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Biology and management of the insect pest threatens global maize production, fall armyworm, *Spodoptera frugiperda*: an Africa and Asia perspective

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ABSTRACT

Fall armyworms, *Spodoptera frugiperda* (J./E. Smith) are among the most serious insect pests in maize and many other crops, particularly in some Asian countries and sub-Saharan Africa. The study aimed to explores the significance of the biological characters and the management strategies to reduce damage caused by FAW. Understanding this destructive insect pest will guide maize growers and agricultural professionals to develop the most effective and sustainable FAW control methods. The caterpillar fed on the leaves and interferes with pollination and fertilization processes, significantly reducing the yield losses in maize, which was one of the main staple food for most smallholder farmers in Africa. Due to their immediate action, synthetic chemical pesticides were the most conventionally used in the control of FAW, even though this method had many weaknesses, including environmental pollution, food safety concerns, insecticide resistance, and effects on non-target organisms. In recent years, biological control agents (BCAs) have been developed as an alternative to the conventional use of chemical pesticides in integrated pest management (IPM) systems of FAW pests. The present BCAs of FAW were parasitoids, predators, and entomopathogens.

Keywords: control methods, fall armyworm, integrated pest management, maize plant

INTRODUCTION

Maize (*Zea mays* L.) is one of the major dietary cereal crops in the world, which accounts for a significant percentage of people's daily food intake and provides millions of employment opportunities for farmers in many tropical and subtropical countries (Morales et al., 2022). It is widely cultivated and used as food worldwide, third after rice and wheat due to its many uses, which is prepared in various ways for human and animal feed (Akeme et al., 2021). However, insect pests are one of the major constraints in maize production and all parts of the plant are susceptible to attacks, including leaves, stems, whorl, and corn cobs (Kareem et al., 2022). The fall armyworm (FAW), *Spodoptera frugiperda* (J. E. Smith) (Lepidoptera, Noctuidae) had recently become one of the major threats to maize production in the world. It is native to tropical and subtropical America and began to spread throughout the American continent (Goergen et al., 2016). The insect is considered a voracious and important polyphagous pest of several host plants, especially cereal crops, with maize being one of the most susceptible to damage (Abbas et al., 2022; Goergen et al., 2016; Venkateswarlu et al., 2018).

Spodoptera frugiperda was first reported in Africa in early 2016 as a pest of maize in Nigeria and São Tomé. Since then, it had invaded more than 44 African countries and more than 100 countries worldwide (Liu et al., 2022). It had been widely distributed and had become a new invasive species throughout Saharan Africa and many other Asian countries (Abbas et al., 2022;

Liu et al., 2022). The young caterpillar feeding on the leaves had been reported to reduce photosynthetic activity in maize plants, and the older one interferes with pollination and fertilization processes, leading to a significant reduction in the quality of farm produce (Bakry & Abdel-Baky, 2024; Kareem et al., 2022). This economic pest, which continues to spread worldwide, might threaten the world's food security (Acharya et al., 2020; De Groote et al., 2020).

Although FAW was a new pest to Africa and many Asian countries, several publications have been conducted to study its biology, the crop losses that it causes, and control programs. Moreover, understanding the damages and crop losses caused by FAW is essential for assessing the impact of these losses on the expenses of controlling FAW and identifying suitable strategies and technology development. The objective of this researchs was to intended to discuss the biology and management of FAW, particularly in the context of maize infestation and yield loss caused by FAW in Africa and Asia.

GENERAL BIOLOGY OF FAW, *S. frugiperda*

Origin and distribution in Africa and Asia

Fall armyworm was a native to tropical and subtropical Americas that first originated in Georgia in the United States in 1797 but currently invaded three other continents, including Africa, Asia, and Oceania (Wan et al., 2021). *Spodoptera frugiperda* was first reported in Africa in early 2016 as a pest of maize in Nigeria and São Tome (Goergen et al., 2016). In 2018, FAW was first reported in Asia from the Indian subcontinent as a pest of maize (Tippannavar et al., 2019). So far, however, a total of 47 African countries out of 54 and a total of 17 out of 48 Asian countries have reported the incidence of FAW (Adhikari et al., 2020).

With the help of wind current, the insect could spread to a wide geographical range and a single generation could spread more than 300 miles before starting oviposition (Abbas et al., 2022; Sagar et al., 2020). Temperature and relative humidity were some of the main factors that greatly influence the spread of FAW (Paudel et al., 2022).

Taxonomy and host range

Spodoptera frugiperda was initially described as *Phaleana frugiperda*, but later, *frugiperda* was placed in the genus *Laphygma,* and in 1958, *Laphygma* and *Spodoptera* were synonymized by Zimmerman after several other names were proposed (Sarkowi & Mokhtar, 2021). The rice strain (R-strain) and Corn strain (C-strain) were the two known genetic strains of FAW, with the former feeding primarily on rice and various pasture grasses and the later on feeding on maize and occasionally on sorghum (Abbas et al., 2022; Wan et al., 2021). FAW was an invasive insect pest with a wide host range of more than 353 recorded plants (Wan et al., 2021). It was a highly polyphagous pest, feeding on many economically important crops, especially maize, rice, millet, cotton, and soybean (Marri et al., 2023).

Morphology of fall armyworm, *S. frugiperda*

Egg

FAW eggs were dome-shaped with a white creamy color that turns dark or black, flattened over time, and usually covered with hairs (Navasero & Navasero, 2020; Sagar et al., 2020). Eggs have an average length and width of 0.4 mm and 0.3 mm, respectively (Sagar et al., 2020).

Larvae

The newly emerged first instar was motile and usually burrowed in nature, both the first and freshly molted second instar were greenish, but become black from the fresh third to sixth instar (Arifin & Abdullah, 2023). During the fourth to sixth instars, the head was reddish brown with an inverted “Y” shape front- clypeal suture and ecdysial line (Navasero et al., 2019). On the dorsal surface, there were black, hair-covered pimple-like spots (Arifin & Abdullah, 2023). The larvae possess eight pairs of fleshy abdominal prolegs as well as one pair at the final abdominal segment (Sarkowi & Mokhtar, 2021; Soumia et al., 2023). An average length of 7 and 12 mm long was recorded for the second and third instar respectively (Arifin & Abdullah, 2023).

A well-developed larva ranges from dark green to purplish green, or brown, but the most common color was purplish green, with a lighter dorsal median stripe and a darker pinnacle stripe along each side (Navasero & Navasero, 2020).

Pupae

The pupa was oval and whitish-green but gradually becomes brown and darker as it approaches the adult stage (Navasero & Navasero, 2020; Sarkowi & Mokhtar, 2021). The genital opening and the anal slot present at pupal stages could be used to identify the female and male FAW (Akeme et al., 2021). An average length of 1.4 to 1.8 cm was recorded for the pupal FAW (Sarkowi & Mokhtar, 2021).

Adult

Adult males have grayish-brown forewings with white patches at the apical regions. The female's forewings were uniformly grayish-brown colored, but they were darker than the male's (Marri et al., 2023). The hind wings of both male and female adults were silver-white with a narrow dark border (Marri et al., 2023). The color variations on the forewings show sexual dimorphism (Navasero & Navasero, 2020).

The Life Cycle of Fall Armyworm, *S. frugiperda*

Generally, members of the Noctuidae family have a characteristic life cycle that consists of an egg, 6 active feeding larval instars, pupa, and adults (Navasero & Navasero, 2020). The female FAW moth deposits about 100–200 eggs per day and approximately 1,500 in her lifetime (Ali et al., 2023; Marri et al., 2023). The eggs were laid in clusters on the distal part of the leaf or the top and stalk of the plant when the population of the moths was high (FAO, 2019). The incubation period takes approximately 2 to 3 days, depending on the environmental conditions (Sharanabasappa et al., 2018). Upon hatching from their eggs, the first, second, and instar larvae feed on the leaf, but they eventually make their way into the leaf whorl, where they molt to older instars and eat on the unfurling leaves, causing extensive defoliation (Navasero & Navasero, 2020). The sixth instar ultimately spent 24 to 48 hours without feeding (prepupa) before pupating in the soil (Soumia et al., 2023). The first to sixth larval instar stages take approximately 20 days to complete, while the pre-pupa and pupa stages could last approximately 1 to 2 weeks (Marri et al., 2023). Adults emerge after 9 to 12 days of pupal period (Sharanabasappa et al., 2018) (Table 1).

Table 1. Successful studies of the development of *S. frugiperda* on maize plant

Life Stage	Average Days	Country Where Work Was Conducted	Reference
Eggs	2-3	Philliphenes; Ghana	(Marri et al., 2023; Navasero & Navasero, 2020)
Larvae	14-20	India, Nepal, Egypt	(Sharanabasappa et al., 2018); (Mohamed et al., 2023); (Pokhrel et al., 2022)
Pupae	8-14	Indonesia, Ghana, Nepal	(Arifin & Abdullah, 2023; Marri et al., 2023; Pokhrel et al., 2022)
Pre oviposition	3-4	Bangladesh, Ghana, Egypt,	(Ali et al., 2023; Marri et al., 2023; Mohamed et al., 2023)
Oviposition	4-9	Egypt, Philliphenes	(Mohamed et al., 2023; Navasero & Navasero, 2020)
Total developmental period (egg- adult)	24-30	Bangladesh, Philippines	(Ali et al., 2023; Navasero & Navasero, 2020)

DAMAGES AND LOSSES CAUSED TO MAIZE BY *S. frugiperda*

Fall armyworms could cause significant economic losses to crops by causing damage to the host plants during feeding by the larvae (Sagar et al., 2020). It was a highly polyphagous voracious pest, feeding on many crop species, especially Poacecae and Fabaceae, including maize, sorghum, cotton, millet, peanut, rice, and others (Akeme et al., 2021). Each stage of growth of maize was affected by fall armyworm, but the damage was greatest during the early growing phase. Heavy infestation may also cause serious damage to maize cobs (Kareem et al., 2022). The first three larval instars were responsible for damage from feeding on the leaves, which was noticeable in the window panes, whereas the older instars fed on whorl, tassel, and corn cobs (Acharya et al., 2020; Goergen et al., 2016; Navasero & Navasero, 2020). fOnce the eggs hatch, maize becomes infested by FAW (Ali et al., 2023). The symptoms include papery windows of varying sizes and ragged edges with an oblong to round appearance on the leaves, which cause the leaves to become loose and separate from the plants (Sagar et al., 2020). However, the damage was also indicated by the color of the leaves being transparent and perforated (Nonci, N., & Amran, 2022). The older larvae consume a lot of plants and use their strong mandible to break silica-rich plant tissues, such as foliage, seedlings, tassels, husks, cobs, and developing kernels (Navasero & Navasero, 2020) (Table 2).

Table 2. Incidence and impact of *S. frugiperda* on maize in some of the largest producing countries in Africa and Asia

Country	Time Frame	Average % Crop Loss/Tonnes	Reference
Nigeria	2018-2022	3,838.9 tons	(Day et al., 2017)
South Africa	2019	26.5-56.8%	(Soumia et al., 2023; van den Berg et al., 2021)
Egypt	2023	63.33%	(Bakry et al., 2024)
Ethiopia	2017-2021	60-70%	(Atnafu et al., 2021)
Tanzania	2018	43%	(Caleb et al., 2022)
Kenya	2019	37-47.3% /883 tonnes	(De Groote et al., 2020; Kumela et al., 2019)
Zambia	2017-2018	67%	(Day et al., 2017; Rwomushana et al., 2018)
China	2019	98.1%	(Zhou et al., 2021)
India	2019	33%	(Balla et al., 2019)
Indonesia	2019	100%	(Trisyono et al., 2019)
Philippine	2021	26.35%	(Punyawattoe, 2021; Thirawut et al., 2023)

The photosynthetic activity of maize leaves was destroyed when FAW larvae were fed. This leads to a significant or complete reduction in the photoassimilates produced in the mesophyll cells (Kareem et al., 2022). Thus, the primary factor influencing plant growth and development was the distribution of photoassimilates among various organs, and lowering it delaying plant growth, drawbacks to plant reproduction, and finally reducing the grain yield (Bakry & Abdel-Baky, 2024; Kareem et al., 2022). The damage caused by *S. frugiperda* on maize was estimated to cause yield losses ranging from 8 to 21 million tons per year and losses worth \$6.1 billion, with over 300 million people affected in Africa (Sagar et al., 2020; Wan et al., 2021). FAW had recently become a destructive pest in three African countries, affecting one-third of maize crops, with the percentage of infested maize fields ranging from 40 to 100% and the annual yield loss estimated at 1 million tonnes (De Groote et al., 2020; Sisay et al., 2019). In Asia, India was the first country to be infested by FAW, during which 70% of maize fields were affected in a particular district and continue to spread to other districts growing maize (Adhikari et al., 2020; Pokhrel et al., 2022). In many Asian and African countries, yield losses in maize have been reported due to severe infestation of the FAW in the past three successive years (Atnafu et al., 2021; Supartha et al., 2021) (Table 2).

CONTROL AND MANAGEMENT OF FAW

Currently, chemical pesticides were the common method used to control FAW despite the development of resistance and several other problems (Wan et al., 2021). In recent years, efforts have been made by researchers to develop more sustainable and safer means of controlling these insect pests. In the IPM system, the control of FAW and many other insect pests of maize was typically based on four strategies: cultural and mechanical measures, host plant resistance, semiochemical control, and chemical and biological. However, monitoring (direct count and use of sticky traps) was an important component in investigating the degree of economic injury for FAW damage.

Host Plant Resistance

Resistance varieties were one of the IPM techniques that have shown great potential to minimize FAW in the field (Rwomushana et al., 2018). The native genetic resistance to FAW had been successfully developed in Africa and Asia and their use had been shown to reduce the application of insecticides (Morales et al., 2022; Prasanna et al., 2022). A genetically modified *Bt* maize resistant to FAW had recently been developed and commercialized in African countries and some Asian countries such as the Philippines and Vietnam (Morales et al., 2022; Prasanna et al., 2022).

However, most Bt maize hybrids have been reported to lose their ability to control FAW within 3 years of application (Rwomushana et al., 2018). Different breeding programs have been initiated to develop FAW-tolerant cultivars (Nuambote-Yobila et al., 2023; Prasanna et al., 2022) Several other maize cultivars' resistance to FAW had been successfully developed due to the increase in damage and insecticide resistance (Morales et al., 2022).

Physical and Mechanical Methods

Since classical times, there have been many ways to tackle insect pests with cultural control tactics. The first good step of FAW infestation in maize includes sanitary practices such as removing weeds or zero tillage and hand-picking or crushing different developmental stages (Nyamutukwa et al., 2022). It had been investigated that maize intercropped with legumes such as soybean (*Glycine max*) and cowpeas (*Vigna unguiculata*) could significantly reduce the population of FAW on maize (Akeme et al., 2021). The application of ash, sand, and detergents in plant whorls had been proven to reduce FAW damage in maize plants (Murray et al., 2019; Praveen et al., 2023). FAW larvae could be prevented from migrating from one region to another by digging a small trench around the farmed area and filling it with water and pesticides (Praveen et al., 2023). Early maize planting during regular rainfall periods may reduce the damaging effects of FAW (Akeme et al., 2021).

Biological Control

The first step in developing biological control of any invasive insect pests was to investigate the biology of that pest from its new host. Once the biology was known, could didate biological control agents could be scouted for and screened for use (Marri et al., 2023). Biological control agents (BCAs), including parasitoids, predators, and entomopathogens, have recently received much attention as an alternative to chemical pesticides in controlling FAW and many lepidopteran pests (Abbas et al., 2022). The combination of two or more of these BCAs had also shown promising outcomes in controlling FAW species (Abbas et al., 2022). Likewise, the combination of BCAs with some insecticides (Khan et al., 2018) or plant extracts (Rioba & Stevenson, 2020; Smith et al., 2022) had shown an increase in the mortality of FAW. There were at least 150 species of FAW parasitoids documented in the inventory of FAW natural enemies in the Americas and the Caribbean (Ballal et al., 2018). In 2018, the parasitoids were first discovered to be associated with FAW in Africa (Sisay et al., 2018). In recent years, several of these parasitoids have been investigated to parasitize and lower the FAW population on maize, with a significant percentage of parasitism rate (Agboyi et al., 2020; RwomuSshana et al., 2018). Four species, *Cotesia icipe, Palexorista zonata, Charops ater,* and *Coccygidium luteum,* were the most common parasitoids found in East Africa (Rwomushana et al., 2018; Sisay et al., 2018).

Cotesia* spp and *Chelonus curvimaculatus

In the FAW pest management program, entomopathogens have also been evaluated as BCAs. The present entomopathogens used as BCAs of FAW were fungi and nematodes (Navasero & Navasero, 2020; Wan et al.., 2021). Both entomopathogenic fungi and entomopathogenic nematode have been demonstrated to control FAW effectively and to provide maximum protection to maize and other cereal crops in numerous studies (Fallet et al., 2024; Garcia et al., 2008; Idrees et al., 2021, 2023; Mekonnen et al., 2024; Mohamed & Shairra, 2023).

Chemical Pesticides

Farmers use different pesticides to control FAW, some of which were prohibited in the invaded regions of Africa and Asia due to the high resistance developed in FAW (Sarkowi & Mokhtar, 2021; Wan et al., 2021). In Africa and Asia, 34 and 20 different active ingredients were used against FAW respectively (Wan et al., 2021). However, chemical insecticides should be applied to maize only when 5% of seedlings were cut or the *S. frugiperda* infests 20% of whorls of young plants (Adhikari et al., 2020; Sarkowi & Mokhtar, 2021). Several chemical insecticides including bifenthrin, cypermethrin, cyfluthrin, chorpyrifos, chlorantraniliprole, deltamethrin, flubendiamide, gamma-cyhalothrin lambda-cyhalothrin, and permethrin have been widely utilized against FAW under laboratory, glasshouse, and field conditions (Ahmad et al., 2023; Gutirrez-Moreno et al., 2019; Mian et al., 2022). The extensive use of these chemicals had contributed to the development of resistance to FAW and given rise to numerous problems such as insecticide resistance, accidental poisoning to man, and hazardous effects to the environment and non-target organisms (Sisay et al., 2019). Moreover, it was recommended to rotate insecticides between various chemical groups to slow the development of insecticide resistance if insecticides must be used (Wan et al., 2021). Based on the principle of IPM, chemical control measures should only be applied when the pest population was above the economic threshold and if other alternatives were not effective against pest infestation on the crops (Halimatunsadiah et al., 2016; Tey & Cheong, 2013).

CONCLUSION

Fall armyworm is currently the most destructive insect pest of maize, which is one of the main staple food for smallholder farmers in Africa and many Asia countries. If uncontrolled, the spread of FAW may threaten global maize production and potential economic losses to growers. Control of FAW is based almost exclusively on synthetic chemical pesticides. However, there are some other control measures such as cultural, biological, and botanicals which have been reported to be promising and safer than using chemicals. Apart from biological control, most of these control measures have one or more limitations in attaining sustainable pest control. While there has been a significant amount of literature published on FAW infesting maize and other crops, there has been a lack of information on the biological characteristics and sustainable management of FAW among rural dwellers farmers. Therefore, advancement in agricultural research with a specific focus on controlling FAW is crucial for achieving consistent maize production and sustainable production for food security and safety.

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