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Current Opinion in Insect Science

# Integrated management of *Spodoptera frugiperda* 6 years post detection in Africa: a review

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The introduction of fall armyworm (FAW) *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) on the African continent has led to paradigm shifts in pest control in maize systems, occasioned by year-round populations. The discovery of resident parasitoid species adapting to the new pest significantly informed decision-making toward avoiding highly hazardous synthetic insecticides to control the pest. A number of biopesticides have shown promise against the fall armyworm, providing a new arsenal for the sustainable management of this invasive pest. However, a few knowledge gaps remain for a fully integrated and sustainable FAW-management approach, particularly on host-resistance potential.

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**Current Opinion in Insect Science** 2022, **52**:100928

This review comes from a themed issue on **Special section on IPM in Africa**

Edited by **Thomas Dubois** and **Manuele Tamò**

For complete overview about the section, refer “Special section on IPM in Africa (December 2022)”

Available online 6th May 2022

https://doi.org/10.1016/j.cois.2022.100928



## Background

The fall armyworm (FAW) *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) is native to the Americas. Following its first detection in Africa in early 2016 [1••], FAW unarguably became the most damaging lepidopteran pest in maize agroecosystems. Before 2016, the predominant lepidopteran pest complex in maize agroecosystems comprised a few foliage-feeding species of *Spodoptera* and stem borers [e.g. *Busseola fusca* (Fuller), *Sesamia calamistis* Hampson, *Chilo partellus* (Swinhoe), and *Eldana saccharina* Walker] [2]. Except for sudden outbreaks of the African armyworm, *S. exempta* (Walker), infestation by these other Lepidoptera either rarely warrants chemical control or is maintained at below economic injury level by native and introduced natural enemies [3].

The accompanying high levels of damage on maize against a backdrop of a limited number of plant-protection products that are yet registered for FAW, and the general unsustainability of chemical control at the smallholder farmer level highlights the need for a holistic integrated pest-management (IPM) strategy. Therefore, continental efforts were launched by several development partners, regional, and international organizations to design and deploy contingency-mitigation measures and medium-term and long-term interventions. Subsequent training, research, and partnership arrangements are leading to the generation of evidence-based knowledge. Coordination mechanisms, breakthroughs, and the potential impact of the tools and innovations developed to manage the invasive pest are discussed in this review. We also assess farmers’ responses to the pest threat and articulate guiding principles for a roadmap for improved delivery of FAW IPM in the context of changing climates.

Following its first detection on the continent, various strategies were employed to manage the new and highly damaging FAW pest. At the smallholder farmer level, techniques employed included physical and mechanical control (e.g. crushing of egg masses and neonates, placement of sand or wood ash inside plant funnels, and drenching plant funnels with laundry-washing powders), application of extracts from neem (*Azadirachta indica*) and velvet bean (*Mucuna pruriens*), application of fish soup, ‘push–pull’, intercropping, and other traditional practices [4–8]. At the commercial farmer level, there was total reliance on synthetic chemical insecticides, some of which are classified as moderately to highly hazardous [9]. Simultaneously, using information from the Americas, governments started fast-tracking registrations of synthetic chemical insecticides that had no known lepidopteran-resistance history and had not yet undergone proper trials.

## Knowledge generation and sharing

A better understanding of the bioecology of the pest in the African context has led to hypothesis-driven FAW research [10].

### Impact assessments and socioeconomic studies, including socioeconomic costs of damage

There have been disparate maize-yield loss estimates between farmer perception-based and socioeconomic surveys of FAW impacts [11–14] and rigorous empirical reports showing much lower consequences [15,16]. However, early outbreaks of FAW were quite devastating, and in some instances, all the maize crops were totally lost. Thus, whether further vast FAW-management campaigns contributed to successful reduction of pest populations, the new associations of natural enemies contributed to FAW-population regulation, or the initial impact assessments were overestimates is unclear. Besides, it was postulated that FAW would outcompete resident communities of stem borers in Kenya and Uganda [2,3]. Indeed, field data collected from several countries from 2016 to 2020 appeared to show an almost total absence of stem borers from maize fields (P. Chinwada, unpublished data; S. Nyamutukwa, unpublished data). However, recent field studies are starting to show increased incidence of some stemborer species in maize fields infested by FAW, thus pointing to a putative partitioning of the niche that is permitting coexistence of both [17]. Evidence from Cameroon associated the FAW infestations with vegetative stages, while stem borers were associated with reproductive stages of maize [18].

### Early warning, monitoring, and surveillance

Data portals were launched to inform pest monitoring and surveillance, including the Food and Agriculture Organization of the United Nations' Fall Armyworm Monitoring and Early Warning System platform (https://www.fao.org/fall-armyworm/monitoring-tools/famews-global-platform/en/), Plantvillage Nuru Application, and CAB International (CABI)'s fall armyworm portal (https://www.cabi.org/isc/fallarmyworm). These are scouting, pheromone trapping, and algorithm-generated products. In West Africa, field trapping with FAW pheromones showed significantly differing results according to the lure component, cropping environment, and country [19]. The most used 2-component lure in the Americas was not efficient for FAW pheromone trapping in Africa. A few studies confirmed potential communication interferences between FAW and the resident communities of *Spodoptera* and *Leucania loreyi* using the generic well-known 2-component, 3-component, and 4-component lures of *S. frugiperda*. This was supported by new insights that only the three acetates *Z*9–14:Ac, *Z*7–12:Ac, and *Z*9–12:Ac were present in female pheromone gland of African FAW specimens [20]. Literally, some pest prediction models and monitoring and surveillance data improved our knowledge of the determinants of the pest's distribution patterns [10,21,22] with hints on potential migration patterns/seasonal spread across different regions in Africa [10]. However, this is still not well documented as in the Americas, which is a gap regarding early warning efforts and deployment of effective management strategies in Africa. This is critical as in locations with transient populations of FAW, some of the sustainable management strategies will not perform well. Further FAW migration-model predictors should consistently include the African ecosystem landscape diversity (skirting from humid forests to the most xeric environments) and cropping cycles and seasons. Moreover, a greater portion of the African continent is suitable for FAW-overlapping generations, while the pest displays a uni- or oligo-voltine population nature, particularly in the Sahel.

### Host range and pest genetic diversity

To the best of our knowledge, little is known regarding the FAW host plant diversity [23•], but most of the gray literature from field-survey efforts concur to the conclusion of not as much as FAW host plant species in Africa compared with the long list of host plant species documented in the Americas (353 FAW host plant species [24]). But these two contexts are not comparable since the pest was introduced to the African continent not long ago. From pest genetic analysis [25], it is now established that FAW strains present on the African continent are to date composed of more than 90% maize strain; the rest are hybrids and some less than 1% rice strain [26]. The haplotype profile from locations examined in 11 African countries indicated that Florida and the Caribbean regions are the most likely Western Hemisphere origins of the African infestations. Conversely, evidence of further recent introductions of the pest into the continent underpins the need for continued surveillance to avoid the incursion of new FAW populations with broader host range and pesticide resistance [27].

### Integrated pest-management techniques

The most effective synthetic insecticides reported are emamectin benzoate (avermectin) [28], and Ampligo® 150 ZC, a binary formulation with 100 g a.i./L chlorantraniliprole (diamide) and 50 g a.i./L lambda-cyhalothrin (pyrethroid) to control FAW on maize at the early-whorl stage [29] (Table 1). The fact that most of the chemicals listed in Table 1 are registered in Southern Africa does not indicate a lack of registrations in other regions of Africa [30], but is merely reflective of the ease with which such information was obtained from national plant-protection organizations in Southern Africa as well as on the Internet. Most insecticide-application

**Table 1**

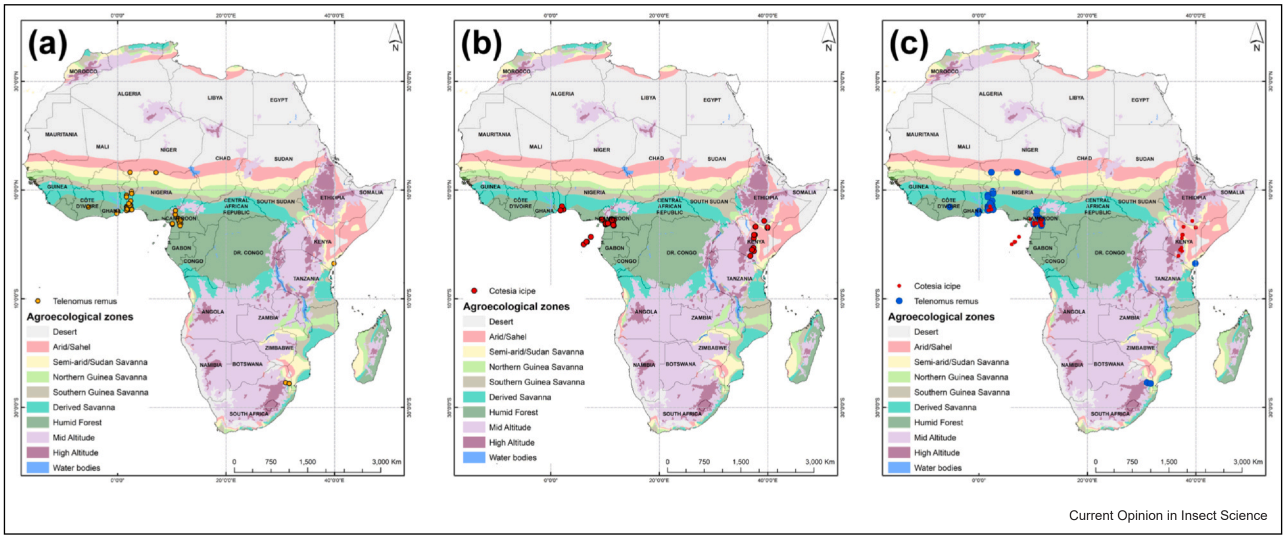
**Some insecticides and biopesticides registered for FAW control in Africa.**

| Active ingredient | Some brand names | Countries[a] | References |
|---|---|---|---|
| *Beauveria bassiana* | Eco-Bb | South Africa | https://www.dalrrd.gov.za/ |
| Spodoptera frugiperda multiple Nucleopolyhedrovirus | Fawligen | Kenya | https://www.pcpb.go.ke/biopesticides-on-crops/ |
| (Z)-9-tetradecen-1-yl acetate 79.15% (Z)-11-hexadecen-1-yl acetate 11.83% | Pherogen | Kenya | https://www.pcpb.go.ke/biopesticides-on-crops/ |
| Maltodextrin | Eradicoat T GH | Ghana | CABI Bioprotection portal |
| Chlorantraniliprole | Coragen, Predation, Mythic FN SC | South Africa, Zambia | Chinwada P, personnal communication; https://www.dalrrd.gov.za/ |
| Chlorantraniliprole + lambda-cyhalothrin | Ampligo, Ampligo 150 ZC | South Africa, Zambia, and Zimbabwe | https://www.dalrrd.gov.za/; Chinwada P, personnal communication |
| Cyantraniliprole | Lumivia 625 FS | Zambia | Chinwada P, personnal communication |
| Cyantraniliprole + thiamethoxam | Fortenza Duo | Zambia, Zimbabwe, and Kenya | Chinwada P, personnal communication |
| Cypermethrin | Cypermethrin, Cypercal 250 EC | Cameroon, Malawi | [6] |
| *Bacillus thuringiensis* subsp. *kurstaki* strain SA-11 | Delfin | South Africa, Zambia | Chinwada P, personnal communication; https://www.dalrrd.gov.za/ |
| Diflubenzuron | Dimilin 25 WP | South Africa | https://www.dalrrd.gov.za/ |
| Emamectin benzoate | Emamectin benzoate, Prove, Proclaim Fit | Malawi, South Africa, Zambia, and Zimbabwe | [6]; https://www.dalrrd.gov.za/ |
| Emamectin benzoate + Lufenuron | Denim Fit | South Africa, Zambia | Chinwada P, personnal communication; https://www.dalrrd.gov.za/ |
| Flubendiamide | Belt 480 SC | Malawi, South Africa | [6]; https://www.dalrrd.gov.za/ |
| Indoxacarb | Steward, Steward 150 EC, Advance | Malawi, South Africa | [6]; https://www.dalrrd.gov.za/ |
| Lufenuron | Judge, Match 050 EC | Kenya, South Africa | https://www.dalrrd.gov.za/ |
| Methomyl | Methomex 900 SP, Methomyl 200 SL | South Africa | https://www.dalrrd.gov.za/ |
| Profenofos | Formag Profenofos 500 | Malawi, South Africa | [6]; https://www.dalrrd.gov.za/ |
| Spinetoram | Delegate 250 WP | South Africa | https://www.dalrrd.gov.za/ |
| Spinetoram + methoxyfenozide | Uphold 360 SC | South Africa | https://www.dalrrd.gov.za/ |

[a] List not exhaustive.

schedules used by farmers are calendar based and not action-threshold based. In the long run, calendar-based spraying would neither be cost-effective nor sustainable and has high risk of FAW-resistance population buildup in Africa. With increasing evidence, more rational application rates will be recommended. For example, in Ghana, Osae *et al.* [29] found two applications of Ampligo 150 ZC (200 ml/ha) at one-week intervals to be sufficient to sustain maize for the whole cropping season. It is important to point out that, in the absence of location-specific data on FAW incidence and temporal dynamics (as influenced by planting dates and season), extrapolating this recommendation on Ampligo application schedules to other regions or countries should be avoided. Although offering fast curative action, the health risks associated with synthetic insecticides and resistance patterns [31] continue to point to the need for alternative pest-management methods, particularly in the African context where the use of the chemicals does not always comply with standards. Thus, the application of biopesticides such as neem-, virus-based, and entomopathogenic fungi-based products may represent such alternatives [32–35]. However, farmer perception of their effectiveness remains a concern to widescale use [36••]. In addition, rotation of active ingredients with different modes of action remains one of the sound resistance-management strategies to be implemented to delay the evolution of resistance of FAW. The earliest report on push–pull technology efficacy exhibited good control levels of FAW in Eastern Africa [4,5]. Success in efforts to expand push–pull to West Africa has been limited due to weak crop–livestock integrations. For successful adoption of the push–pull technology, factors such as return on investments from the intercropped *Desmodium* and trap plants (Brachiara or Napier grass) at post maize harvest, availability of companion crop seeds, and necessities to adapt push–pull to the needs of diverse agroecologies and communities must be strengthened. The first reports of locally prevalent parasitoids associating with FAW in Africa [37–39••] (Figure 1)

**Figure 1**




Distribution maps of two key FAW parasitoid species in Africa: **(a)***Telenomus remus*, **(b)** *Cotesia icipe*, and **(c)** both species. The species were reported in some further localities, but the georeferenced records were not accessible.

have led to more careful assessment of the native fauna before classical biological control considerations using promising co-evolved parasitoids from the Americas such as *Chelonus insularis* Cresson, *Cotesia marginiventris* (Cressson) (both Hym.: Braconidae), or *Eiphosoma laphygmae* Costa Lima (Hym.: Ichneumonidae) [40]. As a result, stakeholders may need to focus more on augmentative and conservation options. The egg parasitoid *Telenomus remus* Nixon (Hymenoptera: Platygastridae) is preferred over *Trichogramma* spp. in biocontrol programs in the Americas due to its capability of parasitizing inner layers of egg masses. The first data of FAW-field parasitism by *T. remus* collected in Benin and Ghana [41] showed 14.5–25.9% attack on egg masses and is lower than the above 50% average recorded in Eastern Africa [38]. This suggests a better performance of *T. remus* at lower temperatures due to a longer duration of the egg stage, and thereby a larger window of opportunity for parasitization. However, further reports on inoculative releases of the egg parasitoid provided contrasting results with no significant differences between the ‘release’ and ‘no-release’ plots in Ghana [42]. New associations between FAW and native *Charops* larval parasitoid species were discovered both in West and East Africa [41,43], although low parasitism rates were frequently reported as is the case elsewhere in Mozambique [44]. Inversely, the findings on *Cotesia icipe* Fernández-Triana and Fiaboe (Hym.: Braconidae) performance on FAW first and second instar larvae indicated more than 60% parasitism rate in the laboratory [45] and up to 45% parasitism in the field in Ethiopia [37]. Most African countries have a precautionary stance regarding the use of genetically modified organisms (GMOs). Candid concerns have been raised on the affordability of the products developed from the GMO technology in the context of smallholder farming systems in sub-Saharan Africa [29]. Bt-maize is currently mostly deployed in South Africa for FAW management [46]. Unfortunately, there is not much cost–benefit analysis on its use against FAW in the African context, while there are some early reports on development of resistance by FAW [47]. Only recently has evidence on FAW host plant resistance become accessible in the public domain [48]. Though host plant resistance can play an important role in FAW management [49•], the rapid decline in resistance (taking on average three years) merits further investigations in order to increase the level of adoption of the technology at the smallholder farmer level. The best IPM package to manage FAW sustainably should therefore be context-specific [50] with emphasis on accessible cost-effective technologies.

## Stories and roadmap for successful integrated pest-management

### Partnerships and coordination

Donors began to commit funding to develop management strategies against FAW when almost the entire sub-Saharan Africa was affected at astonishing speed. Out of panic, a few governments procured huge volumes of synthetic insecticides as emergency response to initial FAW outbreaks. Further, science-led development agencies and international research for development and partnership for development consortia advised otherwise and advocated for sound IPM measures for sustainability reasons. Therefore, decision-makers and governmental institutions were engaged in a series of regional and subregional awareness campaigns and capacity-strengthening events. In addition, local, regional and international FAW task forces were created to improve coordination and synergies across interventions. This was also part of scaling mechanisms to enhance the adoption of proven FAW IPM strategies. However, there is still concern on the sustainability of these initiatives once the sponsoring projects end. Evidence on continued action post project interventions is scant.

### Preconditions to scale best-bet climate-smart integrated pest-management

The lack of suitable cost-effective alternative insect-pest- management technologies often explains farmers' dependence on synthetic insecticides. This in most cases has weakened awareness campaigns against highly toxic insecticides. Accessibility of validated effective technologies is key for their adoption. Equally, the design of any IPM package should be context-specific, matching farming communities' needs and be gender- and social-inclusion-sensitive. For instance, the deployment of resistant/tolerant varieties that do not meet consumer demands will have high-adoption failure rates. The phenomenon of FAW has emphasized the need for enhanced anticipation (horizon scanning) and foresight analysis, particularly in the face of climate change. Any IPM investment that is not climate-smart risks waste of resources and lack of uptake by farmers. For example, biological control programs should increasingly consider the model biocontrol agents' capabilities to adapt, despite changing climates [51•]. Earlier reports design climate-smart IPM [52] as partly including the following elements also relevant for long-term FAW management:

- Developing climate-informed models of pest risks and candidate natural enemies for the reprioritization of management options;
- Enhancing capacity for timely detection of invasive species and preventive action against future climate-driven pest risks;
- Upgrading monitoring, forecasting, and scaling of advisory services as incentives for farmers to contribute to pest surveillance using IC-based early warning tools;
- Enhancing governmental pest-management front agents, farmers, and other next- and end-users' capabilities in reporting, anticipation, proactiveness, and response;
- Fine-tuning pilot evidence-based innovations and fostering the use of digital tools, including Apps-led pest scouting and warning devices;
- Cocreating business models for pest-management services and engaging the private sector for sustainable deployment of impactful products and tools by empowering champion youth and women;
- Engaging policy makers to trigger enabling policies, regulatory environment, and coercive measures, particularly against prohibited and high-toxicity chemicals that have significant nontarget effects;
- Fostering approval procedures and harmonization of low-toxicity biopesticides and measures to guard against abuse/misuse of chemicals; and
- Accelerating the codevelopment and coordination of functional, local, and regional early warning and rapid response systems.

## Funding

The authors thankfully acknowledge the financial support provided by the International Development Association (IDA) of the World Bank to projects aimed at Accelerating Impact of CGIAR Climate Research for Africa (P173398, AICCRA-Ghana). IDA helps the world's poorest countries by providing grants and low- to zero-interest loans for projects and programs that boost economic growth, reduce poverty, and improve poor people's lives. IDA is one of the largest sources of assistance for the world's 76 poorest countries, 39 of which are in Africa. Annual IDA commitments have averaged about $21 billion over circa 2017–2020, with approximately 61% going to Africa. This work was partly funded by the Royal Norwegian Embassy in Mali for "climate smart agricultural technologies for improved rural livelihoods and food security" in Mali (Grant MLI-17-0008) and Niger (Grant NER-17-0005). FAW research at IITA is financially supported by the Federal Ministry for Economic Cooperation and Development (BMZ/GIZ) through project grant 81235252 GA, while FAW research at *icipe* is financially supported by the United States Agency for International Development/Office of US Foreign Disaster Assistance (USAID/OFDA) and the European Union.

## CRediT authorship contribution statement

**Ghislain T. Tepa-Yotto**: Conceptualization, Investigation, Methodology, Writing – original draft, Funding acquisition, Supervision. **Peter Chinwada**: Conceptualization, Writing – review & editing. **Ivan Rwomushana**: Conceptualization, Writing – review & editing. **Georg Goergen**: Writing – review & editing, Funding acquisition. **Sevgan Subramanian**: Conceptualization, Writing – review & editing, Funding acquisition.

## Conflict of interest statement

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. The funders had no role in the design of the study, in the assemblage and interpretation of data, in the writing of the review paper, or in the decision to publish the results.

## Acknowledgements

The authors are indebted to colleagues who shared *Cotesia icipe*'s GPS data, Komi K.M. Fiaboe (Cameroon and Kenya), Koku Lakpo Agboyi (Ghana), and Jeannette K. Winsou (Benin). We are equally grateful to Tunrayo Alabi for developing the distribution map for both *Telenomus remus* and *Cotesia icipe*.

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- •• of outstanding interest

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•
This publication is one of the rare literature reporting on FAW alternative host plants in Africa. The study provided the first information on the occurrence of *S. frugiperda* in onion crops in Africa. The highest average incidence (2.88%) and larval density (0.79 per 9 $m^2$) were observed in onion monoculture compared to onion intercropping with groundnut. Fall armyworm infestations to onion could be considered in future studies to assess this survival strategy of the pest to maintain its population throughout the year and particularly during times when its preferred host (maize) is absent.

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The study predicted habitats of high establishment potential of key parasitoids of FAW in South America, which might prove to be effective as classical biological control agents of FAW in regions where it is an invasive species under current and future climate scenarios. The prospective parasitoids are the following: *Chelonus insularis, Cotesia marginiventris, Eiphosoma laphygmae, Telenomus remus* and *Trichogramma pretiosum*. The results demonstrated overlapping habitat suitability areas of the pest and the parasitoids, suggesting promises for biological control options for the management of FAW under current and future climate scenarios. The paper is a pioneering demonstration of the relevance to construct an IPM stratagem that is climate-smart.

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