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PERSPECTIVES PAPER

The spread of the fall armyworm *Spodoptera frugiperda* in Africa—What should be done next?

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Abstract
The following text summarizes the different perspectives of presenters participating in the section *Plant Protection in the Tropics and Subtropics, 61st German Congress of Plant Protection,* held on September 11, 2018, University of Hohenheim, Germany. The aim of the symposium was to develop a critical perspective on the status of the fight against the spreading of the fall armyworm (FAW) *Spodoptera frugiperda* in Africa. The results of the presentations and discussions are reported here.

Keywords Fall armyworm · Africa · Invasion · Symposium report

The symposium topic

In total, more than 120 scientists from 14 countries participated in the symposium, representing regulatory bodies, universities, federal research institutions, plant protection consultants, and enterprises.

Results

The spread of *Spodoptera frugiperda*

Georg Görgen (IITA) reported on the rapid spread of the fall armyworm (FAW) in Africa. First discovered in Nigeria in January 2016 (Görgen et al. 2016), it is already found in 44 African countries covering more than 25 million km^2 in 2018. Currently, it is spreading around the Sahara desert to the North and has already reached Jemen and even India in the East. The high spreading speed is caused by the ability of the insect to fly more than 100 km per night. Originating from the two Americas, FAW is known to have migrated from Central America to the North as far as Canada and to the South reaching Argentina. The area of permanent reproduction ends north of Mexico and south of Brasil and merges to a certain area where only temporary reproduction occurs.

Görgen pointed out that the genus *Spodoptera* includes 31 species which are distributed on 6 continents, 8 of which occur in Africa. Here, in populations of the FAW two strains are found, which are not distinguishable morphologically, but only by their behavior (resistance formation, pheromone affinity). Invading Africa from America, a new haplotype can be found in West Africa, which seems to be Africa specific (Nagoshi et al. 2018).

African field sizes support the spreading of the FAW in Africa, because small and very small fields are more threatened than medium- to large-scale fields, e.g., in Brasil due to control measures available for the farmers (Fritz et al. 2015).

Görgen pointed out that an integrated pest management system with an encompassing approach is needed to control the spreading of the FAW in Africa, including components like regulatory frameworks, capacity building and education, monitoring and warning systems, pesticide options, biocontrol mechanisms, cultivation aspects and mechanical control, and resistance breeding.

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Biopesticides and farmer scouting for FAW management

Manuele Tamò (IITA-Benin) reported about a real-case-scenario in Benin, West Africa. Here, most of the farmers are planting their crops on small-scale fields, mostly in the range from 0.5 to 3 ha. According to their experience, synthetic pesticides can control FAW, but applying them creates challenges at several levels: national pesticide legislation does exist, but implementing them is problematic. Markets for pesticides are unregulated, imports cheap and often of doubtful quality. Farmers can hardly protect themselves when spraying, because protective equipment is normally not available or affordable, and this is compounded by the lack of technical knowledge. Pesticide residues cannot be properly detected due to insufficient testing infrastructures in Africa, and the inappropriate use of pesticides intoxicates consumers. Undesired environmental side effects like groundwater contamination are common and the negative impact on pollinators and natural enemies of pests currently inevitable.

Against this background FAW management approaches in Africa should be based on the use of biopesticides. There are commercial products on the market like *Spodoptera frugiperda multiple nucleopolyhedrovirus* (SfMNPV) and *Beauveria bassiana*. Locally fabricated biopesticides like neem oil and insect-specific baculoviruses can be produced in the communities and provide additional income to disadvantaged groups such as women and youth.

In order to document the presence of FAW and the severity of the damage it has caused, FAO has developed a new FAW monitoring and early warning system tool (FAMEWS), Tamò said. While the FAMEWS tool is excellent for mapping FAW hotspots, it still does not provide easy-to-handle recommendations for a proper control of the FAW. A farmer interface application (FIA) is currently planned to provide the link between control recommendations and farmer scouting. FIA integrates a scouting algorithm guiding the farmer with voice commands in the local language on how to move randomly in the field and to check a specific number of maize plants, inspect them for the earliest life stages of the pest (egg masses or young caterpillars), and press the right symbol to record the presence/absence of the pest. This will allow the FIA, independently from being connected to the Internet, to calculate an intervention threshold and allow the farmer to make an informed decision about protective measures. At this point, the current FIA prototype is upgraded to allow for collecting real-time and geo-referenced field data (e.g., plant phenology and incidence of pests) and transmitting them to the VIPS platform developed by the Norwegian Institute of Bioeconomy NIBIO (https://www.vips-landbruk.no/information/1/), thus making use of the VIPS "expert system" for implementing an IPM that considers real-time weather data and pest models.

Overall, early warning and rapid response, citizen science and ICT tools, and safe crop protection products including cost-effective biopesticides form together with host plant tolerance and genetic studies of FAW populations, the IITA long-term strategy to manage FAW in Africa.

Biocontrol of *Spodoptera frugiperda*

Jörg Wennmann (Julius Kühn-Institut, Germany) illustrated that a number of natural antagonists of FAW are available in the natural area of its origin in North and South America, which could be used for biocontrol of FAW in Africa and Europe. Resistance control of FAW populations demands all elements of integrated plant protection including innovative and sustainable methods. In contrast to chemical insecticides, biocontrol products have the advantage of a narrow host spectrum, which does not affect nontarget organisms like pollinators and natural enemies. Wennmann explained that this is true for some highly effective, non-toxic bioproducts as well.

As an example, the ubiquitous entomopathogenic bacterium *Bacillus thuringiensis* is used in form of transgenic Bt-maize in North und South America. However, resistances against the insecticidal protein Cry1Fa occurred already. This has to be kept in mind when thinking about the use of transgenic plants in Africa.

Besides cultivation of Bt-maize, the application of products containing *B. thuringiensis*, entomopathogenic fungi, and baculoviruses is most promising. In several countries of Africa, such products have already been developed. It is not yet sure in how far the microorganisms are ubiquitous in Africa, too, or have to be treated as non-indigenous alien organisms.

Currently, baculoviruses of the family Baculoviridae play an important role in organic and integrated plant protection. They are used worldwide in biocontrol products for plant protection to control different Lepidoptera caterpillars in agriculture. Own studies demonstrated that baculoviruses could be isolated from caterpillars of FAW and *S. littoralis*, which have a high effectiveness against FAW, and should be used preferentially as biocontrol agents in Africa.

Chemical control of *Spodoptera frugiperda*

Hartwig Dauck (Bayer) described the current chemical control options of FAW in Africa. Chemical products to control *Spodoptera frugiperda* in maize are essential tools to safeguard the agricultural yield, he said. Until recently, the relevant distribution of *Spodoptera frugiperda* was limited to the warmer zones of the American continents. In the USA and in South America, maize is largely cultivated for animal feed or for energy generation. Here, a number of chemical crop protection products for *Spodoptera frugiperda* control have been available since many years. However, after the invasion of the African continent, *Spodoptera frugiperda* poses a new challenge for chemical crop protection, especially because here maize is mostly used as a staple and essential for human nutrition. Furthermore, availability of registered suitable chemical products is scarce, and the knowledge of many farmers on the correct use of such crop protection products is limited.

The range of potentially suitable chemical crop protection compounds comprises a large number of chemical classes, from older organophosphates and carbamates, through pyrethroids and growth regulators up to modern chemistry like spinosyns and diamides, complemented by a number of rather solitary molecules like emamectin benzoate, indoxacarb and chlorfenapyr, or also biological compounds like azadirachtin (neem) or *Bacillus thuringiensis*.

The decision which suitable compounds to use for the control of *Spodoptera frugiperda* is a challenge for the farmer. He has to consider their strength, mode and speed of action, availability and costs, resistance management needs, and safety for users and the environment. Thus, the subsequent requirements for an appropriate use from a technical and stewardship point of view have to be integrated into a local management action plan.

In Africa, Bayer is in the act of extending the labels of their available and suitable chemical crop protection products to include the control of *Spodoptera frugiperda*, and to prepare corresponding training for the farmers. Furthermore, Bayer is working on the development of biological control measures as well, to be able to offer sustainable, integrated concepts.

Breeding against the fall armyworm

Boddopally M. Prasanna (International Maize and Wheat Improvement Center, CIMMYT) talked about current actions against FAW in Africa, especially by breeding. Developing and deploying effective host plant resistance is one of the pillars of an Integrated Pest Management (IPM) strategy against FAW. Naturally occurring, or "native," resistance has been identified in several maize inbred lines/populations/hybrids, especially in the Americas, where the trait has long been incorporated into conventional breeding programs. Most native resistance in maize is polygenic and quantitative in nature, conferring tolerance or "partial resistance." Throughout the 1970s to the 1990s, research conducted at CIMMYT in Mexico, EMBRAPA in Brazil, USDA-ARS (Mississippi), and some universities in the USA, led to the identification and development of a number of improved tropical/subtropical/temperate maize inbred lines with at least partial resistance to FAW. Some of these sources of insect resistance were specifically tested for FAW resistance, while others were tested for resistance to other insect pests but have a potential to confer resistance to FAW. While identifying materials with native resistance to FAW, it is important to consider not only foliar rating, but also ear/kernel ratings, as FAW can also cause significant ear/kernel damage, especially when the larvae gain entry into the developing ears.

In view of the nature of the pest and the damage it can cause to maize crops in sub-Saharan Africa, it is imperative that international research centers like CIMMYT and IITA (International Institute of Tropical Agriculture), together with the national and private-sector maize breeding programs, initiate and maintain a strong pipeline of elite products that incorporate native resistance to FAW, along with other important adaptive traits relevant for maize smallholders in sub-Saharan Africa. CIMMYT is presently undertaking intensive screening of tropical/subtropical maize germplasm against FAW under artificial infestation (in screen houses) in Kenya. The priorities are: (a) to identify potential sources of FAW resistance in CIMMYT's elite Africa-adapted (sub)tropical maize germplasm (inbreds/DH lines and pre-commercial hybrids) for release and deployment through partners; (b) to identify potential first-generation products with FAW resistance among the CIMMYT-derived hybrids/OPVs released under the Insect Resistant Maize for Africa (IRMA) in sub-Saharan Africa; (c) to fast-track introgression of native resistance to FAW from exotic sources, including germplasm from USDA-ARS and Brazil, using DH technology and backcrossing; (d) to discover/validate genomic regions for FAW resistance using appropriate populations, and explore the possibility of genomic prediction for developing novel Africa-adapted FAW resistant maize varieties.

In his presentation, Prasanna concluded that CIMMYT currently needs to effectively utilize and quantify the benefits of host plant resistance in the IPM strategies for FAW management in African agro-ecologies and cropping system landscapes. The next steps will be (a) scaling up and deploying "first-generation FAW-tolerant maize varieties" (those already released in ESA under IRMA) as an immediate relief to the farming communities, (b) accelerated breeding for improved Africa-adapted varieties with FAW resistance and other farmer-preferred traits, (c) varietal release and deployment of "second-generation FAW-tolerant maize hybrids/OPVs in SSA," (d) systematic analysis of compatibility and possible synergies between host plant resistance with other IPM approaches (e.g., biological control) in regard to FAW in Africa.

Communication, information sharing, and advisory services to raise awareness for fall armyworm detection and area-wide management by farmers

Stefan Toepfer from the Centre for Agriculture and Bioscience International (CABI) (Toepfer et al. 2018) reported that alien species often cause serious problems to agricultural production as specific and effective natural enemies of the "invaders" usually are missing when they arrive in new ecosystems. Farmers, who are most affected, rarely know about the presence of these newly arrived and spreading species until disastrous damage occurs. This scenario has also been observed for the FAW invasion across Africa. FAW caterpillars insatiably feed on maize and about 80 other crop species. The value of maize losses associated with FAW attack has been estimated at between US$2 ½ and US$6 million in Africa in 2017 (Day et al. 2017).

The FAW is somewhat difficult for farmers to distinguish from other local caterpillar pest species, like African armyworm (*Spodoptera exempta*), Beet armyworm (*Spodoptera exigua*), African cotton leafworm (*Spodoptera littoralis*), *Helicoverpa* species, or stalk (stem) borers such as *Busseola* and *Chilo* species (CABI 2017). Therefore, FAW may initially remain unidentified by farmers on their fields, aiding the build-up of pest populations. To mitigate this, dissemination of information on early warning and management practices to key stakeholders is essential. However, in the absence of effectively functioning extension systems—which is common in a number of countries—this remains a huge challenge.

CABI, working with in-country partners, employs mass communication, information sharing, and agricultural extension services to aid early detection and management of FAW at farm level. Unlike face-to-face approaches such as farmer field schools, extension worker visits, or farmer cluster meetings, mass extension achieves wide and fast reach of farmers, often at a lower cost. Various media approaches have been used including farmer television emissions (e.g., Zambia, Kenya), village-based video screening (e.g., Uganda), plant health rallies (e.g., Uganda, Kenya), factsheet and photosheet apps (e.g., Plantwise Factsheet App), or social media chat groups (e.g., Plantwise WhatsApp/Telegram groups—Zambia, Malawi, Uganda). On the medium term, all agricultural extension workers need to be trained by prior trained country trainers. This approach may be effective in countries, where a network of governmental frontline extension workers exists. Besides, CABI has continued to enhance access to extension services through facilitation of plant clinics implemented through the Plantwise program (www.plantwise.org). All the above-mentioned measures need to be combined with knowledge sources, and many are available on FAW (see "CABI Invasives Spodoptera frugiperda twitter list," "PestLens USDA-APHIS," "IITA News," "PestNet Listserve," "EPPO Global Database," among many others).

The FAO´s intervention strategy

Allan Hruska from the Food and Agriculture Organization of the United Nations (FAO) explained FAO´s intervention strategy against FAW. The strategy is based on five elements: (a) farmer education and communication, (b) testing and validation of FAW management practices, (c) monitoring, risk assessment, and early warning systems, (d) policy and regulatory support, and (e) coordination. Hruska pointed out the following key knowledge and necessary actions, which are conveyed: (a) increase plant diversity in plots, (b) scout often and control mechanically, (c) maize plants can compensate for certain levels of foliar damage (d) natural biological control is very important: farmers' friends are present and effectiveness can be increased (e) effective control does not have to be fast, (f) there are many practices to try, based on local knowledge and materials. If this guideline is combined with modern risk assessment methods (use of FAMEWS), a valid action plan can be built up with four key steps:

1. *Prevention* Increase of plant diversity in and around plots. Maize mixed in plots with cassava or yams or other crops may be less attractive to female FAW moths. Some plant species repel female FAW moths. This is the basis of the "push–pull" technology: including a plant species that "pushes" FAW away from maize, and to plants that "pull" them (attract them), where they can be easily controlled.
2. *Knowledge to act* (a) Do not panic: maize plants can compensate for certain levels of foliar damage—a low level of FAW infestation may have little yield impact, (b) scout fields often to observe, learn, and make decisions, (c) control mechanically: very effective for smallholders, (d) farmers' friends (the natural enemies of FAW) are probably present, and their effectiveness can be increased.
3. *Keep innovating and controlling* (a) take action to attract predators and parasitoids. Some farmers have found that they can attract ants to their maize fields by putting cooking grease or fish soup into their maize fields. Some farmers use sugar water to attract and feed the wasps or some ants that can parasitize or eat FAW, (b) "recycling" pathogens: farmers can collect FAW caterpillars killed by pathogens, take them home, grind them, add water, and strain the mixture. The liquid that strains through may be full of fungal spores, bacteria, or virus particles that can be diluted and sprayed back into infested plants. This is a free, effective natural biopesticide. Many farmers spray only into the whorls of infested plants, so as not to waste the natural insecticide, (c) local solutions:

many smallholder farmers around the world try mixtures of local substances applied directly to the whorl of infested plants, and often report satisfaction with their use, (d) local botanicals (neem, Tephrosia, hot peppers, Marigold flowers), (e) other substances often used include soil, ash, sand, lime, salt, soaps, oils. Farmers try these and then compare and share the results, to see which work best under local conditions. Many have been tested and shown to work. Soil often contains pathogens that kill FAW.

4. *Testing and validation of practices* (a) yield loss due to FAW infestation, (b) role of plant diversity (push–pull), (c) use of biological control, (d) attract predators and parasitoids, (e) "recycling" pathogens, (f) locally available substances, applied directly to the whorl of infested plants may be effective.

How is Europe prepared for the invasion of the fall armyworm?

Peter Baufeld (JKI) highlighted that the EU is already aware of the FAW and has declared it as a quarantine pest for Europe. He said *Spodoptera frugiperda* is listed in Regulation 2000/29/EG (Annex IAI and IVAI). This is the legal basis for quarantine measures against the FAW. Furthermore, since April 23, 2018, the EU has implemented the Commission Decision (EU) 2018/638 which regulates protective measures against the introduction into the Community of FAW to plants or plant products and against their spread within the Community. The EU is currently developing intervention strategies to defeat FAW if it should be introduced by trade or naturally.

A first assessment revealed the scenario that a colonization and manifestation of FAW is possible and probable, but only in the southern countries of the EU. Damages have to be expected for different cultivated plant species. Because of the migration potential, damages in northern countries will be possible, but temporary and local. Currently, there is no risk for the occurrence of FAW in northern EU countries in the field, but a risk that it might survive on hosts in glasshouses.

Conclusive statement

In the discussion, delegates pointed out that the measures illustrated in the presentations create a false impression of successful interventions. Frankly spoken, all mentioned elements of the strategies to defeat the FAW may be available in principle, but currently a limited coordination is the major obstacle to bringing the knowledge effectively and rapidly to the farmers (Toepfer et al. 2018). Therefore, existing networks have to be used to bring the information top down into every single country of Africa. Such networks should include round tables, scientific networks, extension services, private consultation including training and developmental options offered by industry and trade including certification systems. As a first step, CABI has developed an invasive species compendium at its open-access "FAW information portal," concentrating all available information on FAW in one place and facilitating easy access to it (CABI 2018). The FAO could be the organization coordinating the single actions, but should work faster than the FAW spreads.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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