Plant Health Cases – Assessment of biopesticide options for managing fall armyworm in Africa

Summary

More than 300 million people in sub-Saharan Africa depend on maize as a staple crop. In the last six years the fall armyworm has spread from the Americas to most nations in Africa, as well as the Middle East, Asia and the Pacific. Maize is the preferred host plant of the fall armyworm. Given that synthetic pesticides are not always used safely or effectively, this case assesses the current state of knowledge of biopesticides for the fall armyworm in Africa, documents information gaps and lists biopesticides that are a priority for research, development and promotion.

Abstract

In the last six years, the fall armyworm (FAW) has spread to the Middle East, Asia and the Pacific, as well as most nations in Africa. This case focuses on sub-Saharan Africa, where more than 300 million people depend on maize, as a staple crop, and the preferred host plant of fall armyworm. Synthetic pesticides against the fall armyworm are not always used safely or effectively. Here we assess work on the current state of knowledge on biopesticides for the fall armyworm in Africa, document information gaps, including compatibility with other recommended management practices, and list biopesticides that are a priority for research, development and promotion.

The case incorporates two earlier assessments, one from 2018 on the status of biopesticide options against FAW, and one from 2020 that led to recommendations for field trials for eight active ingredients – *Bacillus thuringiensis* subsp. *kurstaki*, *Beauveria bassiana*, *Dysphania ambrosioides*, ethyl palmitate, eugenol, garlic extract, *Metarhizium anisopliae* and *Steinernema* spp. Field trials for some of these pesticides have now been carried out but other trials are still ongoing. The team also recommended bioassays to determine the effectiveness of four active ingredients against FAW – GS-omega/kappa-Hx-tx-Hv1a, canola oil, capsaicin and D-limonene.

Learning outcomes

1. Provide an overview of the biopesticide options for the fall armyworm in Africa, including their relative advantages and disadvantages.
2. Detail information gaps in current knowledge of biopesticide potential against the fall armyworm.
3. Describe the biopesticides prioritized for research, development and promotion against the fall armyworm in Africa.
4. Understand how the biopesticide field has developed in recent years.

Introduction

The fall armyworm (FAW, *Spodoptera frugiperda* (J. E. Smith), Lepidoptera: Noctuidae) is native to the Americas, where its larvae are one of the most important pests of maize. The last two instars – four and five – require 50 times more food than earlier stages so an infestation of these larvae can easily destroy an entire crop overnight (CABI PlantwisePlus Knowledge Bank). The adult moths themselves feed on nectar.

Fig. 1: Fall armyworm (*Spodoptera frugiperda*) moth.

Fig. 2: Fall armyworm (*Spodoptera frugiperda*) larva.

Fig. 3: Maize crop damaged by an infestation of fall armyworm.

The FAW has recently spread to much of Africa, the Near East, Asia and the Pacific (FAO 2020a), reaching central and western Africa in 2016 (Goergen et al., 2016) and dispersing rapidly (De Groote et al., 2020). FAW is a particular pest of cereals. As maize is a staple food crop for more than 300 million people in sub-Saharan Africa, FAW poses a major threat to livelihoods and food security in this region.

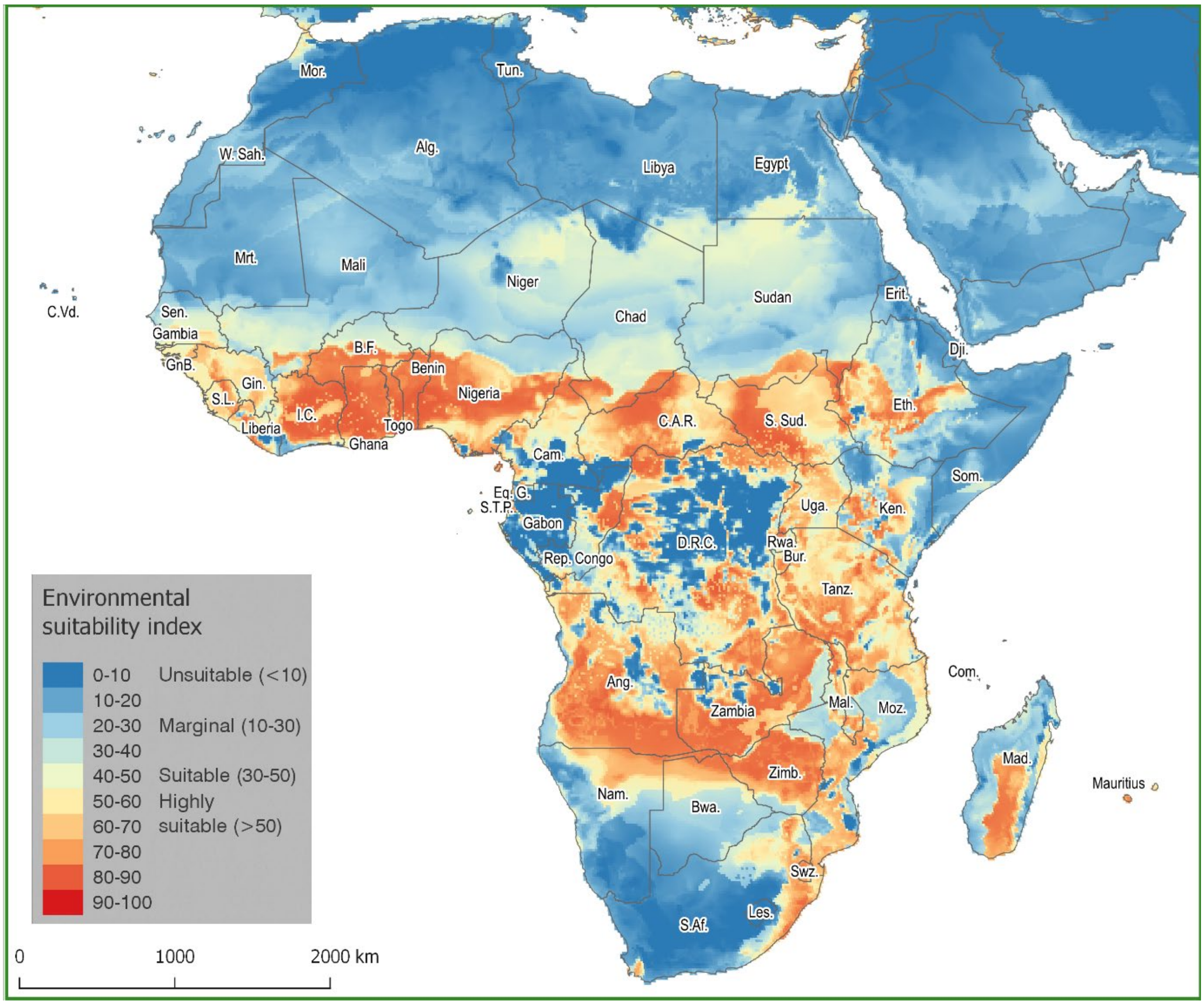

Fig. 4: Environmental suitability index for fall armyworm in Africa.

Generated from modelling by Dr Regan Early (University of Exeter).

Original article: Forecasting the global extent of invasion of the cereal pest Spodoptera frugiperda, the fall armyworm, Regan Early, Pablo Gonzalez-Moreno, Sean T. Murphy, Roger Dy, bioRxiv 391847; doi: https://doi.org/10.1101/391847

Many farmers have increased their use of synthetic pesticides to combat FAW (Kansiime et al., 2019) but this use may not be safe or effective (Rwomushana et al., 2018). It could potentially put farmers' health at risk (Tambo et al. 2020), especially as they often do not use personal protective equipment (Rwomushana et al. 2018). Additionally, broad-spectrum pesticides harm natural enemies that could help to manage FAW. There is a clear need for alternative management options suitable for smallholder farmers - biopesticides could offer effective, sustainable, accessible, practical and affordable outcomes with lower risk to human health and the environment.

Biopesticides – pesticides derived from natural materials – can be divided into three main substance groups: biochemical pesticides, microbial pesticides and macrobials. Biochemical pesticides can be further divided into sub-groups of plant extracts/botanicals, synthetic pheromones/semiochemicals, microbial extracts/fermentation products, insect growth regulators, compounds synthesized by other organisms, and inorganic compounds. Microbial biopesticides can be split into bacteria, fungi, protozoa, viruses, oomycetes, yeasts and algae, whilst macrobials can be sub-divided into insect predators, parasitoids and entomopathogenic nematodes. This case considers all these types of biopesticides, with the caveat that most countries do not include macrobials in their lists of registered pesticides so macrobials are likely to be under-represented. It looks at the state of play in 2018 and 2020 for biopesticides for FAW management based on two previous assessments (Bateman et al. 2018, Bateman et al. 2021), commenting on both progress and remaining information gaps.

2018 assessment

In order to make information on biopesticides for FAW management readily available, in 2018 the authors of this case identified and assessed some fifty biopesticides that had been registered for management of FAW, *Spodoptera* species or Lepidoptera in general, in one or more of 30 countries in FAW's native region and Africa (Bateman et al. 2018). The countries included were Argentina, Benin, Bolivia, Brazil, Burkina Faso, Cameroon, Chile, Colombia, D R Congo, Costa Rica, Ecuador, Ethiopia, Ghana, Kenya, Malawi, Mali, Mexico, Mozambique, Nigeria, Panama, Peru, Rwanda, Sierra Leone, South Africa, Tanzania, Togo, Tunisia, Uganda, USA and Zambia. The team assembled a detailed profile on each of 54 commercially available biopesticide active ingredients (AIs), providing information on its efficacy against FAW, hazard to human health and the environment, agronomic sustainability, and practicality for use by smallholder farmers, including its availability and cost-effectiveness.

Based on these profiles, the team determined whether using each biopesticide would put farmers and the wider community and environment at risk, as well as whether the active ingredient would be practical for smallholder farmers. Using this information, the researchers then developed a decision matrix for designing interventions that would make biopesticides for FAW control more widely available in Africa. Several of the active ingredients had been shown to be effective in field trials in FAW's native range but there was minimal data from the field in Africa. Few biopesticide active ingredients had been registered for most countries in Africa, and almost none of the active ingredients had been specifically registered for use against FAW. In addition, little information about cost-effectiveness was available.

As a result of this assessment, the team recommended 23 biopesticides for follow-up actions such as field trials, participatory trials or laboratory studies (Fig. 1) (Bateman et al. 2018).

2020 assessment

Overview

In 2020, the case authors assessed how the state of knowledge in this field has changed. They provided updated information on the biopesticide active ingredients registered and commercialized that could be used for the management of FAW in the same 30 countries as before.

Completing this update involved accessing lists of registered pesticides and biopesticides for the 30 countries between April and August of 2020 and looking for biopesticides already registered and allowed for use against FAW, *Spodoptera* or Lepidoptera in general. A total of 12 countries specifically identified biopesticide active ingredients in their list of registered pesticides, and 19 countries included information about the specific pests for which products are registered.

The team updated the profiles of previously identified biopesticide active ingredients and created additional profiles for newly identified active ingredients. In total, team members identified 41 biopesticide active ingredients registered and allowed for use for FAW management in at least one of the thirty countries. Four of these were not identified in the previous assessment – *Aspergillus oryzae*, *Autographa californica* multiple nucleopolyhedrovirus (AcMNPV), *Spodoptera littoralis* nucleopolyhedrovirus (SpliNPV) and thyme oil.

As a result of the exclusion of active ingredients that are no longer categorized as biopesticides or are not registered for Lepidoptera, this study identified fewer biopesticide active ingredients than the 54 assessed in 2018. Three inorganic compounds (borax, cryolite and silicon dioxide), two microbial fermentation products (emamectin benzoate and spinetoram) and two insect growth regulators (lufenuron and methoxyfenozide) are no longer categorized as biochemical biopesticides by national authorities in any of the assessed countries. Two other inorganic compounds (kaolin and sulphur), one other microbial fermentation product (spinosad) and one other insect growth regulator (s-methoprene) are still designated as biochemical biopesticides by one or more countries although many definitions would not class them as biopesticides. No products were registered for use against FAW or its relatives for three active ingredients that were identified through the previous study – 2-phenylethyl propionate, octanoate d-glucitol and sucrose octanoate.

In total in 2020, biopesticide active ingredients were represented by more than 1,500 products in the 30 countries. These products included 852 botanicals, 419 microbials, 85 microbial extracts or fermentation products, 125 inorganic compounds and seven insect growth regulators. Some macrobials were also identified, namely eight products containing parasitoids (*Trichogramma pretiosum* Riley) and six products containing entomopathogenic nematodes (*Steinernema carpocapsae* Weiser) were registered for FAW. Most countries do not include macrobials in their lists of registered pesticides so macrobials are likely to be under-represented. Of the 30 countries in this study, only Brazil, Kenya and Uganda include macrobials. The team also identified one product containing spider venom peptide.

In 2018, 18 of the biopesticide active ingredients were registered in three or more countries; by 2020, this figure had increased to 30. Azadirachtin, *Bacillus thuringiensis* Berliner (*Bt*), pyrethrins, soybean oil and sulphur were present in the highest numbers of products.

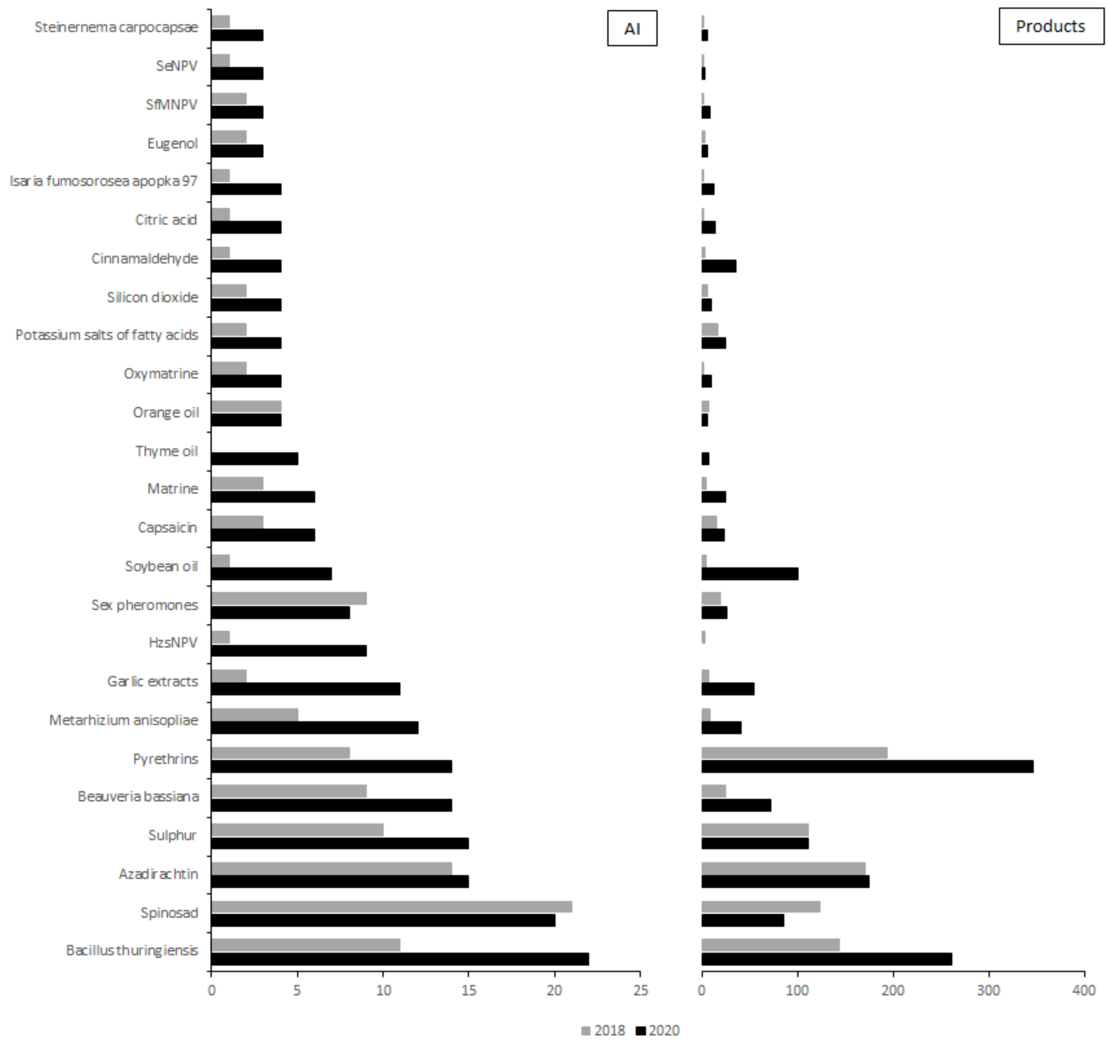

Fig. 5: Numbers of active ingredients (AIs, left) and corresponding products (right) registered in three or more countries in 2018 (pale) and 2020 (dark).

Efficacy

The number of biopesticides demonstrated to be effective against FAW, *Spodoptera* spp. or Lepidoptera increased between 2018 and 2020, rising from 26 to 34. A total of 23 active ingredients in 2020 showed efficacy against FAW versus 15 in 2018. There was also more evidence of efficacy from the field in Africa – 13 active ingredients in 2020 compared to 4 in 2018. Only five studies concluded that any of the active ingredients were ineffective against FAW (Fig. 2).

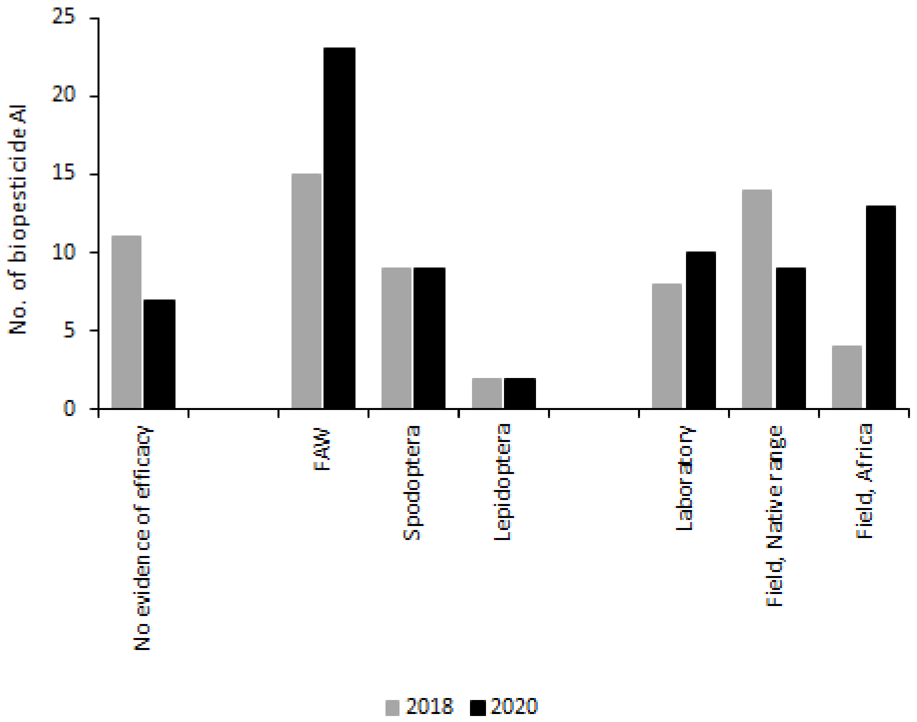

Fig. 6: Comparison of the findings of the assessment of the efficacy of the biopesticide active ingredients (AIs) in 2018 (left, pale) versus 2020 (right, dark).

Hazard profiles

A total of 26 of the hazard profiles for the identified biopesticide active ingredients were unchanged from the 2018 assessment. Five active ingredients had data gaps filled, three were assigned higher toxicity categories and three were assigned to lower categories. All 41 active ingredients have relatively low levels of hazard. Only kaolin clay met any of the criteria for highly hazardous pesticides (HHP) but US regulators have categorized it 'Generally Recognized as Safe'.

Agronomic sustainability

The team concluded that 28 of the biopesticide active ingredients would be agronomically sustainable, offering low risks to non-target organisms, low risks of pests developing resistance, and low risks of becoming invasive. Eleven of the active ingredients would need mitigation measures. Four active ingredients – allyl isothiocyanate, pyrethrins, S-methoprene and spinosad – are highly or very highly toxic to non-target organisms. There are examples in the literature of FAW developing resistance to spinosad and to genetically-modified maize incorporating genes of *Bt*, whilst another Lepidoptera species showed resistance to products containing *Bt* in the field (Mota-Sanchez & Wise, 2020). Neem trees (*Azadirachta indica* A. Juss.) and *Dysphania ambrosioides* (L.) Mosyakin & Clemants both have the potential to be invasive weeds in Africa (CABI International, 2017) so local production should only take place after risk assessments have been conducted. Data on agronomic sustainability were not available for matrine and oxymatrine.

Practicality of use by farmers

According to the literature and their product labels, 27 of the biopesticides would be suitable for smallholder farmers to use, whereas six would be difficult for such use in the short term – allyl isothiocyanate, soybean oil, *Steinernema carpocapsae, Steinernema feltiae* and *Trichogramma* spp.

Reasons for this impracticality included requirements for application equipment, high frequency of application, storage needs, shelf life, and the need for an area-wide management approach. The assessment of practicality of use in 2020 was virtually unchanged from the 2018 findings.

Registration status and availability of biopesticide active ingredients in Africa

The national lists of registered biopesticides for the 19 African countries in the study included products containing 32 of the 41 biopesticide active ingredients under assessment. Many, but not all, countries had more products registered for 2020 than 2018. In 2018 only South Africa had biopesticide products specifically registered for use against FAW. By 2020, Ghana, Kenya and Tanzania had joined South Africa in this respect. These four and most other countries had products that were broadly registered for Lepidoptera and that would potentially be effective against FAW. Ghana has registered products containing *Bt*, maltodextrin, and the combination of *Metarhizium anisopliae* and *Beauveria bassiana* for use against FAW in maize whilst some other products, such as ones containing ethyl palmitate, have registrations that broadly cover all caterpillars. Many biopesticides are registered in Kenya but only one product containing *Bt* is specifically registered for use against FAW. Kenya had the highest number of registered biopesticide active ingredients and products that could potentially be used against FAW, with 22 active ingredients and 125 products whilst South Africa listed 14 such active ingredients and 37 products, Ghana had 14 active ingredients and 26 products, and Tanzania registered 13 active ingredients and 117 products.

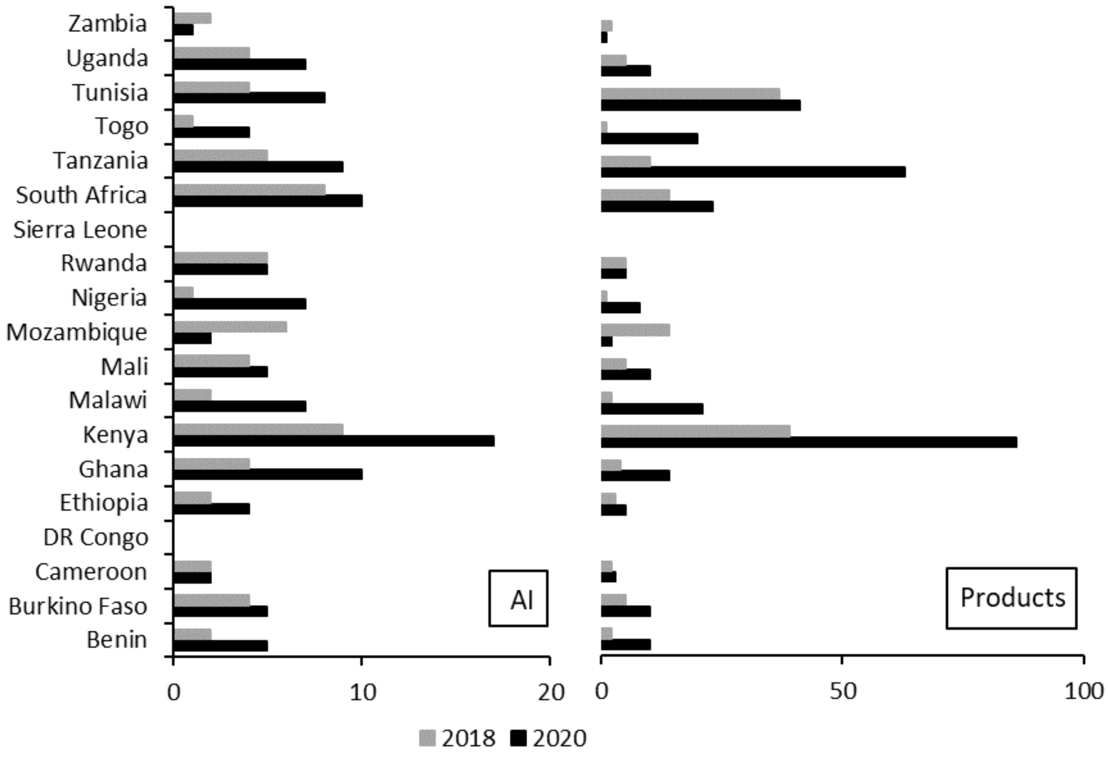

Fig. 7: Numbers of biopesticide active ingredients (AIs) (left) and corresponding products (right) registered in 19 countries in Africa in 2018 (pale) and 2020 (dark).

According to surveys of farmers in [countries such as] Ghana, Rwanda, South Africa, Uganda, Zambia and Zimbabwe, several of these biopesticides are used in the field, often through input support schemes, including *Aspergillus oryzae,* azadirachtin*, Bt* (on its own and in formulation with *Pieris rapae* granulosis virus), ethyl palmitate, GS-omega/kappa-Hxtx-Hv1a and maltodextrin (Kansiime et al. 2019, Rwomushama et al 2018, Tambo et al. 2020). There are also reports of farmers in South Africa using homemade extracts of *D. ambrosioides* (Skenjana & Poswal, 2017).

Affordability

Little information on cost or cost-effectiveness was available for most of the biopesticide active ingredients. Field trials and farmer surveys in Africa indicate that azadirachtin is cost-effective and relatively affordable for smallholder farmers (Babendreier et al. 2020) whereas ethyl palmitate (Rwomushana et al. 2018) and maltodextrin (Babendreier et al. 2020) are less cost-effective and not as affordable. Assessments for other pests or in other countries indicated that a number of active ingredients were cost-effective, including capsaicin, *Chromobacterium subtsugae,* garlic extracts, *Isaria fumosorosea, Metarhizium anisopliae,* spinosad and *Trichogramma* spp. (Dougoud et al. 2019, Kivett et al. 2015, Manisha et al. 2020, Nayak et al. 2019).

Gaps and challenges

It is encouraging that the number of biopesticide active ingredients registered per country that could potentially be used to manage FAW had more than doubled and that increases in the number of products registered were similar. There's also more evidence of efficacy for many of the active ingredients, particularly for FAW itself, and from the field in Africa. However, the findings are not always clear cut, for example, it's uncertain whether several of the botanical extracts are effective on their own or must be combined with other active ingredients.

Some of the case authors participated in field trials that showed efficacy in Africa for eight active ingredients – *A. oryzae,* azadirachtin*, B. thuringiensis subsp. Aizaiwai,* maltodextrin, FAW sex pheromones, spinosad, *Spodoptera frugiperda* multiple nucleopolyhedrovirus and *Spodoptera littoralis* nucleopolyhedrovirus*.* As a result, products have been registered across some countries in Africa. While some of these biopesticide active ingredients have already been incorporated into integrated pest management (IPM) schemes or are being provided to farmers, most still have IPM information gaps that need to be filled. For example, most biopesticide active ingredients, including many that have been registered and are being recommended to farmers, lack data on cost-effectiveness. Findings from the literature on other cropping systems are not transferable as they will be out of date and inaccurate for other locations. Costs need to be in the form of price sold to farmers by in-country distributors and calculated per hectare per season. Most maize in Africa is grown by smallholder farmers for subsistence (Hruska 2019), making most pesticides – whether synthetic or biopesticides – too expensive for use. In addition, many governments and other initiatives are scaling back the distribution of pesticides, making cost likely to become a bigger issue (Hruska 2019). Conducting further field work that establishes the most cost-effective methods for using many of these active ingredients would be beneficial.

Since most countries do not include macro-organisms in their lists of registered pesticides, it would be helpful to conduct a separate review on natural enemies. There's currently much research in progress on parasitoids, including field trials on *Telenomus remus* and *Trichogramma* in Kenya. So far, *T. remus* seems more promising than *T. pretiosum* but is more difficult to mass-produce and not yet available as a commercial product.

The increase in the number of biopesticide active ingredients that have been registered in Africa is lower than in FAW's native countries, and registrations for some active ingredients have moved more quickly in countries in Asia. This disparity could be due to registration costs, regulatory hurdles or lack of manufacturer action due to their perception of the size of the pesticide market (Constantine et al 2020, Nyangau et al 2020).

What's more, registration of an active ingredient does not make it locally available to or affordable for a farmer. Awareness and confidence can also limit uptake by smallholders. Surveys show that farmers in some countries are using biopesticides but it would be useful to examine biopesticides' availability and affordability to farmers, as well as farmers' perceptions of their efficacy, in more detail.

Recommendations for future study

A decision matrix has been created to make recommendations for field trials in Africa for eight active ingredients that were registered in at least one country and had been reported effective against FAW either in field trials in FAW's native range or in lab bioassays – *B. thuringiensis* subsp. *kurstaki, B. beauveria, D. ambrosioides,* ethyl palmitate, eugenol, garlic extract, *M. anisopliae* and *Steinernema* spp (Bateman et al. 2021). Some of these field trials are underway. We also recommended bioassays to determine the effectiveness of four active ingredients against FAW, namely GS-omega/kappa-Hx-tx-Hv1a, canola oil, capsaicin and D-limonene. If the ingredients prove effective, field trials could follow. We do not recommend the follow-up of 18 active ingredients. This group is similar to the group receiving the same evaluation in the 2018 study, with the addition of some active ingredients such as sucrose octanoate that are no longer registered for FAW in any of the 30 countries, other ingredients that the hazard data now indicate are an HHP (for example, kaolin), or in the case of matrine and pyrethrins, because studies do not indicate they are effective.

Registered for field use against FAW or other Lepidoptera in our survey	**Reported effective against FAW in field trials in Africa**	**Reported effective against FAW in field trials in native range; field trials and evaluation needed in Africa**	**Reported effective against FAW in lab bioassays; field trials needed in Africa**	**Reported effective against related pests; bioassays needed for FAW, followed by field trials if justified**	**Not recommended for follow up on available information (at this time)**
No longer registered as a biopesticide					Borax Cryolite Emamectin benzoate Lufenuron Methoxyfenozide Silicon dioxide Spinetoram
Not registered					2-phenylethyl propionate Cinnamaldehyde d-glucitol, octanoate

					Sucrose octanoate
Registered outside sub-Saharan Africa			*Dysphania ambrosioides*	GS-omega/ kappa-Hxtx-Hv1a[d]	Allyl isothiocyanate Anagrapha falcifera NPV Autographa californica MNPV *Chromobacterium subtsugae* Citric acid Helicoverpa zea SNPV *Isaria fumosorosea* Kaolin clay Spodoptera exigua NPV
Registered within sub-Saharan Africa	*Aspergillus oryzae* Azadirachtin *Bacillus thuringiensis subsp. Aizaiwai* Maltodextrin[c] Sex pheromones[b] Spinosad[a] Spodoptera frugiperda MNPV Spodoptera littoralis NPV *Trichogramma* spp.[b]	*Bacillus thuringiensis subsp. Kurstaki* Ethyl palmitate Garlic extract *Steinernema* spp.	*Beauveria bassiana* Eugenol *Metarhizium anisopliae*	Canola oil Capsaicin D-limonene	Matrine Oxymatrine Potassium salts of fatty acids Pyrethrins S-methoprene Soybean oil Sulphur Thyme oil

[a]There are concerns regarding toxicity.
[b]In many countries, sex pheromones and macrobials do not need to be registered, hence we include them here rather than list them as not registered or omit them from the table.
[c]Treatment costs are potentially too high to justify its use.
[d]Used by farmers in Zambia.

Table 1 Overview of conclusions regarding readiness of biopesticide active ingredients (AI) for deployment in Africa. Not all AI fit comfortably in this classification, and the detailed supplementary information should also be reviewed.

Conclusions

Finding effective and cost-effective biopesticides suitable for use by smallholders for FAW management in Africa remains a high priority. After updating our assessments of biopesticide active ingredients and the extent of their registration and use in sub-Saharan Africa, we employed a decision matrix to make recommendations for field trials for eight active ingredients – *B. thuringiensis* subsp. *kurstaki, B. beauveria, D. ambrosioides,* ethyl palmitate, eugenol, garlic extract, *M. anisopliae* and *Steinernema* spp. Some of these field trials are underway. We also recommended bioassays to determine the effectiveness of four active ingredients against FAW, namely GS-omega/kappa-Hx-tx-Hv1a, canola oil, capsaicin and D-limonene.

Discussion Points

Two to three topics that encourages critical thinking and discussion with others. Readers could be asked to (1) describe factors that reduces the effect of the current control measures; (2) evaluate potential new management methods; (3) compare progress with similar problems in other crops; (4) discuss controversial topic such as: GMO, trade barriers, pesticide exposure, unsustainability, climate change, gender inequality etc.

1) Is the rate of progress in knowledge about and development of biopesticides for FAW in proportion to the threat this species poses to smallholder livelihoods?
2) What do you predict that smallholders will be using against FAW in ten years' time and how will they have reached this point?
3) What are the advantages and challenges of updating knowledge of biopesticides for FAW in this comprehensive way?
4) Would this approach to developing biopesticides for FAW be appropriate for other pests?

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Further reading

A list of various types of publications including websites to begin a more in-depth study of the topic.

Bateman ML, Day RK, Rwomushana I, et al. Updated assessment of potential biopesticide options for managing fall armyworm (Spodoptera frugiperda) in Africa. J Appl Entomol. 2021;145:384–393 https://doi.org/10.1111/jen.12856

CABI PlantwisePlus Knowledge Bank Pest Management Decision Guides Fall army worm (FAW) on maize: *Spodoptera frugiperda*; https://doi.org/10.1079/pwkb.20197800348

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