meeting NIOSH standards of at least N-95, R-95 or P95 is used along with general PPE. Grandevo has a toxicological rating of category 4 (>5000 mg/kg for dermal and oral exposure and >5000 for gases, vapours are >20 mg/l and dusts and mists are >5mg/l) making it non-toxic or practically non-toxic to mammalian wildlife, beneficial insects and mites and freshwater aquatic life in short-term studies. Long-term data are unavailable. Grandevo was found to be practically non-toxic to honey bees (Marrone Bio Innovations 2015).
3. *Agronomic sustainability:* Can be used in organic production. For Grandevo it is recommended that it is not 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 the USA.
6. Affordability: $170 for 5 lbs.

**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

The essential oil of the bark of cinnamon and cassia trees contains 70%-90% cinnamaldehyde, and food-grade cinnamaldehyde is used industrially to give a cinnamon flavour or smell to non-alocholic beverages, ice cream, candy, baked goods, gum, condiments, etc (US EPA, 2000b). In agriculture, it is used as a fungicide, insect attractant and animal repellent (CABI, 2017c). In particular, it has been used as an attractant for corn rootworm (*Diabrotica ssp.*). On one product label reviewed (Cinnacure), insecticidal action was listed for a wide range of insects and mites, including armyworm.

1. *Efficacy:* Cinnamaldehyde has been shown to cause mortality in stored product pests such as *Callosobruchus maculatus* and *Sitophilus oryzae* (Brari and Thakur, 2015). In field studies, cinnamaldehyde was not effective at controlling wireworm in potato (Ester & Huiting, 2007). Review of the literature failed to identify any references demonstrating the efficacy of cinnamaldehyde against FAW or any other Lepidoptera 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). Cinnamon oil is also classified as GRAS and is used as a food flavour (US EPA, 2000b). The AI does not meet any of the HHP criteria (NCBI, 2017f), so it is not considered to be an HHP. Human health hazards associated with the AI include that it 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(CABI, 2017c), and it has low toxicity to bees.
4. *Practicality:* In the case of Cinnacure, the product can be applied using conventional equipment such as backpack sprayers. The product should be sprayed directly onto the pest. Spray solutions should not be below pH of 3.0 or exceed a pH of 8.0. The product should not be applied to newly transplanted or otherwise stressed plants. The required elements of PPE are as follows: long-sleeved shirt and long trousers, waterproof gloves, protective eyewear and shoes plus socks. No extraordinary equipment, storage or disposal requirements were listed on the labels reviewed.
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:** While one product on the market in the USA is labelled for use against armyworm, there is little evidence in the literature for efficacy. Having to spray the pest directly could also present challenges for management. Given these points in conjunction with that fact that cinnamaldehyde 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.

Citric acid

Citric acid is found in citrus fruits. Different sources list different targets for citric acid: the Bio-Pesticides DataBase (BPDB) (University of Hertfordshire, 2017b) lists it as a disinfectant and fungicide and an acidity regulator in some pesticide formulations. The CABI Crop Pest Compendium (CABI, 2017d) indicates that it is a plant-derived insecticide; and the US EPA (1992b) states that it is used as as a disinfectant, sanitiser and fungicide, which in combination with other active ingredients, kills odour-causing bacteria, mildew, pathogenic fungi, certain bacteria and some viruses. One product containing citric acid (Gomite) is registered for use against thrips, spider mites, aphids and whiteflies in roses and French beans in Kenya. The label for this product was not available for review.

1. *Efficacy:* Review of the literature failed to identify any references which demonstrated efficacy of citric acid against FAW or any other Lepidoptera in agricultural settings.
2. *Human health and environmental hazards:* The hazard profiles for citric acid on the ECHA C&L Inventory (ECHA, 2017b) and Pubchem (NCBI, 2017g) were markedly different. According to the notifications provided by companies to ECHA no hazards have been classified. Pubchem, on the other hand, lists several human health hazard statements: harmful if swallowed (H302); causes skin irritation (H315); may cause an allergic skin reaction (H317); causes eye irritation (H320); may cause allergy or asthma symptoms or breathing difficulties if inhaled (H334); may cause genetic defects (H340); suspected of causing genetic defects (H341); may cause cancer (H350); suspected of causing cancer (H351); may damage fertility or the unborn child (H360); causes damage to organs through prolonged or repeated exposure (H372). Based on these human health hazard statements, it is categorised as 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. According to the notifications in the Pubchem database, it is very toxic to aquatic life with long lasting effects.
3. *Agronomic sustainability:* No data available regarding toxicity to bees.
4. *Practicality:* No data available.
5. *Availability:* Citric acid is registered in Kenya.
6. *Affordability:* No data available.

**Recommendation:** Given the limited information available regarding citric acid and the indications that citric acid may be an HHP, further follow-up action for this AI is not recommended.

Cryolite

Cryolite is the naturally occurring form of sodium aluminum fluoride, and it is typically mined in Greenland (NCBI, 2018a). Dusts or aqueous suspensions of powdered cryolite are used as insecticides. Several cryolite-based products are registered for use against armyworm in the USA.

1. *Efficacy:* Laboratory studies have demonstrated that feeding on cryolite by *S. litura* results in a reduction of larval and pupal weight, a reduction of pupation and also a reduction in adult emergence (Prasad, Krishnayya, & Vijayalakshmi, 1999). In laboratory studies comparing cryolite’s efficacy against *S. exigua* to that of other synthetic pesticides and biopesticides, it was found that cryolite was less effective than spinosad and *Bacillus thuringiensis subsp. aizawai* (Yee & Toscano, 1998). Higher concentrations of cryolite were needed to have an effect.
2. *Human health and environmental hazards:* Cryolite does not meet any of the HHP criteria (NCBI, 2018a), so it is not considered to be an HHP. Human health hazards associated with the AI include the following; it is toxic if swallowed (H301), harmful if swallowed (H302), harmful if inhaled (H332), and causes damage to organs through prolonged or repeated exposure (H372). 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 the EU. The AI is very toxic to aquatic organisms with long lasting effects.
3. *Agronomic sustainability:* In field tests in groundnut crops, cryolite did not cause any phytotoxic symptoms (Prasad et al., 1999).
4. *Practicality:* Cryolite is most effective when coverage of plants is thorough and all plants in an area are treated. Cryolite should not be applied in combination with products containing lime. Required PPE elements include long sleeved shirt and long trousers, chemical resistant gloves, and shoes plus socks. Depending on the crop, the pre-harvest interval for cryolite may be up to 30 days. Treatment with cryolite leaves a residue which may be removed by washing/ brushing/ field trimming/ and other means.
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:** Given the limited information available and the low availability, further follow-up action for this AI is not recommended.

d-glucitol, octanoate

D-glucitol, octanoate can be produced from corn syrup, cane or beet sugar (NCBI, 2017h). 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 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:* According to the majority of notifications provided by companies to ECHA notifications no hazards have been classified (ECHA, 2017c).
3. Agronomic sustainability: No data available.
4. *Practicality:* Application should be initiated as soon as the pest is observed, and applications should be repeated at 7-10 day intervals to maintain good control. The required elements of PPE are as follows: long-sleeved shirt and long trousers, waterproof gloves, protective eyewear and shoes plus socks. 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 the USA. It is not registered in any of the 19 countries assessed in Africa.
6. *Affordability:* No data available.

**Recommendation:** Given the limited information available, further follow-up action for this AI is not recommended.

*Dysphania ambrosioides* (Mexican tea)

Leaves of the flowering plant “American Wormseed” or “Mexican tea” (*Dysphania ambrosioides*, formerly known as *Chenopodium ambrosioides* near *ambrosioides*) have been consumed as a green and herb in traditional Mexican cooking (US EPA, 2009). Historically, extracts of *D. ambrosioides* have been used as a folk medicine, and more commercially, as a nematicide for humans and livestock. More recently, extracts of *D. ambrosioides* have been commercialised as a biopesticide, as monoterpenoids contained in the essential oil of *D. ambrosioides* possess insecticidal properties (J. Dougoud, S. Toepfer, & W. Jenner, pers. comm. (in prep.)). Extracts of *D. ambrosioides* work through a physical mode of action, softening the cuticles of treated insects which then disrupts insect respiration.

1. *Efficacy:* One laboratory study found that aqueous extracts of *Dysphania ambrosioides* at 20% concentration reduced FAW larval viability to 12% (Trindade et al., 2015). Lower concentrations also caused larval mortality and reduced pupal viability. In other laboratory studies, application of extracts of *Dysphania ambrosioides* did not cause FAW mortality (Tagliari, Knaak, & Fiuza, 2010) and did not deter FAW feeding (Mazzonetto et al., 2013).
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 (2017d) this substance may be fatal if swallowed and enters airways, is toxic if swallowed, is toxic in contact with skin, causes skin irritation and may cause an allergic skin reaction. 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 *Global Compendium of Weeds* lists *D. ambrosioides* as a noxious weed in the United States, Central and South America, Asia, Africa, Australia and Europe (Randall, 2012).
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 the USA. It is not registered in any of the 19 countries assessed in Africa.
6. *Affordability:* No data available.

**Recommendation:** Products containing extracts of *Dysphania ambrosioides* are labelled for use against FAW in the USA. While one laboratory study suggested that extracts of *Dysphania ambrosioides* are effective against FAW, another did not support that conclusion. Further laboratory studies and field studies would 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 developed for the control of Lepidoptera; it is active by both contact and ingestion and has been registered in many countries for use on a wide variety of crops.

1. *Efficacy:* The authors found numerous references demonstrating the efficacy of Emamectin benzoate against Lepidoptera, including *Spodoptera*, in both lab and field settings (e.g., Ishaaya, Kontsedalov, & Horowitz, 2002; El-Sheikh, 2015).
2. *Human health and environmental hazards:* According to ECHA and PAN Emamectin benzoate has high acute toxicity to aquatic life and honeybees.
3. *Agronomic sustainability:* There are a number of references of insect resistance to Emamectin benzoate (including *Spodoptera*) (e.g., Ahmad, Sayyed, Saleem, & Ahmad, 2008; Lebedev, Abo-Moch, Gafni, Ben-Yakir, & Ghanim, 2013).
4. *Practicality:* Emamectin benzoate is available in a number of formulations (e.g., granule, powder and liquid) and is compatible with standard spray equipment
5. *Availability:* Emamectin benzoate is registered in many countries around the world, including Kenya and Ghana, for use on a wide variety of crops
6. Affordability: prices vary

**Recommendation**: Strong evidence of efficacy, practicality and availability with a number of registrations already present in Africa, however there are serious concerns regarding acute toxicity to various non-targets, including bees. Further follow-up action is not recommended.

Ethyl palmitate

Ethyl palmitate is the ethyl ester of palmitic acid, an oil found in fruits such as apricot, sour cherry, grapefruit, bilberry, guava fruit, melon, pineapple, Chinese quince and clary sage (NCBI, 2018f).

1. *Efficacy:* One laboratory study showed strong activities against carmine spider mites *Tetranychus cinnabarinus* xx (>90% mortality at 2mg/ml) (Bu, Duan, Wang, Ma, Liu, & Shi, 2012)
2. *Human health and environmental hazards:* Ethyl palmitate does not meet any of the HHP criteria, so it is not an HHP. Ethyl palmitate causes serious eye irritation and may be irritable to the mucous membranes and upper repiratory tract. It may also be harmful by inhalation, ingestion or skin absorption. Ethyl palmitate may also cause, acute and delayed, anaemia, cough, CNS depression, drowsiness, headache, heart damage, lassitude, liver damage, narcosis, reproductive effects, teratogenic effects (Cayman Chemical Company, 2014). 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.
3. *Agronomic sustainability:* There is no data available regarding toxicity to bees.
4. *Practicality*: Flammable and may cause serious eye damage/irritation - keep away from heat/open flame, wash hands thoroughly after handling. PPE: appropriate personal protection (compatible chemical-resistant gloves, safety glasses, overalls, rubber boots) plus NIOSH approved respirator. Handling precautions: avoid breathing it in, avoid prolonged or repeated exposure, take precautionary measures against static discharge. Storage precautions: keep away from heat, sparks, and flame, keep container tightly closed. No special disposal considerations (Cayman Chemical Company, 2014).
5. Availability: No data available.
6. Affordability: No data available.

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

Eugenol

Eugenol is an essential oil of plants such as clove oil, nutmeg, cinnamon, basil and thyme, which exhibits insecticidal, fungicidal and anti-bacterial activity (NCBI, 2018b; University of Hertfordshire, 2018a). Only one product containing eugenol was found which is registered for use against Lepidoptera, and this product also contains an additional AI (2-phenylethyl propionate).

1. *Efficacy:* In laboratory studies, mixtures of eugenol with compounds isolated from the Spodopteran frass (Klein, Schildknecht, Hilker, & Bombosch, 1990, Anderson, Hilker, Hansson, Bombosch, Klein, & Schildknecht, 1993) and with plant essential oil (Farag, Abd-El-Aziz, Abd-El-Moein, & Mohamed, 1994) were found to deter oviposition and influence feeding behaviour of *Spodoptera littoralis* and *S. litura*.
2. *Human health and environmental hazards:* Eugenol does not meet any of the HHP criteria (NCBI, 2018b), so it is not considered to be an HHP. Human health hazards associated with the AI include that it may cause an allergic skin reaction (H317) and causes serious eye irritation (H319).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:* No cautions regarding pollinators were listed on the label of the product assessed, but Hymenoptera such as wasps, hornets and yellow jackets are listed as targets, suggesting that it may be toxic to bees.
4. *Practicality:* No special requirements for PPE, application equipment, storage or disposal were listed.
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.

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

Garlic oil

Garlic oil is extracted from garlic. Thanks to the sulphur-containing secondary metabolites, it acts as an insect repellent when applied to a wide range of agricultural and ornamental plants (CABI, 2017e). In lab and field studies, it is also reported to have insecticidal and acaricidal properties (J. Dougoud, S. Toepfer, & W. Jenner, pers. comm. (in prep.)). For several of the products reviewed, the garlic extract was used in formulation with other AI such as azadirachtin, capsaicin and soybean oil.

1. *Efficacy:* In a field study in clover in Egypt, treatment with a product containing garlic extract resulted in comparatively high initial reductions in the cotton leafworm (*Spodoptera littoralis*) in clover.
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 (2017e) this substance is a flammable liquid and vapour, is harmful if swallowed, causes serious eye irritation, causes skin irritation and may cause an allergic skin reaction. 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:* Of the 30 countries assessed, garlic oil is only registered in the USA. Garlic extracts are also registered for use in the EU. It is not registered in any of the 19 countries assessed in Africa. Even so, garlic solutions are often used as a traditional means of pest control.
6. *Affordability:* No data available.

**Recommendation:** Products containing garlic oil or garlic are labelled for use against FAW in the USA, and field studies with the related species, *Spodoptera littoralis,* suggest that it could potentially be effective against FAW. That said, some references indicate that garlic oil primarily acts as an insect repellent, which may indicate it would not be very effective against FAW once it is established. Given that garlic oil is potentially a candidate for local production, efficacy tests in the laboratory may be merited.

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*. Its mode of action is primarily by contact and it is labelled for use against Thysanoptera, Lepidoptera and Coleoptera pests. GS-omega/kappa-Hxtx-Hv1a was first registered in 2014, in the USA.

1. *Efficacy:* The authors found no peer-reviewed records of GS-omega/kappa-Hxtx-Hv1a efficacy. There would appear to be just one company (Vestaron Cooperation, USA) producing products containing GS-omega/kappa-Hxtx-Hv1a as the active ingredient (the SPEAR range). According to the label SPEAR can be used against ‘armyworm loopers’ on maize.
2. *Human health and environmental hazards:* According to the label, exposure of adult bees to direct treatment or residues on blooming crops can harm honey bee larvae. No other negative toxicity data were found.
3. Agronomic sustainability: No data found
4. *Practicality:* According to label GS-omega/kappa-Hxtx-Hv1a is compatible with standard spray and irrigation equipment
5. *Availability:* GS-omega/kappa-Hxtx-Hv1a is registered in the USA, however no other country information was found.
6. Affordability: no data found

**Recommendation:** Limited evidence of efficacy found – this is a relatively new active ingredient so it is probably too early for follow-up action.

Helicoverpa zea single capsid nucleopolyhedrovirus (vpn-hzsnpv)(baculovírus)

HZSNPV is a naturally occurring baculovirus that infects and kills larvae of *Heliothis* and *Helicoverpa* species (Farrar & Ridgway, 1999).

1. *Efficacy:* Trials carried out by Certis, using their product Gemstar LC to assess corn earworm control in organic sweet corn, demonstrated that Gemstar on its own reduced the percentage of infected ears of sweet corn. When combined with alternate spraying using Entrust every three days even better control of the corn earworm was observed (Schreiber, 2011). Little, Luttrell, Allen, Perera, & Parys (2017) concluded that Gemstar was as effective as chemical pesticides for controlling *Helicoverpa zea* in non-Bt cotton.
2. *Human health and environmental hazards:* For the product Gemstar LC a general emergency overview states that this product poses no health concerns through normal use in accordance with label directions. There have been no documented effects on human health or symptoms of overexposure. General first aid measures apply, such as flushing eyes with plenty of water, washing skin with soap and water, remove to fresh air if inhaled.
3. *Agronomic sustainability:* Gemstart LC can be applied up to and including the day of harvest and storage. Gemstar LC should not be tank-mixed with *Bacillus thuringiensis* spray products. It is not recommended to apply Genstar LC 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 only registered in Brazil.
6. *Affordability:* US$40/acre (in 2011).

**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, 2011). It infects a range of agricultural pests including aphids, spider mites, whiteflies and thrips.

1. *Efficacy:* Zemek, Hussein, & Prenerová (2012) showed that *Isaria fumosorosea* is effective in controlling *Spodoptera littoralis*.
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.

**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 which, when applied to crops, acts as a broad spectrum crop protectant, controlling for damage from a wide range of insects, mites and diseases (US EPA, 1999).

1. *Efficacy:* Laboratory and field studies in the Americas and in Africa document the efficacy of kaolin against many Lepidoptera species, including FAW and other *Spodoptera* species (e.g. Abdel-Aziz, 2003; Alavo, Yarou and Atachi, 2010).
2. *Human health and environmental hazards:* Kaolin does not meet any of the HHP criteria (NCBI, 2018c), so it is not classified as an HHP. Human health hazards associated with the AI include the following; causes skin irritation (H315), causes serious eye irritation (H319), and causes damage to organs through prolonged or repeated exposure (H372 and H373). 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. Kaolin is approved for use in the EU but is not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* No non-target effects were found.
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 for use against fruit flies in mango in Burkina Faso and Mali.
6. *Affordability:* No data available.

**Recommendation:** Given that kaolin clay is registered for use in Burkina Faso and Mali, bioassays to determine its efficacy against FAW in those countries is recommended. Use of kaolin clay may not be compatible with very wet climates.

Lufenuron

Lufenuron is an insect growth regulator which inhibits chitin biosynthesis and is used to control chewing and sucking insects (University of Hertfordshire, 2018b).

1. *Efficacy:* Various studies carried out in the field in Brazil have demonstrated that lufenuron is effective against FAW (Silva, 1999; Azevedo, Grörtzmacher, Loeck, da Silva, Storch, & Herpich, 2004; López & Reyes, 1995, Dal Pogetto et al., 2012).
2. *Human health and environmental hazards:* Lufenuron does not meet any of the HHP criteria, so it is not considered to be an HHP. It may cause an allergic skin reaction. Based on these human health hazards, the signal word “Warning” applies to this AI. Lufenuron is not listed in the Rotterdam database of notifications; and it is not a candidate POP. It is however on PAN’s list of HHPs. The AI is very toxic to aquatic organisms with long-lasting effects.
3. *Agronomic sustainability:* Lufenuron is listed as an HHP by PAN because it is very bioaccumulating; very persistent in water, soil or sediment; and very toxic to aquatic organisms. Studies have found that lufenuron does not have a detrimental effect on development of the parasitoid *Trichogramma pretiosum* (Pratissoli, Thuler, Pereira, Reis, & Ferreira, 2004)*.* Resistance to lufenuron has been documented in some FAW populations in Brazil (Nascimento, Fresia, Consoli, & Omoto, 2015).
4. *Practicality:* The required elements of PPE are as follows: long-sleeved shirt and long trousers, and shoes plus socks. No extraordinary equipment, storage or disposal requirements were listed on the reviewed label.
5. *Availability:* Lufenuron is registered in a number of countries in Africa including Burkina Faso, Kenya, Malawi, Mali, Mozambique and South Africa.
6. *Affordability:* In Brazil, lufenuron was found to have a high cost-benefit ratio compared to other insecticides (López & Reyes, 1995).

**Recommendation:** Carry out field trials in countries where lufenuron is registered. Apply mitigation measures to reduce potentially harmful impacts on aquatic organisms.

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. It is usually supplied as a soluble concentrate that is mixed with water before spraying.

1. *Efficacy*: Review of the literature failed to identify references which demonstrated efficacy of maltodextrin against FAW specifically, however Fening, Billah, & Kukiriza (2017) note activity against another lepidopteran pest, the false codling moth (*Thaumatotibia leucotreta* (Meyrick), Tortricidae). Maltodextrin has been recommended for FAW control by the Ministry and Food and Agriculture of Ghana (<http://agrihomegh.com/control-fall-armyworm/>). There are also a number of publications highlighting the potential of maltodextrin for microencapsulation of insecticidal ingredients to improve application (Fernandez, Borges, & Botrel, 2014; López et al., 2014).
2. *Human health and environmental hazards*: None found when used as an insecticidal spray
3. *Agronomic sustainability*: Whilst no evidence of non-target effects were found in scientific literature a maltodextrin product label (Majestik®, Certis Europe BV) states there is a risk to non-targets and other arthropods and that safety to bees has not been demonstrated; furthermore the European Food Safety Authority concluded that data relating to non-targets and honey-bees is lacking and should be further addressed (EFSA, 2013).
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 insecticidal products are registered in at least six EU countries for outdoor and/or protected crops and are recommended by the Government of Ghana for FAW control, however no information was found on specific availability in-country.
6. *Affordability*: No available data.

**Recommendation**: There is some evidence of activity against Lepidoptera and, furthermore, maltodextrin has been recommended by the Government of Ghana for FAW control. The concern will be its impact on non-targets, including bees. If testing is to be undertaken, bioassays to assess FAW efficacy and, its impact on key non-targets, would be the next steps.

Matrine

Matrine is an alkaloid found in plants from the *Sophora* genus (University of Hertfordshire, 2018c).

1. *Efficacy:* Bioassays in the laboratory demonstrated that matrine has lethal and sub-lethal effects on FAW (Zanardi et al., 2015). Mortality in the field trials was less pronounced.
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria (NCBI, 2018d), 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 registered for used in Burkina Faso, Kenya and Mali.
6. *Affordability:* No data available.

**Recommendation:** Bioassays suggest that matrine may be effective against FAW, but the available field trials did not support this conclusion. It is not an HHP. Data was not available on agronomic sustainability, practicality and affordability. Given that matrine is registered for use in Burkina Faso and Mali, field trials to determine its efficacy are recommended. These trials could also be used to assess its agronomic sustainability and the practicality of its use.

*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:* Han, Jin, Kim and Lee (2014) demonstrated that *M. anisopliae* was effective at controlling beet armyworm in laboratory bioasssays. In Pakistan, Freed, Saleem, Khan, & Naeem (2012) demonstrated that *M. anisopliae* was effective against *S. exigua* in semi-field trails. 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. A product known as “Real Metarhzium anisopliae 69” is effective across a range of insect pests but to date has not been tested/registered against FAW.
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. In a review on the safety of *M. anisopliae* Zimmermann (2007b) concluded that *Metarhizium anisopliae* is considered to be safe with minimal risk to humans, vertebrates and the environment.
3. Agronomic sustainability: Metarhizium anisopliae has a low toxicity.
4. *Practicality:* Real Metarhzium anisopliae 69 has a recommended application rate of 200 ml/hectare and a shelf life of 12 months if stored in a cool, dry conditions at 15-20°C.
5. *Availability: Metarhizium* products are available in 3 African countries; Mozambique, Uganda and Zambia, however it is not clear if they are effective against *Spodoptera* spp. There are also three products registered in Panama.
6. *Affordability:* No data available

**Recommendation:** Although there are *M. anisopliae* products registered in three African countries they do not appear to have been tested on *Spodoptera* spp. Lab bioassays would therefore be recommended on the registered products, as *M. anisopliae* is known to infect *Spodoptera* spp.

Methoxyfenozide

Methoxyfenozide is a synthetic insect growth regulator which mimics the moulting hormone of Lepidopteran insects (Bouzeraa & Soltani-Mazouni, 2014). It acts as an ecdysone agonist, leading to the cessation of feeding and premature moulting.

1. *Efficacy:* It has been used effectively to manage FAW in its native range (e.g. Zamora et al., 2008).
2. *Human health and environmental hazards:* This AI does not meet any of the HHP criteria (University of Hertfordshire, 2018d), so it is not considered to be 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 allowed for use in the EU but not approved for use in organic agriculture in the EU.
3. *Agronomic sustainability:* It is toxic to bees and very toxic to aquatic life with long-lasting effects. It should not be applied close to aquatic areas or to permeable soils where the water table is shallow.
4. *Practicality:* Methoxyfenozide acts primarily through ingestion so for internal or cryptic feeding larvae application must be made just prior to egg hatching. The number of applications needed will depend on the level of infestation. The required elements of PPE are as follows: long-sleeved shirt and long trousers; chemical-resistant gloves made of any waterproof material; and shoes plus socks. No special requirements for application equipment, storage or disposal were listed.
5. *Availability:* Methoxyfenozide is registered in Kenya and Malawi. In Malawi it is broadly registered for Lepidoptera. In Kenya it is registered for diamondback moth, sawfly and *Spodoptera* in brassicas.
6. *Affordability:* No data available.

**Recommendation:** Given that methoxyfenozide is registered for use in Kenya and Malawi, field trials to determine its efficacy are recommended.

Orange oil

Commercial products containing orange oil are made of extracts of orange peel and orange seeds. The AI of these extracts is D-limonene and linalool. Some products containing orange oil are marketed as repellents whereas others are insecticidal sprays and fungicides. Limonene and linalool are thought to cause an increase in the spontaneous activity of nervous system, leading to over-stimulation of motor nerves and ultimately knockdown paralysis (Texas A&M, 2017).

1. *Efficacy:* Orange oil insecticidal sprays are typically labelled for sucking insects and certain plant pathogens. Caterpillars of FAW reared on an artificial diet containing orange oil extracted from orange seeds, peel and leaves at various concentrations deterred feeding, caused larval mortality and resulted in pupal mortality (Villafañe, Tolosa, Bardón, & Neske, 2011).
2. *Human health and environmental hazards:* Orange oil does not meet any of the HHP criteria (ECHA, 2017f), so it is not an HHP. Human health hazards include that orange oil may be fatal if swallowed and enters airways. 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.
3. *Agronomic sustainability:* Orange oil has low toxicity to bees.
4. *Practicality:* No extraordinary requirements for PPE, application equipment, storage or disposal were listed on the reviewed label.
5. *Availability:* A product containing orange oil is registered for use against powdery mildew in Kenya. Products containing orange oil are registered as repellents in the USA. Products containing orange seed extract are registered for use in Costa Rica. Orange oil is not registered in any of the other 19 countries assessed in Africa.
6. *Affordability:* No data available.

**Recommendation:** There is some 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 potentially candidates for local production, efficacy tests in the laboratory and field are recommended.

Oxymatrine

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

1. *Efficacy:* While no studies were found that examined the efficacy of oxymatrine against FAW, there were some studies in Africa and Asia which found that oxymatrine was effective against other Lepidoptera, e.g. the brinjal borer, *Leucinodes orbonalis* (Adiroubane and Raghuraman, 2008; Aetiba and Osekre, 2015) in Asia and Africa.
2. *Human health and environmental hazards:* The AI does not meet any of the HHP criteria (NCBI, 2018e), 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.
5. *Availability:* Oxymatrine is registered for use in Ghana.
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. It is not an HHP. Data was not available on agronomic sustainability, practicality and affordability. Given that oxymatrine is registered for use in Ghana, field trials 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

Potassium salts of fatty acids 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 (NPIC, 2001). In the USA, the first pesticide product containing soap salts was registered for use in 1947, and products containing potassium salts of fatty acids are generally used as insecticides, herbicides, fungicides, and algaecides. Against insects, potassium salts of fatty acids work by penetrating insect body coverings and disrupting the cell membranes, causing cell contents to leak out and ultimately resulting in death (NPIC, 2001). Potassium salts of fatty acids are typically more effective against soft bodied insects than insects with hard body coverings such as beetles (NPIC, 2001). 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:* In field experiments to assess its efficacy against diamondback moth (*Plutella xylostella*) and *Pieris rapae* on cabbages, potassium salts alone and in combination with pyrethrins and/or garlic did not prevent larval feeding damage (Endersby, Morgan, Stevenson, & Waters, 1992). Meanwhile, products containing azadirachtin and potassium salts of fatty acids reduced the number of cabbage looper (*Trichoplusia ni*) and diamondback moth larvae in field tests (Leskovar and Boales, 1996). Potassium salts of fatty acids have been shown to be effective against other insects such as aphids and other sucking insects. For example, a field study in Italy found that a product containing potassium salts of fatty acids was more effective than the reference pesticide, armitraz, against *Cacopsylla pyri* on pear (Pasqualini, Civolani, Vergnani & Natale, 1999). Review 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. In field tests against southern armyworm (*Spodoptera eridania*) in Florida, potassium salts had few effects on larvae (Valles & Capinera, 1993).
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. Human health hazards associated with potassium salts of fatty acids include the following; they cause skin irritation (H315), cause serious eye damage or irritation (H318 and H319), and may cause respiratory irritation (H335). 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 approved for use in organic agriculture in the EU. Potassium salts of fatty acids are toxic to aquatic organisms, including fish and invertebrates.
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. It is not registered in any of the 19 countries assessed in Africa.
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

The dried, powdered flowers of *Chrysanthemum cinerariaefolium* Vis. (formerly *Pyrethrum*) from which pyrethrins are derived have been used as an insecticide from ancient times (CABI, 2017g). Pyrethrins 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 (University of Hertfordshire, 2018e). Pyrethrins cause knockdown, paralysis and death by binding to the sodium channels in insects. Pyrethrins are often formulated with synergist piperonyl butoxide.

1. *Efficacy:* There is documented evidence of pyrethrin efficacy against many Lepidoptera in the field in Africa, but in its native range there is limited evidence that pyrethrins are effective against FAW (Bailey, 1940; Reid & Cuthbert 1952)*.* Some products are labelled specifically for use against armyworm.
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 (2017g) pyrethrins are harmful if swallowed, harmful in contact with skin and harmful if inhaled. 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:* Pyrethrins are highly toxic to bees, but they also exhibit a repellent effect (CABI, 2017g). Pyrethrins are also very toxic to aquatic organisms with long lasting effects.
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, Selection Category E. 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 six of the 19 countries assessed in Africa: Ghana, Kenya, Mozambique, Rwanda, South Africa and Tanzania.
6. *Affordability:* No data available.

**Recommendation:** There is some evidence for efficacy against FAW in its native range. Pyrethrins pose no unacceptable hazards to human health. Field trials should be conducted in countries where pyrethrins in order to assess efficacy. Pyrethrins are toxic to aquatic organisms and bees, so, if used, mitigation measures should be applied. Farmers should be informed of the need to apply these mitigation measures.

Sex pheromones

Female FAW moths attract males by emitting a pheromone. Tumlinson, Mitchell, Teal, Heath, & Mengelkoch (1986) identified the main chemical component of FAW sex pheromones as Z9-14:OAc, with Z7-12:OAc as a critical secondary component. However, a further eight compounds have also been identified (Guerrero, Malo, Coll, & Quero, 2014).

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 et al., 2014). 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 is in progress in Africa by public and private sector organisations, though in the context of monitoring rather than control. 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 (Savana) did indicate that they were interested in exploring using FAW pheromones for mating disruption as this approach is used in cotton for other Lepidoptera, but they have not yet tested this approach for FAW.

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 |
| E7-12:OAc | (E)-7-Dodecanyl acetate | 1 |
| 12:OAc | Dodecanyl acetate | 1 |
| Z9-14:Ald | (Z)-9-Tetradecanal | 3 |
| Z9-14:OAc | (Z)-9-Tetradecenyl acetate | 1,2,3 |
| 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 |

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

2. Andrade, Rodriguez, & Oehlschlager (2000)

3. Tumlinson et al. (1986)

1. *Efficacy:* Pheromones have not been widely used for the control of *Spodoptera spp.* (Guerrero et al., 2014). Andrade et al. (2000) reported that mass trapping had been used in Costa Rica for FAW control since 1992 in over 2000 hectares of melon fields, deploying four to five traps per hectare. However, this was only said to reduce the need for expensive applications of *B. thuringiensis* by 30%-70%. In Honduras, Kuniyoshi, Rueda, Trabanino, & Cave (2003) evaluated mass trapping for the control of FAW in sweetcorn, but found no significant effect on yield, although the percentage of damaged ears was lowered through trapping. It appears that mass trapping is at best only partially effective.
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-OPP, 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.
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; South Africa allows importation.
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. Given that the method is not fully effective, it is unlikely to be effective for smallholders at least*.*

**Recommendation:** Develop for monitoring rather than control.

Spodoptera frugiperda nucleopolyhedrovirus (SfMNPV)

Spodoptera frugiperda nucleopolyhedrovirus (SfMNPV) is a baculovirus which infects FAW (Shapiro, Fuxa, Braymer, & Pashley, 1991).

1. *Efficacy:* Barrera, Simón, Villamizar, Williams, & Caballero (2011) and Behle and Popham (2012) showed that SfMNPV isolates were effective in killing *S. frugiperda*. Behle and Popham (2012) also demonstrated that formulation improvements can help to increase the speed and rate of kill. Cruz, Figueiredo, Valicente and Oliveira (1997) had control rates of 93.4% when an application rate of 1.25x1012 PIB/ha were applied with a tractor mounted sprayer. Escribano, Williams, Goulson, Cave, Chapman, & Caballero (1999) showed that the mean time to death for each instar increased from an average of 102.7 hours in 2nd instars to 136.9 hours in 5th instars.
2. *Human health and environmental hazards:* This assessment is based on the product Spod-X LC produced by Certis USA, which has an AI of *Spodoptera exigua* and not *frugiperda*. However, these are close enough to be assessed in a similar way. Spod-X is not classified as hazardous by OSHA and the EPA signal word is ‘caution’. The product can cause moderate eye irritation and is harmful if absorbed through the skin. It is recommended that applicators wear long-sleeved shirt and long trousers, shoes plus socks and avoid breathing in the mist/dust. LD50 (oral) = toxicity category iV bassed on similar NPV’s. Toxicity to rainbow trout is LC50 96-h > 1000mg/l. Toxicity to *Daphnia magna* = LC50­ 48-h > 2202.7 mg/l. This AI rapidly degrades in air by UV light and bioaccumulation is not expected.
3. *Agronomic sustainability:* This AI should not be applied directly to water, surface water or intertidal areas below the mean high water mark. Do not contaminate water when cleaning equipment or disposing of equipment wash waters or rinsate.
4. *Practicality:* Wear coveralls, waterproof gloves and shoes plus socks. Application rate of 100-200 billion occlusion bodies/acre, which is equivalent to 50100 ml/acre (1.7-3.4 fl. oz/acre). Apply application 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:* Products containing SfMNPV are registered for use in Brazil and USA (1 in each country). SfMNPV is not registered in any of the 19 countries assessed in Africa.
6. *Affordability:* No data available.

**Recommendation:** As this AI is not currently available in any of the 19 African countries it is not a priority. However, if SfMNPVs are available it is worth carrying out bioassays on FAW and possibly as a joint formulation with Spinosad.

Silicon dioxide (diatomaceous earth)

Diatomaceous earth (diatomite) is composed of naturally occurring fossilised diatoms (Chintzoglou, Athanassiou & Arthur, 2008). Chemically it is mainly silicon dioxide, which occurs in amorphous and crystalline forms, but diatomaceous earth is largely amorphous. It has many uses, including as a pesticide and other applications in agriculture.

1. *Efficacy:* There is little evidence of the efficacy of silicon dioxide for control of FAW in the field, but laboratory tests demonstrate some effect on the growth and survival of FAW larvae. Goussain, Moraes, Carvalho, Nogueira, & Rossi (2002) treated potted maize plants with sodium silicate solution [25-27% (w/v) SiO2] and fed the leaves to FAW larvae. Higher mortality and cannibalism was seen in instars 2 and 6, and the mandibles of 6th instar larvae showed marked wear. Constanski, Zorzetti, Santoro, Hosino and Neves (2016) tested various inert powders in laboratory trials, but the highest dose of diatomaceous earth dust caused less than 50% mortality. Rios-Velasco, Gallegos-Morales, Berlanga-Reyes, Cambero-Campos, & Romo-Chacón (2012) tested various formulations of NPV but the one including diatomaceous earth caused no more mortality than the virus alone. Ebeid, Metwally, & Gesraha (2016) conducted laboratory trials using castor oil leaves treated with silica nano-particles, against *S. littoralis* rather than *S. exempta*, and found reduced growth rates, lower larval weights, and higher mortality.
2. *Human health and environmental hazards:* Silicon dioxide can cause reversible irritation of the nasal passages and eyes. The amorphous form has not been associated with cancers in people, though mice forced to breathe diatomaceous earth for an hour daily for a year had higher rates of lung cancer, while rats fed with silica did not (Bunch, Bond, Buhl, & Stone, 2013). Diatomaceous earth has several applications in food storage and is also marketed as a food supplement. Silicon dioxide is widely present in the sea, where marine organisms use it in building their skeletons. It also plays a role in the development of terrestrial as well as marine plants, and silicon is a major component of soil. Silicon dioxide is chemically inert, and does not vaporise or dissolve easily, which is why diatomaceous earth has persisted since the fossils were formed. Thus no harmful environmental effects have been observed or are expected.
3. *Agronomic sustainability:* No effect on agronomic sustainability is expected.
4. *Practicality:* Diatomaceous earth can be applied as a suspension or as a dust. Given its abrasive qualities, and the need for water, dust formulations may be more practical for smallholder farmers in Africa. Manual application of dusts would be practical for those who cannot afford pesticide application equipment.
5. *Availability:* Diatomaceous earth has many uses, so in principle is widely available, including in Africa. However, it is not widely registered as a pesticide. In Kenya (where it is also mined), it is registered for the control of maize weevil in stored grain (but not for larger or lesser grain borers).
6. *Affordability:* No information.

**Recommendation.** If diatomaceous earth is affordable to smallholder farmers, it would be worth testing as a dust applied to the whorl of attacked maize.

S-methoprene

S-methoprene (as distinct from R-methoprene) was first registered in US as an insecticide in 1975 (NPIC, 2012). It is an analog of the juvenile hormone in insects that controls their development from one stage to the next. It thus interferes with normal development, and must be applied to larval stages to be effective. It is available in a variety of formulations and a common use is in the treatment of pets for ectoparasites (University of Hertfordshire, 2018d).

1. *Efficacy:* There is limited evidence on the effect of s-methoprene on FAW. González Valenzuela, Portilla, Ruiz and López (1991) reported that oviposition of treated females was not affected, but fertility decreased with dose. However, bearing in mind that the larvae would be the main target, Ross & Brown (1982), and González Valenzuela, Portilla, Ruiz and Baro (1989) found that methoprene generally increased larval growth rate and food consumption, although 6th instars ate less and developed more slowly.
2. *Human health and environmental hazards:* S-methoprene has low toxicity to mammals, with an oral LD50 of 5000mg/Kg or more for several species. It is slightly toxic when absorbed through the skin, but generally does not irritate the skin or eyes. It is rapidly broken down or excreted in mammals, and no carcinogenic or other impacts of sustained exposure have been observed, apart from liver enlargement in some trials with rats and mice fed large doses daily over long periods. Methoprene is generally of low toxicity to terrestrial organisms and birds, but it is moderately toxic to fish, and can be highly toxic to some aquatic organisms, especially invertebrates. The environmental concentrations found in practice may limit any non-target impacts, although some species of zooplankton, and the larval stages of freshwater crustaceans and small flies are affected (Lawler 2017).
3. *Agronomic sustainability:* There are a few cases of resistance to methoprene reported, all in diptera, and particularly human health pests. Immature stages of other insects that come into contact with the pesticide could be affected.
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, and no agricultural registrations were found in the countries in Africa surveyed.
6. *Affordability:* No information.

**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 often 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:* 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. According to the majority of notifications provided by companies to ECHA no hazards have been classified. Based on this, the AI is “low hazard”. 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 has been registered for use in the EU, and is permitted to be used in organic agriculture in the EU.
3. *Agronomic sustainability:* There are no adverse effects expected for non-target organisms like bees.
4. *Practicality:* Soybean oil should be applied when insects first appear, and the target pests should be completely covered by the spray. Sprays should be repeated on a weekly basis for additional control. 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:* 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:** 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.

1. *Efficacy:* The authors found references demonstrating the efficacy of Spinetoram against Spodoptera, including FAW, in both lab and field settings (e.g., Hardke et al., 2011; Muthukrishnan, Visnupriya, Muthiah, & Babyrani, 2013; Seal, Schuster, & Klassen, 2007).
2. *Human health and environmental hazards:* According to the Pesticide Properties Database (PPDB, University of Hertfordshire, 2018g) and the EFSASpinetoram can have moderate to high toxicity to aquatic life and sediment-dwelling organisms, and could therefore be classed as an HHP. However, EFSA indicates that high risk could be reduced if mitigation measures are implemented
3. *Agronomic sustainability:* According to PAN Spinetoram has high acute toxicity to honeybees and chronic toxicity to honeybees. There are references of insect resistance to Spinetoram (including from Lepidoptera) (e.g., Sial, Brunner, & Doerr, 2010; Sparks, Dripps, Watson, & Paroonagian, 2012).
4. *Practicality:* Spinetoram is available in a number of formulations (e.g., water dispersible granule and liquid suspension concentrate) and is compatible with standard spray equipment
5. *Availability:* Spinetoram is registered in many countries around the world, including USA, Canada, South Africa, Kenya and the EU
6. Affordability: prices vary

**Recommendation**: Strong evidence of efficacy, practicality and availability with a number of registrations already present in Africa, however there are serious concerns regarding its impact on non-targets, in particular bees. Proceed with caution, perhaps for use solely as an emergency measure.

Spinosad

Spinosad is an insecticide compound derived from the fermentation of a naturally occurring soil actinomycete bacterium, *Saccharopolyspora spinosa* (University of Hertfordshire, 2018h). 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.

*1. Efficacy*: The authors found numerous references demonstrating efficacy of Spinosad against FAW in both lab and field settings (e.g., Hardke et al., 2011; Williams, Cisneros, Penagos, Valle, & Tamez-Guerra, 2004).

*2. Human health and environmental hazards*: According to PAN, Spinosad is highly toxic to aquatic life, hence it can be classed as an HHP.

*3. Agronomic sustainability*: According to PAN Spinosad has high acute toxicity and high chronic toxicity to honeybees. There are references of FAW resistance to Spinosad (e.g., Okuma, Bernardi, Horikoshi, Bernardi, Silva, & Omoto, 2018; Sparks et al., 2012).

*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.

6. Affordability: prices vary

**Recommendation**: Strong evidence of efficacy, practicality and availability with multiple registrations in Africa, however there are serious concerns regarding impact on non-targets, in particular bees. Proceed with caution, perhaps for use solely as an emergency measure.

*Steinernema carpocapsae* and *S. feltiae*

*Steinernema carpocapsae* and *S. feltiae* are entomopathogenic (insect-killing) nematodes (EPNs) and have been used for some years for augmentative biological control (Kaya et al., 2006). The 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. against FAW in a field setting (Andaló, Santos, Moreira, Moreira, & Moino, 2010; Richter & Fuxa, 1990); these have included good mortality from both soil and above-ground applications.
2. *Human health and environmental hazards*: *Steinernema* spp. do not meet any of the HHP criteria. *Steinernema* spp. are not listed in the Rotterdam database of notifications; are not candidate POPs; and PAN does not list them as HHPs.
3. *Agronomic sustainability*: The authors have found no reports of long-term effects on non-target organisms or other environmental impacts following the application of indigenous or exotic EPNs, however there is evidence of some short-term negative impact on bumble bees, albeit lab-based (Dutka, McNulty, & Williamson, 2015); the authors found limited reports of acquired resistance by insect targets.
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.
5. *Availability*: *Steinenema* spp. are registered for use in Kenya, however they are not labelled for Lepidoptera, although a different EPN genus *Heterorhabditis* 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, although set-up and running costs can be expensive.
6. *Affordability*: No data available; however applications at a field scale (>1ha) 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 suggests they will be inappropriate for field conditions in a number of African regions. These factors, compounded by a relatively high product cost and the need for re-application means that no follow-up action is recommended.

Sucrose octanoate

Sucrose octanoate is a synthetic sugar ester that is produced by reacting sugars with fatty acids (Puterka, Farone, Palmer, & Barrington, 2003). Sucrose octanoate is used to control mites and various soft-bodied insects (University of Hertfordshire, 2018f) such as aphids, caterpillars, mites, thrips and whiteflies. The product reviewed (Avachem Sucrose Octanoate [40.0%]) is registered in the USA for use in a wide range of crops.

1. *Efficacy:* In laboratory bioassays with pear psylla (*Cacopsylla pyricola* Foerster) on pear, tobacco aphid (*Myzus nicotianae*) Blackman and tobacco hornworm (*Manduca sexta* [Johannson]) on tobacco, and two-spotted spider mite (*Tetranychus urticae* Koch) on apple, sucrose octanoate had superior insecticidal activity than insecticidal soap (Puterka et al., 2003). Laboratory studies indicate that sucrose octanoate causes mortality of *Lymantria dispar* (Song, Li, Chen, Liu, & Song, 2006).
2. *Human health and environmental hazards:* Sucrose esters are currently used as additives in the food industry (Puterka et al., 2003). 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:* Sucrose octanoate is moderately toxic to bees (University of Hertfordshire, 2018f). There are products registered for use in hives against varroa mite.
4. *Practicality:* Sucrose octanoate should be applied when infestation is first detected, and applications should be repeated as necessary at 7-10 day intervals in order to maintain control. The required elements of PPE are as follows: long-sleeved shirt and long trousers, waterproof gloves, protective eyewear and shoes plus socks. 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 the USA. It is not registered in any of the 19 countries assessed in Africa.
6. *Affordability:* No data available.

**Recommendation:** No evidence for evidence of efficacy against FAW was found in the literature. Given that no products containing this AI are registered in Africa, this AI is not considered to be a high priority for testing. If testing were to be undertaken, bioassays to judge whether it might be effective against FAW would be the first step.

Sulphur

Sulphur is an element widely found in numerous organic compounds. However, it is the elemental form that is used as a pesticide, particularly as a fungicide, and has been registered in the US since the 1920s (Boone, Bond, Hallman, & Jenkins, 2017), although Homer mentioned “pest-averting sulphur” almost three centuries ago (Rosen, Magee, & Casida, 1981). In the 1990s, sulphur was a very widely used pesticide, although its use has lessened since then.

1. *Efficacy:* Dickinson, Meadows, & Witman (1941) reported significant mortality to FAW larvae in laboratory trials with dusting sulphur and wettable sulphur. No more recent published trials of sulphur on FAW have been found.
2. *Human health and environmental hazards:* Sulphur presents little hazard to human health. Chronic exposure to high doses in mines can cause respiratory problems such as bronchitis, but in agriculture skin and eye irritations are the most common symptom of over exposure. There are no known oncogenic, teratogenic or reproductive effects. Sulphur has low toxicity to birds, fish, bees and aquatic organisms. However, it can be dangerous and even fatal to livestock. Accumulation in organisms is not expected as due to its insolubility in water, it will not be readily bioavailable.
3. *Agronomic sustainability:* Sulphur is a permitted pesticide in organic farming. The arthropod pesticide resistance database ([www.pesticideresistance.org](http://www.pesticideresistance.org)) cites only one case of resistance to sulphur, interestingly in a predatory rather than pest species.
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.
6. *Affordability:* No information.

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

*Trichogramma* spp.

Wasps in the *Trichogramma* genus are egg parasitoids of lepidopteran pests and are among of the most widely used biological control agents (Holmes et al., 2018). *Trichogramma* are released as parasitized eggs attached to a piece of card (known as a Tricho-card) or in pupal phase. Adult *Trichogramma* females emerging from these Tricho-cards search for pest eggs into which they can lay their eggs. This will kill the larvae before they hatch, thus preventing them from doing any damage. Applying *Trichogramma* in combination with other cultural controls means that farmers are often able to replace or reduce their use of conventional CPAs. In many countries *Trichogramma* is produced locally using low tech means.

1. *Efficacy:* *Trichogramma spp.* have been successfully used for biological control of FAW in its native range (Uriartt, 2012; Figueiredo, Cruz, da Silva, & Foster, 2015). Commercial products of *Trichogramma 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. Residues are not an issue, and Tricho-cards can be applied up to the day of harvest.
3. *Agronomic sustainability: Trichogramma* parasitizes the eggs of Lepidopteran species, so their non-target effects are limited. *Trichogramma* species vary in their specificity so risk assessments should be conducted to assess whether the *Trichogramma* species under consideration for release pose any risk to other non-target Lepidoptera. The development of resistance to *Trichogramma* is unlikely.
4. *Practicality:* For the management of FAW, *Trichogramma* should be released when moths are first detected in monitoring traps and re-released every 7 days thereafter. *Trichogramma* should be released prior to their emergence from the egg cards or the pupae, thus it has a limited shelf life (approximately 7 days at 8°-12°C). *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. 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*: No data available.

**Recommendation:** *Trichogramma* can be effective against FAW. If local *Trichogramma* species are present that are able to parasitize FAW, these 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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