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BIOLOGY, DISTRIBUTION AND MANAGEMENT OF FALL ARMY WORM *SPODOPTERA FRUGIPERDA* (J E SMITH) IN ETHIOPIA

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ABSTRACT

Fall army worm *Spodoptera frugiperda* (J E Smith) is a destructive insect pest that is native to tropical and subtropical regions of the Americas and later reported in Africa in 2016. The pest was first detected in Ethiopia in March 2017 and is likely to spread in the country. It is one of the most devastating pests in terms of crop loss and economic impact in developing countries like Ethiopia. It is a voracious pest that can cause significant yield loss. The most preferable host of *S. frugiperda* is maize and it causes serious damage by feeding on the ears of maize. Prevention of introduction, control, or eradication of *S. frugiperda* with appropriate measures is important. The IPM is one of the most preferred as complete elimination is not possible. There is a need to develop flexible, coordinated, and effective IPM approach combining various control measures including host plant resistance, mechanical, botanical, biological methods, cultural methods, and suitable doses of pesticides. This study generates information towards these ends.

Key words: Biology, distribution, fall armyworm, host, insect pest, loss, maize, management methods, *Spodoptera frugiperda*, symptom, IPM, Ethiopia, strategies

Fall army worm *Spodoptera frugiperda* (J E Smith) is a lepidopteran insect native to tropical and subtropical regions of the Americas (Bateman et al., 2018). It is an invasive pest in West Africa and is cosmopolitan in distribution. The invasion of *S. frugiperda* predominantly occurs in the warmer region with its presence regulated by climate, temperature, and precipitation (Goergen et al., 2016; Early et al., 2018). The occurrence of *S. frugiperda* was first reported in West Africa in late 2016 (Goergen et al., 2016), which then spread across the continent due to unsafe quarantine measures (Abrahams et al., 2017); *S. frugiperda* has strong migration ability and it has invaded 47 African countries, 18 Asian countries, and now Australia where it seriously threatens crop production (Jing et al., 2021). Maize and rice strains are the two genetic strains of *S. frugiperda* with maize strain being more prevalent (Frerot et al., 2017). The maize strain feeds mostly on maize, cotton, and sorghum, and the rice strain is mostly associated with rice and various pasture grasses (Nagoshi and Meagher, 2004). It feeds on leaves and stems of >350 plant species belonging to 76 plant families including maize, rice, millet, and vegetable crops (Pogue, 2002) with many generations/year (Rice, 2017).

The pest was first detected in Africa in 2016 Nigeria and subsequently in southern Africa (Goergen et al., 2016). In just one year, the insect moved to East Africa and reached Ethiopia in March 2017; reaching more than 30 countries on the continent (Prasanna et al., 2018) which later reached over 44 countries (Sisay et al., 2019). In Africa, the invasion of *S. frugiperda* has two major consequences. The pest is found in a new area where its natural enemies are absent, which would favour an initial period of rapid population growth and dispersal, with negative impacts on agriculture. The pest may have new resistance traits in its new environment, which puts the crops at risk (Nagoshi et al., 2017). A warm and humid growing season with heavy rainfall is favorable (Early et al., 2018). On account of its incapability to survive in freezing temperatures, this pest migrates to warmer regions for overwintering. For efficient reproduction of *S. frugiperda*, tropical and subtropical regions are favoured. The most preferable host of *S. frugiperda* is maize (Fenta and Dereje, 2019). Larvae feed on the maize whorl, ears, and tassel reducing the yield and quality (Capinera, 2017). It estimated a 21 to 53% loss (Abrahams et al., 2017). Integrated pest management (IPM) is considered the best approach for the management of *S. frugiperda* (Day et al., 2017). Entomopathogens and biopesticides are also becoming popular as management options these days (Kushal et al., 2020).

Biology

The lifecycle of *S. frugiperda* consists of egg, larvae, pupa, and adult. The life cycle is completed in about 30 days during the summer, 60 days in the spring and autumn, and 80 to 90 days during the winter (Capinera, 2001). Eggs are dome-shaped, creamy white, and have a flattened base. They have a diameter of 0.4 mm and a height of 0.3 mm (Prassana et al., 2018). The color of the egg changes to dark up to the stage of hatching. The favorable temperature is 20-30°C for the maturing of eggs within 2-3 days (Kandel and Poudel, 2020). The *S. frugiperda* typically deposits its eggs in clusters on the underside of leaves close to the plant's base, where the leaf and stem meet. They are covered with protective scales rubbed off from the moths' abdomen. *S. frugiperda* moth can lay over 1500 eggs in her lifetime (Kushal et al., 2020). Eggs can be identified based on the clustered nature of the eggs ranging from few to hundreds in numbers. The eggs are dorso-ventrally flattened which looks greenish-gray during early days and later turns brown and almost black before hatching. The female covered a layer of scales (downy materials) on the egg mass and this gave a moldy appearance (Kalleshwaraswamy et al., 2018).

Larvae are the destructive stage of the *S. frugiperda*. Larval development occurs between 28- 30°C. They have a biting mouthpart that damages the crop. A larva of *S. frugiperda* goes through six instars to complete the larval phase. During the first instar larvae are greenish which during the second instar changes to orange color. Larvae are about 1mm in the first instar and length changes to 45mm in six instars (Prasanna et al., 2018). During the fourth and sixth instar, the head is reddish-brown mottled with white with lateral lines (Sisay et al., 2019). The duration of the larval stage tends to be about 14 days during the summer and 30 days during cool weather (Capinera, 2001). A dark head with an inverted Y-shaped mark is observed in the sixth instar stage. A distinct pattern of four "dots" is also seen on the eighth abdominal segment (Kushal et al., 2020).

The pupa is an oval-shaped reddish-brown with a size of 14 to 18 mm in length and 4.5 mm in width inside a 20-30 mm in length cocoon. *S. frugiperda* pupate in soil up to 2-8 cm below the surface, forming a cocoon at a temperature between 13 and 16°C. A cocoon is formed by tying together particles of soil with silk. If soil is hard for penetration, the caterpillar will cover itself in leaf debris (Kushal et al., 2020). The duration of the pupal stage is about 8-9 days during the summer but reaches 20-30 days during the cooler weather. The adult is nocturnal and mostly remains active during the humid and warm evenings (Prasanna et al., 2018). They possess two antennae in their head. They have forewings which are grey and brown. Compared to males, female moths are larger. Distinct triangular white spots can be observed in male moths at the tip and center of the forewings. They have a wingspan of 32-40 mm and can travel long distances being mostly active in the evening. Female moths can fly and migrate 500 km before oviposition (Kushal et al., 2020). The duration of adult life is estimated to average about 10 days, with a range of about 7 to 21 days (Murua and Virla, 2004).

Host range

S. frugiperda has a wide host range of more than 350 recorded plants from 76 plant families (Pogue, 2002), principally Poaceae, Asteraceae, and Fabaceae. Among them, it has a strong preference for maize, rice, sorghum, cotton, pasture grasses, and sugarcane (Dumas et al., 2015; Montezano et al., 2018), which are all major cultivated crops in America, Africa, and Asia. *S. frugiperda* has developed two defined strains, C-strain and R-strain, which are morphologically identical but differ in host range (Groot et al., 2010), mating behaviors (Schofl et al., 2009), genetics (Dumas et al., 2015), and pheromone components (Groot et al., 2010). The C-strain eats predominantly on maize, cotton, and sorghum while the R-strain eats primarily on rice and pasture grasses (Dumas et al., 2015). The most frequently consumed plants in the field are maize, sorghum, cotton, clover, oat, millet, peanut, rice, wheat, sugar beet, soybean, sugarcane, and tobacco. Other crops are occasionally damaged like orange, peach, papaya, strawberry, apple, grape, and numerous flowers. Weeds known to serve as hosts include bentgrass, crabgrass, johnson grass, morning glory, nutsedge, pigweed, and sandspur (Abrahams et al., 2017).

Damage

Constant fecundity of the pest at favorable environmental conditions is anticipated to result in severe damage to crops (Goergen et al., 2016). Both vegetative and reproductive structures of the plants are consumed by the larvae. Epidermal leaf tissues are mostly preferred by young larvae and make holes in leaves, which is the unique damage symptom of *S. frugiperda*. The dead heart is a symptom caused by the feeding of young plants through the whorl. The most preferable host of *S. frugiperda* is maize which is the major crop grown in the world. It causes serious damage by feeding on the ears of maize and also causes a dead heart by feeding the maize plants through whorl. Larvae feed on the maize whorl, ears, and tassel reducing the yield and quality (Capinera, 2017). It can also cause exposure to cob which can cause infection by other microorganisms which can result in total damage to the maize and loss of yield. Such damage also can increase the mycotoxin risk like aflatoxin with the infestation through mycotoxin-producing fungi (FAO, 2020). *S. frugiperda* larva is a voracious feeder that consumes maize from seedling emergence to its maturity and defoliates the whole plant causing yield loss. This pest attacks the leaves, stems, and other reproductive parts of the host plant (Tefera et al., 2019). *S. frugiperda* cause heavy damage to corn and yield losses of over 70% have been recorded (Hruska and Gould, 1997). According to Abrahams et al. (2017) maize yield also losses have been estimated at 21 to 53% when infested with *S. frugiperda*. Yield reduction in maize due to damage to *S. frugiperda* larvae by about 39% was reported in America (Cruz et al., 2012). Maize yield loss of 20-50% in recent estimates in Africa suggests a severe impact on the livelihoods of the farmers who depended on maize farming (Early et al., 2018). Successive investigations have shown in Sub-Saharan African countries, it has caused extensive damage to crops especially maize fields (Prasanna et al., 2018).

Distribution

S. frugiperda is a destructive insect pest that is native to tropical and subtropical regions of the Americas. The high variation of the weather in the Americas makes the *S. frugiperda* which has no diapause, migrate seasonally and continentally so far from Canada to Argentina (Nagoshi et al., 2012). In the Eastern United States, annual migrations of adults occur from Northeastern towards Southeastern. It has recently spread to Asia, being confirmed in India, Yemen, Thailand, Myanmar, and Sri Lanka. Because of trade and the moth's strong flying ability, it has the potential to spread further (Nagoshi et al., 2017). In Africa, it was first reported from Benin, Nigeria, Sao Tome, and Togo in early 2016 (Goergen et al., 2016). In April 2017, it affected Ghana, South Africa Tanzania, Kenya, Mozambique, the Democratic Republic of Congo, and suspected in Burkina Faso, Cote d'Ivoire, Sierra Leone, Senegal, Ethiopia, Zimbabwe, and many Sub-Saharan African countries. At the end of the year 2017, most Sub-Saharan African countries were invasive by the *S. frugiperda*. In 2018, all the Sub-Saharan African countries were invasive except Lesotho (FAO, 2019). Generally, it is distributed in Africa 43 countries, North America 41 countries, Central America 28 countries, South America 32 countries, recently detected in India (Prasanna et al., 2018).

Status

S. frugiperda was first detected on the African continent in 2016 (Goergen et al., 2016; Harrison et al., 2019) the outbreak of the pest was reported in West and Central Africa and spread in Ethiopia, Tanzania, and Zimbabwe in February 2017 (Midega et al., 2018). The spread of the pest within a country and among the African countries was rapid. For instance, within Ethiopia, *S. frugiperda* infestations were reported in the Southern Nations, Nationalities, and Peoples' States in March 2017 and spread fast to all states to become an epidemic pest in June 2017. That is the pest spreads to all states of the country within three to four months (Haftay, 2020).

In Ethiopia, *S. frugiperda* mainly affects maize and damage may be observed in all plant parts depending on the development stage. In February 2017, the *S. frugiperda* was discovered in a small area of irrigated maize fields in southern Ethiopia. Since then, it has spread to approximately 640.8 thousand hectares across 144 districts in six of the main regional states that grow maize namely Benishangul Gumuz, Amhara, Tigray, Gambella, Oromia, and SNNPs (Fenta and Dereje, 2019). The *S. frugiperda* is still challenging maize farmers and investors in Oromia, Amhara, Tigray, Gambella, Benishangul, and Southern Nations Nationalities and Peoples' Regions. Maize cultivated in 145 hectares of land in Somali and 1,224 hectares of land in Afar has been affected by the *S. frugiperda* and also currently 342,708 hectares of maize in Oromia, 133,705 hectares in the Southern Nations Nationalities and Peoples' states, 36,677 hectares in Benishangul Gumuz, 122,520 hectares in Amhara and 5230 hectares in Tigray regions have been affected by the armyworm (Fenta, 2018).

S. frugiperda is widely distributed across maize-growing districts of Ethiopia and the percent of infested maize fields ranged from 33% to 100% loss in Ethiopia (Birhanu et al., 2019). Similarly, an evaluation in Ethiopia indicated that *S. frugiperda* caused up to 30% loss at the late whorl stage unless the pest is timely controlled (Fenta and Dereje, 2019). In Ethiopia, *S. frugiperda* poses a significant risk for 9.6 million maizeproducing smallholders. Current reports suggest that a quarter of the 2.9 million ha of land planted with maize is infested by *S. frugiperda*, resulting in a loss of more than 134,000 tons of maize production (Beemer, 2018). Such losses could have fed about 1.1 million individuals. In addition to yield reductions, the country has also incurred significant expenditures on insecticides and monitoring costs. For instance, in the 2017 cropping season, the country spent about US$4.6 million to purchase 277,000 liters of insecticides and equipment for surveillance work to trace and track pest infestations. Moreover, *S. frugiperda* infestation can affect the performance of other businesses, including food processing industries and suppliers of input, such as seeds and fertilizer along the maize value chain (Menale et al., 2020).

Management

Cultural control: The cultural method is the widely used and eco-friendly method of management of *S. frugiperda*. Early planting, improved agronomic practices with quality seed, recommended doses of fertilizer application, mixed and intercropping rather than sole cropping, crop rotation, and mulching help reduce the infestation of the pest (Harrison et al., 2019).

Early planting of maize can help to escape the arrival time of pests as a result plants can be protected from the attack of this pest. Another technique can be the use of trap crops like legumes which can attract pests as a result plants can be protected. Another method can be a deep plowing field before planting maize. Deep plowing can expose the pupa and larvae to a predictor which can decrease infestation of *S. frugiperda*. Exposing larvae and pupae in winter can also help to control *S. frugiperda*. Maize intercropped with edible legume crops helps to reduce the abundance of *S. frugiperda*. The intercropped leguminous crops i.e. french bean, soybean, and groundnut provide better protection to the crop compared to that when it's mono-cropped (Hailu et al., 2018).

Push-pull techniques have been widely used in controlling *S. frugiperda* in which *Desmodium spp* is used as a push crop and Napier grass is used as a pull crop (Hailu et al., 2018). Push and pull strategies are becoming popular as the cultural method of *S. frugiperda* control. Push-pull cropping is the combination of repellent and attractant crops that can be used in an intercropping system for insect pest control. In a recent study conducted across East Africa, farmers who fully implemented the Push-Pull approach reduced *S. frugiperda* infestation and crop damage by up to 86%, with an increase in yield compared to neighboring fields that did not apply the approach (Midega et al., 2018). Other techniques that come under cultural methods are sanitation, picking of larvae by hand, clean cultivation, weeding, etc. Pest monitoring can be another best method for the management of *S. frugiperda*. Pheromone traps and light traps are mostly used for *S. frugiperda* monitoring. Pheromones have been a useful tool for monitoring male populations in different parts of the world (Malo et al., 2004; Batista-Pereira et al., 2006).

Semiochemicals emitted by the trap plants are attractive to the gravid female moths while those emitted from intercrops deter oviposition on the maize (Chamberlain et al., 2006) and help to attract the natural enemies of the pest (Midega et al., 2009). The trap plants act as non-suitable crops for the survival and development of the larval stages of the pests, resulting in high mortality rates (Midega et al., 2011). Increased abundance, diversity, and activity of predatory insects in this system, further contribute to reducing pest populations and controlling them (Midega et al., 2006). Cultural control is an important component of a pest management strategy for *S. frugiperda*. Maize-only cropping systems offer a favorable environment for *S. frugiperda* to spread fast. Control of armyworms is possible through a combination of cultural and chemical control methods (Fenta and Dereje, 2019). Most subsistence farmers in Africa also do not apply pesticides to maize to control pests; nevertheless, they do practice cultural control methods that deter or kill pests, such as intercropping of maize, hand-picking, and killing caterpillars, applying wood ashes, and soils to leaf whorls (Abate et al., 2000). A survey conducted in Ethiopia and Kenya showed that 14% and 39% of the farmers practiced cultural methods (such as handpicking), respectively, for *S. frugiperda* management (Kumela et al., 2019).

Mechanical control: Firake et al. (2019) reported that handpicking and destruction of egg masses and neonate larvae in mass by crushing or immersing in kerosene water is one of the control measures of *S. frugiperda*. The application of dry sand into the whorl of affected maize plants soon after observation of *S. frugiperda* incidence in the field has been reported as another control measure. The number of eggs or caterpillars of *S. frugiperda* is few so handpicking and crushing them can act as a practical measure for small gardens or a few affected plants. 54% of the pest control has been found through the adoption of mechanical control of management (Fenta, 2018; Fenta and Dereje, 2019). FAO (2017) reported that the pheromone traps that attract male armyworm moths are recommended for scaling as this method is simple to use. The standard bucket trap with a green canopy, yellow funnel, and white bucket has been the most effective for capturing the moths of *S. frugiperda* (Meagher, 2001; Hardke et al., 2015).

Biological control: Biological control refers to the direct or indirect use of living natural enemies to reduce the population of pests below the economic damage level. This method is widely used in place of applying pesticides. In this method, different biological agents such as parasites, predators, and pathogens are used (Prasanna et al., 2018). Predators eat pests as their prey. Ladybird beetles, earwigs, predatory bugs, soil surface beetles, and ants can be used as predators for the control of *S. frugiperda* (FAO, 2018). Parasitoids kill their host by feeding them. *Trichogramma* or *Telenomus* wasps are widely used species to control *S. frugiperda* eggs. Pathogens like viruses, fungi, bacteria, nematodes, and protozoa act as biological control agents by causing the infection (Kushal et al., 2020). Biological control can reduce contamination of the environment and offer an economically and environmentally safer alternative to synthetic insecticides that are currently being used. A great diversity of natural enemies of *S. frugiperda* has been reported in the Americas, Africa, and Asia (Prasanna et al., 2018; Shylesha et al., 2018). As the native regions for *S. frugiperda*, the Americas have the most abundant parasitoids against *S. frugiperda*, which have been recorded from 13 families, nine in Hymenoptera and four in Diptera (Molina-Ochoa et al., 2003).

There are many natural enemies of *S. frugiperda* like; parasitoids (*Telenomus remus* Nixon, *Chelonus insularis* Cresson, *Cotesia marginiventris* Cresson, *Trichogramma* spp., *Archytas*, *Winthemia* and *Lespesia*), predators (*Doru luteipes* (Scudder), *Cycloneda sanguinea* (Linnaeus), *Calosoma granulatum* Perty and *Zelus* spp.) and entomopathogens (Viruses such as Nuclear Polyhedrosis Virus (NPVs), fungi (*Metarhizium anisopliae*, *Metarhizium riley,* and *Beauveria bassian*) and bacteria such as the *Bacillus surigensis*, nematodes, and protozoa (Prassana et al., 2018). In Ethiopia, three species of parasitoids namely, *Cotesia icipe* (Hymenoptera: Braconidae), *Palexorista zonata* (Diptera: Tachinidae), and *Charops ater* (Hymenoptera: Icheneumonidae) were recovered from *S. frugiperda* larvae in eleven districts of Ethiopia (Birhanu, 2018). *Cotesia icipe* was the most prevalent parasitoid that emerged in Hawassa, Jimma (Southwestern Ethiopia), and Awash Melkassa surveyed areas. The parasitism ranged from 33.8 to 45.3% in Awash Melkassa and Jimma, respectively. Recruitment and host adaptation of native parasitoids to *S. frugiperda* suggests the potential for biological control of the pest (Fenta and Dereje, 2019).

Botanical pesticides: Botanical pesticides are those pesticides that are derived from plant or plant extract. Botanical pesticides are environment-friendly and have no residual effect on natural enemies and human beings. Among various plants, neem (*Azadiracta indicia*) is effective against the larva of *S. frugiperda*. Application of bio-pesticide with 0.25% neem oil under laboratory conditions showed 80% mortality of the larva (Tavares et al., 2010). Other plants such as long pepper (*Pepper hispidinervum*), castor (*Ricinus communis*), *Couroupita guianensis, Milletia ferruginea, Croton macrostachyus, Phytolacea docendra, Jatropha curcas, Nicotina tabacum*, *Chrysanthemum cinerariifollium* and others have also been found to be effective (Kandel and Poudel, 2020). They have diverse biological activities resulting in high mortality, extended larval duration, decreased pupa weight, insecticidal effects, growth inhibition, antifeedants effect, reduced fecundity, as well as sub-lethal and acute toxicity. Rioba and Stevenson (2020) have reviewed the opportunities and scope for botanical extracts and products for the management of *S. frugiperda* in Africa. They summarized the efficacy and potential of 69 plant species from 31 families including *Azadirachta indica*, *Schinnus molle,* and *Phytolacca dodecandra*. In China, indoor toxicity and control effect of azadirachtin in a maize field for *S. frugiperda*. Azadirachtin has good toxicity and antifeedant activity on fall armyworm and the control effect reached a peak seven days after treatment (Lin et al., 2020).

There are reports in which farmers try and report satisfaction with using many botanicals or extracts from local plants. The use of botanical pesticides is recommended as a substitute for synthetic insecticides, such as pyrethroids and organophosphorus which may result in disturbances in the environment, increasing user cost, pest resurgence, and pest resistance to insecticides (Bateman et al., 2018). Botanicals are friendly to natural enemies of *S. frugiperda* (Mora and Blanco-Metzler, 2018). Because of the affordability and availability of botanical insecticides, farmers in developing countries have been using botanicals and are highly recommended that smallholder farmers use them as they are safer and more environmentally friendly tools (Haftay, 2020).

Host plant resistance: All crop species have genetic diversity, at least to some extent. It is exploited by agriculturalists to increase crop productivity and to avoid the most damaging effects of pests. This is achieved by selecting and adopting genotypes that yield satisfactory and avoid or in some way withstand biotic and abiotic constraints (Thresh, 2003). The United States uses both native and transgenic *S. frugiperda* resistances to manage *S. frugiperda* in maize and transgenic have recorded the highest levels of resistance to the pest (Wightman, 2018). Native resistance is naturally available in the gene pool, harnessed through selection for effective use in agricultural production systems (Ni et al., 2014). Native resistance offers minimal but significant protection to a crop, but it is usually combined with other management measures in an integrated pest management (IPM) strategy. This strategy may work better for African farmers, who have limited access to finances to purchase chemical insecticides. Access to cultivars with some level of resistance or tolerance to *S. frugiperda* brings cost-effective control to the resource-poor smallholder farmers in sub-Saharan Africa. Native resistance has not been reported in sub-Saharan Africa, due to *S. frugiperda* is a new pest and no cultivars with native resistance have been released so far. *Bt* maize has effectively managed *S. frugiperda* in the Americas (Womack et al., 2018) but with a three to four-year cycle of resistance breakdown (Fatoretto et al., 2017). The adoption of genetically modified maize in the United States, Brazil, and Argentina has surpassed 85% (Hruska, 2019).

Chemical control: Chemical control refers to managing the pest through the application of chemical pesticides. Chemical pesticides are artificially synthesized in the industry in such a way that they affect different stages of pests hence reducing their number. Chemical control methods are used as the last option during integrated pest management when there is severe damage by the pest or have been infested by a large population. Different chemical pesticides are used against *S. frugiperda*. Some of the recommended insecticides for *S. frugiperda* are esfenvalerate, carbaryl, chlorpyrifos, Malathion, permethrin, emamectin benzoate, pyrethroids, organophosphates spinosad, chlorantraniliprole, and others (Evans, 2017; CABI, 2019). However, the use of chemicals should be discouraged as they may affect soil fertility and be the natural enemy of *S. frugiperda* (Kandel and Poudel, 2020).

Most commonly, the pesticides are diluted with water and sprayed on growing plants at around 200-400 liters/ hectare, though this can vary considerably with the age of the plant and the application method. The best performance of the insecticide spinosad, causing >90% larval mortality was reported by Cruz et al. (2012). In laboratory studies, mortality of *S. frugiperda* was reported better with new insecticides (*Cholarantraniliprole*, *flubendiamide,* and spinetoram) compared to traditional ones (lambda-cyhalothrin and novaluron) when applied (Hardke et al., 2014).

The chemical control method is one of the most common methods used to slow the spread of *S. frugiperda* and minimize damage to maize fields. However, it becomes much more difficult since the caterpillar feeds inside the whorl of the plant, which thus hinders the insecticides to penetrate through the canopy and locate the caterpillar (Bissiwu et al., 2016). The use of insecticides to control the *S. frugiperda* needs to be reconsidered and integrated with other control methods. Contact or systemic insecticides based on pyrethroids, carbamates, or organophosphates are used in Africa as an immediate management measure (Sisay et al., 2019). Since the greatest damage usually occurs before the reproductive phase of maize, early pest detection that allows insecticide treatment of young larval stages is crucial, and spraying should target the middle portions of plant leaves (apical meristem) where the pest hides and lays its eggs (Bissiwu et al., 2016). There are several ways of managing the pests reported in other parts of the world that can potentially be adapted validated and used in Ethiopia (Fenta, 2018). In Ethiopia, 26% of the farmers combined handpicking larvae with insecticide sprays, while 15% of the farmers practiced only handpicking for *S. frugiperda* management (Kumela et al., 2019). At present, the major problems affecting *S. frugiperda* management efforts in Ethiopia are lack of adequate knowledge of the pest and its management options in the Ethiopian context, lack of sound contingency and long-term plans, lack of coordinated research and development interventions, scarcity of financial and material resources (Fenta and Dereje, 2019).

IPM: Integrated pest management (IPM) is the one of most preferred and effective management of *S. frugiperda* (Day et al., 2017). Since the complete elimination of pests is not possible from the field it is important to develop flexible, coordinated, and effective techniques. IPM techniques have been widely used and have also been effective. In the long run, this holistic approach has been found to reduce the use of pesticides and has been economical and safe for the environment (Ehler, 2006). Integrated pest management approach to control *S. frugiperda* includes an integrated approach including host plant resistance, biological methods, cultural methods, and suitable doses of pesticides which reduces the negative impacts on non-target organisms and controls the pest effectively (Prasanna et al., 2018). It is difficult to control *S. frugiperda* with a single stand-alone control method. It is advisable to consider an integrated approach, an integrated *S. frugiperda* management that keeps the pest below the economic threshold with the least disturbance to the environment. Integrated management might involve integrating two or more two of the previously described methods that discourage the development of *S. frugiperda* population with the least possible disturbance to agro-ecosystems and promote natural pest control mechanisms. The integrated *S. frugiperda* management involves preventative methods to prevent the occurrence of the pest, monitoring the presence and absence of the pest through regular scouting, light traps, or pheromone lures, and based on the result of monitoring, deciding on what control methods have to be applied or integrated. Along with prevention and monitoring, cultural methods, push-pull technology, biological control methods, or integration can be applied (Haftay, 2020).

Regular monitoring, early warning, and preparation with scouting and application of IPM measures early help to reduce the loss and outbreak of the pest (Kushal et al., 2020). Monitoring and prevention of pests is an effective method to control the spread and establishment of *S. frugiperda*. Prediction of infestation time and assessing the severity helps in the timely management of invasive pests. Monitoring, surveillance, and scouting are an important step in implementing the IPM strategy (Prasanna et al., 2018). Light traps and pheromone traps can be used for the monitoring and collection of moths (Gebreziher and Gebreziher, 2020).

CONCLUSIONS

The *S. frugiperda*, a new devastating insect pest is one of the serious major problems for agricultural crop production and productivity. It can quickly multiply, spread, and establish itself in new regions. It is a migratory polyphagous pest with a wide range of hosts. It feeds on leaves and stems of many plant species, including economically important cultivated crops like maize, rice, millet, and vegetable crops causing severe damage. So, prevention of introduction, control, or eradication of *S. frugiperda* with appropriate measures is necessary. It is controlled by different management methods. But, *S. frugiperda* with a stand-alone single management method is difficult to control and it is advisable to consider an integrated approach. IPM includes combinations of various control measures available locally with cultural control, host plant resistance, mechanical, biological, and safer use of pesticides, so it is an eco-friendly, sustainable, and cost-effective method for the management of *S. frugiperda*. Hence, an integrated pest management strategy is considered the best option to manage *S. frugiperda.* Therefore, farmers should be made aware of this damaging insect pest and integrated pest management practices should be adopted by the farmers to sustainably manage *S. frugiperda.*

CONFLICT OF INTEREST

No conflict of interest.

REFERENCES

Abate T, van Huis A, Ampofo J K O. 2000. Pest management strategies in traditional agriculture: An African perspective. Annual Review of Entomology 45(1): 631-659.

Abrahams P, Bateman M, Beale T, Clottey V, Cock M, Colmenarez Y, Corniani N, Day R, Early R, Godwin J, Gomez J, Moreno P G, Murphy S T, Oppong-Mensah B, Phiri N, Pratt C, Richards G, Silvestri S, Witt A. 2017. Fall armyworm: Impacts and implications for Africa. Evidence Note (2); Report to DFID.

Bateman M, Day R, Luke B, Edgington S, Kuhlmann U, Cock M. 2018. Assessment of potential biopesticides options for managing fall armyworm (*Spodoptera frugiperda*) in Africa. Journal of Applied Entomology 142(9): 805-819.

Batista-Pereira L G, Stein K, De Paula A F, Moreira J A, Cruz I, Figueiredo M, Perri J, Correa A G. 2006. Isolation, identification, synthesis, and field evaluation of the sex pheromone of the Brazilian population of *Spodoptera frugiperda*. Journal of Chemical Ecology 32(5): 1085-1099.

Beemer L. 2018. Fall armyworm a serious threat to sub-Saharan African food security in 2018. https://www.agribusinessglobal.com/markets/africa-middle-east/fall-armyworma-serious-threat-to-sub-sarahan-african-food-security-in-2018/.

Birhanu S, Josephine S, Esayas M, Paddy L, Gashawbeza A, Samira M, Sevgan S, Tadele T. 2019. Fall Armyworm, *Spodoptera frugiperda* infestations in East Africa: Assessment of damage and parasitism. Insects 10(7): 195.

Birhanu S. 2018. Evaluation of different management options of fall armyworm, *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) and assessment of its parasitoids in some parts of Ethiopia. Dire Dawa: Haramaya University.

Bissiwu P, Perez M J, Walter N T. 2016. Control efficacy of *Spodoptera frugiperda* using the entomopathogens Heterorhabditis bacteriophora and Metarhizium anisopliae with insecticide mixtures in corn. M.Sc. thesis, Earth University, Guacimo, Limon, Costa Rica, 36-43.

CABI. 2019. Fall armyworm: Life cycle and damage. https://www.cabi.org/isc/FullTextPDF/2019/20197800314.pdf.

Capinera J L. 2001. Handbook of vegetable pests. Academic press, San Diego. 729 pp.

Capinera J L. 2017. Fall armyworm, *Spodoptera frugiperda* (J E Smith) (Insecta: Lepidoptera: Noctuidae). http://entomology.ifas.ufl.edu/creatures.

Chamberlain K, Khan Z R, Pickett J A, Toshova T, Wadhams L J. 2006. Diel periodicity in the production of green leaf volatiles by wild and cultivated host plants of stem borer moths, *Chilo partellus* and *Busseola fusca*. Journal of Chemical Ecology 32: 565-577.

Cruz I, Figueiredo M D, Silva R B, Silva I F, Paula C D, Foster J E. 2012. Using sex pheromone traps in the decision-making process for pesticide application against fall armyworm (*Spodoptera frugiperda* [Smith] [Lepidoptera: Noctuidae]) larvae in maize. International Journal of Pest Management 58(1): 83-90.

Day R, Abrahams P, Bateman M, Beale T, Clottey V, Cock M, Colmenarez Y, Corniani N, Early R, Godwin J, Gomez J, Moreno P G, Murphy S T, Oppong-Mensah B, Phiri N, Pratt C, Silvestri S, Witt A. 2017. Fall armyworm: Impacts and implications for Africa. Outlooks Pest Management 28(5): 196- 201.

Dumas P, Legeai F, Lemaitre C, Scaon E, Orsucci M, Labadie K, Gimenez S, Clamens A L, Henri H, Vavre F, Aury J M, Fournier P, Kergoat G J, d'Alencon E. 2015. *Spodoptera frugiperda* (Lepidoptera: Noctuidae) host-plant variants: Two host strains or two distinct species? Genetica 143: 305-316.

Early R, Gonzalez-Moreno P, Murphy S, Day R. 2018. Forecasting the global extent of invasion of the cereal pest *Spodoptera frugiperda*, the fall armyworm. NeoBiota 40: 25-50.

Ehler L E. 2006. Perspective integrated pest management (IPM): definition, historical development and implementation, and the other IPM. Pest Management Science 62(9): 787-789.

Evans O. 2017. Fall armyworm: Most effective and recommended pesticides and controls. Agri home. https://blog.agrihomegh.com/control-fall-armyworm/.

FAO. 2017. Fall armyworm continues to spread in Ethiopia's maize fields. Facilitates national awareness training for key partners and field offices. http://www.fao.org/food-chain-crisis/howwework/plant-protection/fall-armyworm/en/.

FAO. 2018. Management of the fall armyworm in Africa. FAO Regional Conference for Africa. http://www.fao.org/3/mv553en/mv553en.pdf.

FAO. 2019. FAO statement on fall armyworm in Sri Lanka. Rome, Italy.

FAO. 2020. The global action for fall armyworm control: Action framework 2020-2022. Working together to tame the global threat. Food and Agriculture Organization.

Fatoretto J C, Michel A P, Filho M C, Silva N. 2017. Adaptive potential of fall armyworm (Lepidoptera: Noctuidae) limits *Bt* trait durability in Brazil. Journal of Integrated Pest Management 8(1): 17.

Fenta A, Dereje A. 2019. Status and control measures of fall armyworm (*Spodoptera frugiperda*) infestations in maize fields in Ethiopia: A review. Cogent Food and Agriculture 5(1): 1641902.

Fenta A. 2018. Status of fall armyworm (*Spodoptera frugiperda*), biology and control measures on maize crop in Ethiopia: A review. International Journal of Entomology Research 6(2): 75-85.

Firake D, Behere G, Babu S, Prakash N. 2019. Fall armyworm: Diagnosis and management. An Extension Pocket Book. Umiam-793, 103.

Frerot B, Leppik E, Groot A T, Unbehend M, Holopainen J K. 2017. Chemical signatures in plant insect interactions. Advance in Botanical Research 81: 139-177.

Gebreziher H, Gebreziher J. 2020. Effect of integrating night-time light traps and push-pull method on monitoring and deterring adult fall armyworm (*Spodoptera frugiperda*). International Journal of Entomology Research 5(1): 28-32.

Goergen G, Kumar P L, Sankung S B, Togola A, Tamo M. 2016. First report of outbreaks of the fall armyworm *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera, Noctuidae), a new alien invasive pest in West and Central Africa. PLoS One 11(10): e0165632.

Groot A T, Marr M, Heckel D G, Schofl G. 2010. The roles and interactions of reproductive isolation mechanisms in fall armyworm (Lepidoptera: Noctuidae) host strains. Ecological Entomology 35: 105-118.

Haftay G G. 2020. Review on management methods of fall armyworm (*Spodoptera frugiperda* JE Smith) in Sub Saharan Africa. International Journal of Entomology Research 5(2): 9-14.

Hailu G, Niassy S, Zeyaur K R, Ochatum N, Subramanian S. 2018. Maize–legume intercropping and push–pull for management of fall armyworm stem borers, and striga in Uganda. Agronomy Journal 110(6): 2513-2522.

Hardke J T, Jackson R E, Leonard B R. 2014. Opportunities to manage fall armyworm (Lepidoptera: Noctuidae) on Bollgard IIVR cotton with reduced rates of insecticides. Journal of Cotton Science 18(1): 59-67.

Hardke J T, Lorenz G M, Leonard B R. 2015. Fall armyworm (Lepidoptera: Noctuidae) ecology in Southeastern cotton. Journal of Integrated Pest Management 6(1): 10.

Harrison R, Thierfelder C, Baudron F, Chinwada P, Midega C, Schaffner U, van den Berg J. 2019. Agro-ecological options for fall armyworm (*Spodoptera frugiperda* JE Smith) management: Providing low-cost, smallholder friendly solutions to an invasive pest. Journal of Environmental Management 243: 318-330.

Hruska A J, Gould F. 1997. Fall armyworm (Lepidoptera: Noctuidae) and Diatraea lineolata (Lepidoptera: Pyralidae): Impact of larval population level and temporal occurrence on maize yield in Nicaragua. Journal of Economic Entomology 90(2): 611-622.

Hruska A J. 2019. Fall armyworm (*Spodoptera frugiperda*) management by smallholders. CAB Reviews 14(043): 1-11.

Jing W, Huang C, Li C, Zhou H, Ren Y, Li Z, Xing L, Zhang B, Qiao X, Liu B, Liu C, Xi Y, Liu W, Wang W, Qian W, Simon M, Wan F. 2021. Biology, invasion and management of the agricultural invader: Fall armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae). Journal of Integrative Agriculture 20(3): 646-663.

Kalleshwaraswamy C M, Maruthi M S, Pavithra H B. 2018. Biology of invasive fall army worm *Spodoptera frugiperda* (JE Smith) (Lepidoptera: Noctuidae) on maize. Indian Journal of Entomology 80(3): 540-543.

Kandel S, Poudel R. 2020. Fall armyworm (*Spodoptera frugiperda*) in maize: An emerging threat in Nepal and its management. International Journal of Applied Sciences and Biotechnology 8(3): 305-309.

Kumela T, Simiyu J, Sisay B, Likhayo P, Mendesil E, Gohole L, Tefera T. 2019. Farmers' knowledge, perceptions, and management practices of the new invasive pest, fall armyworm (*Spodoptera frugiperda*) in Ethiopia and Kenya. International Journal of Pest Management 65(1): 1-9.

Kushal N, Sabina R, Niruta S. 2020. A review on invasion and management of fall armyworm (*Spodoptera frugiperda*) in Nepal. Reviews in Food and Agriculture 1(1): 6-11.

Lin S K, Liu K H, Wang R F, Liu B J, Zhang Y, Wu J Y Z, Cheng D M, Xu H H, Zhang Z X. 2020. Indoor toxicity of azadirachtin to *Spodoptera frugiperda* and its control effect in field. Journal of South China Agricultural University 41(1): 22-27.

Malo E A, Bahena F, Miranda M A, Valle-Mora J. 2004. Factors affecting the trapping of males of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) with pheromones in Mexico. Florida Entomologist 87(3): 288-293.

Meagher Jr R L. 2001. Collection of fall armyworm (Lepidoptera:

Noctuidae) adults and non-target Hymenoptera in different colored unitraps. Florida Entomologist 77-82.

Menale K, Tesfamicheal W, Hugo D G, Tadele T, Subramanian S, Solomon B. 2020. Economic impacts of fall armyworm and its management strategies: evidence from southern Ethiopia. European Review of Agricultural Economics 47(4): 1473-1501.

Midega C A, Khan Z R, Pickett J A, Nylin S. 2011. Host plant selection in *Chilo partellus* and its implication for effectiveness of a trap crop. Entomologia Experimentalis Applicata 138(1): 40-47.

Midega C A, Khan Z R, van den Berg J, Ogol C K, Bruce T J, Pickett J A. 2009. Non-target effects of the 'push-pull' habitat management strategy: parasitoid activity and soil fauna abundance. Crop Protection 28(2): 1045-1051.

Midega C A, Khan Z R, Van den Berg J, Ogol C K, Pickett J A, Wadhams L J. 2006. Maize stem borer predator activity under 'push-pull' system and *Bt*-maize: a potential component in managing *Bt* resistance. International Journal of Pest Management 52(1): 1-10.

Midega C A, Pittchar J O, Pickett J A, Hailu G W, Khan Z R. 2018. A climate-adapted push-pull system effectively controls fall armyworm, *Spodoptera frugiperda* (J.E Smith), in maize in East Africa. Crop Protection 105: 10-15.

Molina-Ochoa J, Carpenter J E, Heinrichs E A, Foster J E. 2003. Parasitoids and parasites of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas and Caribbean Basin: an inventory. Florida Entomologist 86(3): 254-289.

Montezano D G, Specht A, Sosa-Gomez D R, Roque-Specht V F, Sousa-Silva J C, Paula-Moraes S D, Peterson J A, Hunt T E. 2018. Host plants of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in the Americas. African Entomology 26(2): 286-300.

Mora J, Blanco-Metzler H. 2018. Evaluation of botanical insecticides in controlling the population of fall armyworm (*Spodoptera frugiperda* Smith) present on corn crops (*Zea mays*) located in Santa Cruz, Guanacate. IOP Conf. Series: Earth and Environmental Science 215(1): 012013.

Murua G, Virla E. 2004. Population parameters of *Spodoptera frugiperda* (Smith) (Lep: Noctuidae) fed on corn and two predominant grasses in Tucuman (Argentina). Acta Zoologica Mexicana 20(1): 199-210.

Nagoshi R N, Koffi D, Agboka K, Tounou K A, Banerjee R, Jurat-Fuentes J L, Meagher R L. 2017. Comparative molecular analyses of invasive fall armyworm in Togo reveal strong similarities to populations from the eastern United States and the Greater Antilles. PLoS One 12(7): e0181982.

Nagoshi R N, Meagher R L, Hay-Roe M. 2012. Inferring the annual migration patterns of fall armyworm (Lepidoptera: Noctuidae) in the United States from mitochondrial haplotypes. Ecology and Evolution 2(7): 1458-1467.

Nagoshi R N, Meagher R L. 2004. Behavior and distribution of the two fall armyworm host strains in Florida. Florida Entomologist 87(4): 440-449.

Ni X, Xu W, Blanco M H, Williams W P. 2014. Evaluation of fall armyworm resistance in maize Germplasm lines using visual leaf injury rating and predator survey. Insect Science 21(5): 541-555.

Pogue M G. 2002. A world revision of the genus Spodoptera Guenee: (Lepidoptera: Noctuidae). American Entomological Society Philadelphia 43: 1-202.

Prasanna B M, Huesing J E, Eddy R, Peschke V M. 2018. Fall armyworm in Africa: A guide for integrated pest management, first edition. Mexico, CDMX: CIMMYT.

Rice M E. 2017. Fall armyworm (FAW). Food and Agriculture Organization.

Rioba N B, Stevenson P C. 2020. Opportunities and scope for botanical extracts and products for the management of fall armyworm (*Spodoptera frugiperda*) for smallholders in Africa. Plants 9(2): 207.

Schofl G, Heckel D G, Groot A T. 2009. Time-shifted reproductive behaviors among fall armyworm (Noctuidae: *Spodoptera frugiperda*) host strains: evidence for differing modes of inheritance. Journal of Evolutionary Biology 22(7): 1447-1459.

Shylesha A N, Jalali S K, Gupta A, Varshney R, Venkatesan T, Shetty P, Ojha R, Ganiger P C, Navik O, Subaharan K, Bakthavatsalam N, Ballal C R, Raghavendra A. 2018. Studies on new invasive pest *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) and its natural enemies. Journal of Biological Control 32(3): 1-7.

Sisay B, Tefera T, Wakgari M, Ayalew G, Mendesil E. 2019. The efficacy of selected synthetic insecticides and botanicals against fall armyworm, *Spodoptera frugiperda*, in maize. Insects 10(2): 45.

Tavares W S, Costa M A, Cruz I, Silveira R D, Serrao J E, Zanuncio J C. 2010. Selective effects of natural and synthetic insecticides on mortality of *Spodoptera frugiperda* (Lepidoptera: Noctuidae) and its predator *Eriopis connexa* (Coleoptera: Coccinellidae). Journal of Environmental Science and Health 45(6): 557- 561.

Tefera T, Goftishu M, Ba M, Muniappan R M. 2019. A guide to biological control of fall armyworm in Africa using egg parasitoids.

Thresh J M. 2003. Control of plant virus diseases in sub-Saharan Africa: the possibility and feasibility of an integrated approach. African Crop Science Journal 11(3): 199-223.

Wightman J A. 2018. Can lessons learned 30 years ago contribute to reducing the impact of the fall army worm *Spodoptera frugiperda* in Africa and India? Outlook on Agriculture 47(4): 259-269.

Womack E D, Warburton M L, Williams W P. 2018. Mapping of quantitative trait loci for resistance to fall armyworm and southwestern corn borer leaf-feeding damage in maize. Crop Science 58(2): 529-539.

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