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A REVIEW ON FALL ARMY WORM *SPODOPTERA FRUGIPERDA* (J E SMITH) INVASION IN GHANA: CURRENT STATUS

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ABSTRACT

The fall army worm *Spodoptera frugiperda* (J E Smith) (Lepidoptera: Noctuidae) which invaded Africa in 2016 continue to pose food security threat due to its destructive effect on maize. This article assesses current research outputs, management strategies and future projections. Levels of infestation vary across districts, ranging from 12 to 88% with corresponding leaf damage score of 2 to 7 and larval density of 0.16 – 1.44/ plant on farmers' maize field. Infestation and damage levels were higher in 2021 than in 2020 possibly due to gradual withdrawal of free insecticide by government. Several indigenous practices were employed by farmers during early invasion but synthetic insecticides usage assumed high acceptance. Some commercial microbials and botanicals showed significant efficacy. Results from indigenous entomopathogenic nematodes and fungi are satisfactory and are under field validation. A number of predators and parasitoids identified have shown varied level of suppression. Mass release of parasitoids, complemented with entomopathogens will put the infestation below economic threshold levels in most maize fields.

Key words: *Spodoptera frugiperda,* natural enemies, parasitoids, predators, entomopathogens, nematodes, fungi, *Telenomus remus*, biological control, insecticides, indigenous technologies

The fall army worm (FAW) *Spodoptera frugiperda* (J E Smith) (Lepidoptera: Noctuidae), a new invasive pest insect, is native to the Americas but has established as one of the biggest threats to agriculture in- Africa in recent years (Devi, 2018). While the pest was first reported in some parts of West Africa in 2016, by 2018, it had invaded almost every country in sub-Saharan Africa (Hruska, 2019). It is a polyphagous pest that feeds on about 76 plant families (Cheema et al., 2022; Chormule et al., 2019) of which the Poaceae, Fabaceae and Asteraceae are of immense agricultural importance (Chormule et al., 2019). In Ghana, while maize is the main host plant, this pest has been reported to attack other important crops including sorghum, millet, cabbage and coconut seedlings (Asare-Nuamah, 2021). *Spodoptera frugiperda* was first reported in Ghana in 2016 and it has since been observed in all agroecological zones (Koffi et al., 2020). *Spodoptera frugiperda* threatens food security of millions of people in sub-Saharan Africa (SSA) (Day et al., 2017; Devi, 2018). This is because, maize is the most important staple food crop for over 300 million people in SSA (Smale, Byerlee and Jayne, 2013; Ekpa et al., 2019). The crop is cultivated on over 25 million ha (Okweche et al., 2013). In Ghana, it is the most important cereal crop. Interestingly, every maize farmer is aware of the pest and has an idea of how it can be managed (Safo et al., 2023). This is owing to an aggressive effort by the government of Ghana through the Ministry of food and Agriculture (MoFA) to contain the spread and establishment of the pest at the initial years. MoFA took numerous measures to contain the pest during its outbreak. These included the provision of free insecticides, training of staff for early detection, surveillance, monitoring, farmer sensitization etc. The government, through the ministry procured 72,774 ℓ of liquid and some powdered insecticides for use (Safo et al., 2023).

While some level of control has been achieved in Ghana through the use of insecticides, their indiscriminate use exposed the farmers, the agroecology and the environment to pesticide pollution (Godwin et al., 2017). Despite the awareness of the pest and available insecticides for their management, several maize farms continue to suffer huge damage. This is likely because not all farmers adhere to timely application of insecticides and therefore their farms become reservoirs for rapid multiplication of the pest. In addition, some farmers plant maize as hobby and therefore do not attach any economic importance to it. Such farmers do not bother applying any insecticides but are comfortable with whatever yield they obtain without pest management. To sustainably manage *S. frugiperda*, there is need to explore alternative management tactics other than synthetic insecticides which are applied on farm basis. Biological control using natural enemies and other biocontrol agents provide sustainable means of managing FAW. These biological control agents diffuse into the agroecosystem, establish, multiply and continually attack the pest for sustainable control. In Ghana, some research activities on biological control of *S. frugiperda* have been carried out and at various stages. We review the invasion of *S. frugiperda* in Ghana, the current status, including results of recent studies carried out by the authors, current management practices including biological control and the potential for an integrated management of the pest.

1. Current status

Monitoring of occurrence, density and damage levels of FAW has been carried out in about 18 selected districts/municipalities across Ghana between 2020 and 2022. In each district, three farms that are at least 10km apart are sampled. In each farm, 50 maize plants are assessed following the FAO 'W'- shape scouting method (FAO 2018). Two scouting were done in the southern and middle regions of the country while a single scouting was done in the northern part of the country. In the major rainy season of 2020, as low as 12% infestation were recorded in the Bolgatanga municipal while 88% infestation was recorded in the Atebubu-Amantin district. In the minor rainy season, Nkwanta South in the Oti Region and Kintampo in the Bono East Regio recorded the lowest and the highest infestation rates of 28 and 70%, respectively.

While knowledge about managing FAW continues to increase with time, it appears that percentage infestation was higher in 2021 compared to 2020. In 2021, infestation as high as 95% was observed in the West Gonja district while average infestation was 44% in the same district in 2020. This could possibly be attributed to the withdrawal of government free insecticide distribution programme started in 2017. Adequate insecticides were given to farmers at the early stages of the programme but quantities reduced overtime until it was completely stopped. Thus, some farmers were not ready to purchase insecticides at the market price. Managing FAW in one farm does not affect adjourning farms. Therefore, the few farmers who decline to apply any insecticidal treatment on their farm may end up harbouring, multiplying and redistributing the pest to farms that receive treatment applications.

2. Current management strategies

Spodoptera frugiperda is one of the invasive insects that have extremely high potential to rapidly spread over wide area upon its introduction. Evidence from this is the fact that the pest was able to expand its coverage from 12 African countries in April 2017 to 28 countries after just 6 months (Day et al., 2017). In Ghana, it spread throughout the entire country, except the Evergreen Tropical Rainforest areas in the western part of the country, within few months after it was first detected in the Eastern Region (Abrahams et al., 2017). The rapid expansion of coverage of the FAW with associated destruction of maize in particular warranted an equally rapid intervention to maintain the integrity of food security in the country. The obvious option then was the use of synthetic insecticides (Abrahams et al., 2017; Rwomushana et al., 2018). In this regard, the government of Ghana in 2017 supplied free insecticides, mainly synthetic, to farmers throughout the country. This free supply of insecticides continued for four successive years although the quantities dwindled over time. Also, the proportion of biorational insecticides such as microbial and botanic insecticides increased over that period (Tulashie et al., 2021). This notwithstanding, the use of synthetic insecticides which characteristically gave rapid knockdown of the FAW larvae, was braced by most farmers as the first line of action against the pest. For this reason, majority of farmers continued to apply the synthetic insecticides although a wide range of biorationals have been introduced and are easily accessible on the agrochemical market space in the country.

Most of the widely used insecticides by farmers or registered by the Environmental Protection Agency EPA) are binary, mainly a combination of the following class of insecticides: neonicotinoid, pyrethroid, Ivermectin and organophosphate (Table 2). The single active ingredient insecticides commonly used are the Chlorpyrifos, Imidacloprid, Acetamiprid and Emamectin benzoate. The major setbacks in the use of these insecticides are the excessive dose and high application frequency leading to insecticide residues above permissible levels, non-usage of personal protective equipment and detrimental effect on non-target organisms, including natural enemies of FAW (Jepson et al., 2018; Issa et al., 2020). Additionally, Chlorpyrifos, Imidacloprid, Acetamiprid are also the insecticides most commonly used for tree crops and vegetable production across the country (Bempah and Boateng, 2012). This increases the chances of resistance development by wide spectrum of insect pests against these insecticides.

Table 1. *S. frugiperda* larval incidence and damage (Ghana, 2020 and 2021)

District	Infestation (%)		Mean larvae/ plant (50 plants assessed)		Leaf damage score (Scale 1–9)	
Year (2020-2021)	2020	2021	2020	2021	2020	2021
Adansi North	32	60.7	0.80	1.52	4	7
Tema Metro	65	17.3	1.44	0.44	5	5
Dangme West	43	78	1.08	1.68	4	4
Yilo Krobo	53	94.0	1.28	1.64	4	8
Kajebi	46	67.0	1.04	1.30	4	6
Nkwanta South	28	37.4	1.08	0.84	3	5
Ejura/ Sekyeredumase	28	60.7	1.28	1.34	3	5
Atebubu/ Amantin	88	60.5	0.72	1.0	7	4
Pru West	18	44.7	0.24	1.16	2	5
East Gonja	18	82.7	0.36	1.20	2	7
Nanumba North	48	52.0	0.24	0.80	4	6
Yendi Municipal	42	60.7	0.60	1.10	4	6
Tamale Metro	60	43	0.64	0.6	5	4
West Mamprusi	12	42	0.20	0.7	2	5
Bolgatanga Municipal	12	33	0.16	0.5	2	4
Bawku Municipal	14	79.3	0.16	1.32	2	7
Kasena Nankana East	46	54.0	0.96	0.82	4	5
Wa Municipal	22	54	0.44	1.0	3	6
Sissala East	34	68.0	0.72	1.06	4	5
Sawla-Tuna-Kalba	56	59	0.76	1.0	5	6
West Gonja	44	95.3	0.80	1.36	4	8
Kintampo North	64	68	1.86	1.5	6	7
Techiman Municipal	52	62	0.76	1.1	5	6
Sisala West	55	90.7	0.8	1.06	5	8
Kintampo East	42	52.0	1.2	1.02	4	6
Builsa North	22	30.7	0.6	1.06	3	5
Sisala East	55	68.0	0.8	1.2	5	6

A number of indigenous natural enemies including parasitoids (Hymenoptera, Diptera), predators (ladybird beetles, earwigs, ants, spiders etc), microbials (entomopathogenic fungi and entomopathogenic nematodes) have been identified in Ghana since the FAW invasion (Danso et al., 2021: Koffi et al., 2020 and Issa et al., 2020). Assessment of efficacy of these indigenous natural enemies for the management of the FAW are far advanced and results are very promising. The high potential of using natural enemies to suppress the FAW suggest, the excessive use of chemical insecticides has to be looked at, since it can be a major impediment in realizing the full potential of these natural enemies. This suggests the need for re-orientation of the farming community on the balance between the use of insecticides and conservation of natural enemies.

3. Farmers indigenous technologies

Desperate situations call for desperate action, appeared to have been the order of the day at the initial invasion of the FAW in Ghana. Many farmers exploited cultural practices that were employed to suppress various pests, particularly those that were already known against lepidopterous pests. Among the common pest management practices used included:

'Alata soap' and other detergents: 'Alata soap' is a crude local potassic soap that local farmers have been using in the management of a wide range of agricultural pests in Ghana (Asare-Nuamah, 2021). Its use against the FAW was thus a way of testing a known strategy on new problem. Other farmers also used powder detergents, and this was a novel approach

Table 2. Insecticides commonly used or registered for use against *S. frugiperda* (Ghana)

Active ingredient(s)	Class of insecticide	Type of insecticide
Imidacloprid	Neonicotinoid	Chemical
Acetamiprid	Neonicotinoid	Chemical
Deltamethrin	Pyrethroid	Chemical
Emamectin benzoate	Ivermectin	Microbial extract
Ethyl palmitate	Botanical	Plant extract
Azadirachtin	Botanical	Plant extract
Maltodextrin	Botanical	Plant extract
Bacillus thuringiensis + Monosultap	Microbial, Nereistoxin	Bacteria, Chemical
Bacillus thuriengiensis + *Pieris rapae* granulosis virus	Microbial	Bacteria, virus
Sophora flevescen plant extract + Emamectin benzoate	Botanical + Ivermectin	Plant extract, bacterial extract
Cypermethrin + Teflubenzuron	Pyrethroid, Acylureas	Chemical, Insect growth regulator
Acetamiprid + Lambda-cyhalothrin	Neonicotinoid, Pyrethroid	Chemical
Acetamiprid + Emamectin benzoate	Neonicotinoid, Ivermectin	Chemical + Microbial extract
Acetamiprid + Indoxacab	Neonicotinoid, Organochlorine	Chemical
Dimethoate + Cypermethrin	Organophosphate, Pyrethroid	Chemical
Methoxyfenozide + Spinetoram	Carbohydrazide, Spinosyn	Insect growth regulator
Methomyl + Novaluron	Carbamate, Acylureas	Chemical, Insect growth regulator
K-Optimal	Pyrethroid, Neonicotinoid	Chemical
Imidacloprid	Neonicotinoid	Chemical
Acetamiprid	Neonicotinoid	Chemical
Deltamethrin	Pyrethroid	Chemical
Emamectin benzoate	Ivermectin	Microbial extract
Ethyl palmitate	Botanical	Plant extract
Azadirachtin	Botanical	Plant extract
Maltodextrin	Botanical	Plant extract
Bacillus thuringiensis + Monosultap	Microbial, Nereistoxin	Bacteria, Chemical
Bacillus thuriengiensis + *Pieris rapae* granulosis virus	Microbial	Bacteria, virus
Sophora flevescen plant extract + Emamectin benzoate	Botanical + Ivermectin	Plant extract, bacterial extract
Cypermethrin + Teflubenzuron	Pyrethroid,	Chemical, Insect growth regulator
Acetamiprid + Lambda-cyhalothrin	Neonicotinoid, Pyrethroid	Chemical
Acetamiprid + Emamectin benzoate	Neonicotinoid, Ivermectin	Chemical + Microbial extract
Acetamiprid + Indoxacab	Neonicotinoid,	Chemical
Dimethoate + Cypermethrin	Organophosphate, Pyrethroid	Chemical
Methoxyfenozide + Spinetoram	Diacylhydrazine, Spinosyn	Insect growth regulator
Methomyl + Novaluron		Chemical, Insect growth regulator
K-Optimal		

Source: EPA/CCMC, 2021

in the Ghanaian agricultural space – probably came about through experimentation based on knowledge of the 'alata soap'. Wood ash: some farmers sprinkled wood ash in the maize whorl, where the late instar larvae normally hide and cause destruction. Soil: This is a common practice during manual weeding in the vegetative phase. Soil is scooped and sprinkled into the whorl, similar to the wood ash. Neem extract: Application of crude aqueous extracts of neem seeds and leaves, particularly the latter, was also widespread in managing FAW on maize (Bariw et al., 2020). Chilli pepper and ginger: A solution of crude extracts of these hot spices is prepared from either grounded mixture of the two or sole ingredient and sprayed on maize (Bariw et al., 2020). Handpicking: The late instars larvae, which are more visible physically due to their size, frass and holes created in leaves, are handpicked and crushed by farmers maize (Bariw et al., 2020). All these practices had their inherent degree of effects on the fall armyworm larvae but some field results suggest impacts are not statistically significant (Tambo et al., 2019, 2020; Babendreier, 2020). The seemingly slow acting and laborious nature of these practices for relatively larger farms compared to the synthetic insecticides caused some apprehension about the use of these methods by farmers.

4. Potential of using biological control

Biological control (biocontrol) relies on organism to reduce insect pest numbers (Van Lenteren, 2012) and it is the safest and the most economically profitable pest management option (Cock et al., 2010; Messing and Brodeur, 2018). Predators, parasitoids, and pathogens are capable of exercising significant impact on insect pest populations and these natural enemies can form the foundation of an integrated pest management strategies in many agroecosystems (Furlong and Zalucki, 2010). Biocontrol occurs in every ecosystem and it contributes immensely to crop productivity (Muneret et al., 2019). Biological control agents such as microbial pathogens, predators, parasitoids and nematodes are vital in managing arthropod pests in the agroecosystem. While there is an increasing availability of synthetic insecticides, there is need to constantly explore the potential of integrating with biological control. Increased rate of human and animal poisoning, environmental contaminations, pest resistance and aggression as a result of misuse of synthetic insecticides are a lot reasons to pursue biological control (Godfray and Garnett, 2014; Gurr and You, 2016). This is especially true in Africa and other parts of the developing world where agrochemical poisoning is on the ascendency. In these regions, most of the agrochemical users lack the capacity to read and understand pesticides labels and therefore resort to unconventional methods including tongue-testing of mixed chemical to determine potency. In these parts of the world, however, poor financial circumstances and favorable farming practices such as minimum use of agrochemicals could be a source of motivation to incorporate natural enemies in insect pest management

Predators: Predators are important biocontrol agents in the agroecosystem. However, the suppressive ability of these agents, which consume their prey and often leave no direct evidence of their activity, are difficult to study compared with parasitoids, which can easily be sampled from host populations (Furlong and Zalucki, 2010). A number of predators have been observed on fall armyworm in Ghana. A study published in 2017 revealed three important predators; *Pheidole megacephala* (F.) (Hymenoptera: Formicidae), *Haematochares obscuripennis* Stal, and *Peprius nodulipes* Signoret (Heteroptera: Reduviidae) that attack FAW in Ghana (Koffi, et al., 2020). In a similar study, Issa et al. (2021) found coccinellids (*Harmonia octomaculata* (F) and *Coccinella transversalis* (F) (Coleoptera: Coccinellidae), earwigs and spiders as the prime predators attacking fall armyworm in Ghana. In a recent survey, the tropical paper wasp, *Polistes versicolor* (Olivier) (Hymenoptera: Vespidae) was seen aggressively consuming fall armyworm larvae in the Northern region of Ghana (B. Amoabeng et al., unpublished data). This wasp can be very efficient in managing all larval stages of the pest. In a close observation captured on video, the wasp was seen going down the maize tunnel, bringing up a sixth instar larvae of FAW and consuming the whole larva. This species has been reported as an important predator in other parts of the world. An inventory of the native natural enemies in Bhutan, *P. versicolor* was among 48 other natural enemies associated with the pest (Dorji et al., 2022). Southon et al. (2019) also reported on the effectiveness of this predatory wasp in managing the fall armyworm and the sugarcane borer *Diatraea saccharalis* (F) (Lepidoptera: Crambidae). A good number of this wasp in an agroecosystem could be an important biological control agent.

Parasitoids: Parasitoids are an important component of terrestrial ecosystems through their diversity, abundance, and functions (Rodriguez Hawkins, 2000). Their life history is often linked with the host usually

Table 3. Natural enemies of *S. frugiperda* (Ghana)

Order/ Family	Species	Type of natural enemy
Hymenoptera		
Braconidae	*Bracon* sp.	Larval parasitoid
Braconidae	*Coccygidium luteum* Brulle	Larval parasitoid
Braconidae	*Chelonus bifoveolatus* Szpligeti	Egg-larval parasitoid
Braconidae	*Cotesia icipe* Fernandez	Larval parasitoid
Braconidae	*Meteoridea testacea* (Granger)	Egg-larval parasitoid
Ichneumonidae	*Campoletis sonorensis* (Cameron)	Larval parasitoid
Formicidae	*Pheidole megacephala* (F)	Predator
Formicidae	*Plectoctena* sp.	Larval predator
Vespidae	*Polistes*a *versicolor*	Larval predator
Platygastridae	*Telenomus remus*	Egg parasitoid
Diptera	*Exorista* sp.	Larval parasitoid
Tachninidae	*Anatrichus erinaceus* Loew	Larval parasitoid
Chloropidae		
Coleoptera	*Harmonia octomaculata* (F)	Egg/larval predator
Coccinellidae	*Coccinellatrans versalis* (F)	
Dermaptera: Forficulidae	*Forficula* sp.	Egg predator
Heteroptera:	*Haematochares obscuripennis* Stål	Predator
Reduviidae	*Peprius nodulipes* (Signoret)	Predator
Rhabditida:		
Steinernematidae		Parasitic nematode
Heterorhabditidae		Parasitic nematode

Source: Agboyi et al., 2021; Danso et al. 2021; Issa et al. 2021; Koffi et al. 2020;

exhibiting aggregative numerical response (Rohani et al., 1994; Amoabeng et al., 2020). The invasion of FAW in Ghana and other parts of Africa means that it arrived without its natural parasitoids. Ultimately, for effective biological control using parasitoids, there was need for classical biological control which is generally expensive. Henry et al. (2010) suggested that ecologically, some indigenous parasitoids may adapt to a new pest species. Within one year after FAW was found in Africa, four parasitoids were identified to be associated in Kenya, Ethiopia and Tanzania (Sisay et al., 2018) indicating the potential of endemic parasitoids adapting to the new pest.

In Ghana, a number of parasitoids have been identified to attack FAW. In a study to identify the various natural enemies, Koffi et al. (2020) recorded seven parasitoid species namely; *Chelomus bifoveolatus* Szpligeti, *Coccygidium luteum* Brull, *Cotesia icipe* Fernandez, *Meteoridea testacea* Granger, *Bracon sp* (Hymenoptera: Braconidae), *Anatrichua erinaceus* Loew (Diptera: Chloropidae) and an undertermined tachinid fly (Diptera: Tachinidae). A similar study in Ghana and Benin found ten species parasitizing the pest (Agboyi et al., 2020). These include two egg parasitoids, one egg-larval parasitoid, five larval and two larval-pupal parasitoids. The study found two most abundant parasitoid species in both countries as the egg-larval parasitoid *Chelonus bifoveolatus* and the larval parasitoid *Coccygidum luteum.* Parasitism rates for these were determined in three regions in Ghana and varied from 0 to 75% between sites and from 5 to 38% between regions (Agboyi et al., 2020). Five species of egg and larval endemic parasitoids comprising three Braconidae *Coccygidium luteum* Brullé, *Chelonus* sp. and *Cotesia* sp., one Ichneumonidae *Campoletis sonorensis* (Cameron) and one Tachinidae *Exorista* sp. were identified during a nationwide survey to identify natural enemies (Issa et al., 2021). While the various authors have found several taxa of parasitoids to be associated with the pest in Ghana, two species; *C. luteum* and *Chelonus* sp. appear in all the studies. Howbeit, the egg parasitoid, *Telenomus remus* Nixon (Hymenoptera: Platygastridae) has been mass-reared and released in experimental trials and appears to have the greatest potential. This is because the parasitoid can easily be mass-reared in the laboratory. Already, series of releases have been carried out in field trials in the Eastern region of Ghana to assess the potential of this hymenopteran (Agboyi et al., 2021). In that study, parasitism rate of about 33% in the major rainy season and between 72 and 100% in the minor rainy season, respectively, were reported. Mass rearing and releases of *T. remus* by the Crops Research Institute has also been ongoing. Prior to the field releases, parasitism study at the laboratory showed about 94% parasitism of egg masses (Amoabeng et al., unpublished results).

Entomopathogenic nematodes: Entomopathogenic nematodes (EPN) are soft-bodied, non-segmented roundworms that are obligate or facultative parasites of insects. Entomopathogenic nematodes occur naturally in soils and search for their host in response to carbon dioxide, vibration, and other chemical cues (Kaya and Gaugler, 1993). According to Vashisth et al. (2013), the only nematodes possessing optimal balance of biological control attributes against insect pests are entomopathogenic nematodes. Species of EPN in two families (Steinernematidae and Heterorhabditidae) have been used as biocontrol agents (Grewal et al., 2005). These nematodes form mutualistic associations with bacteria of the genus *Xenorhabdus* and *Photorhabdus* and are able to kill their host insects within 24 to 48 hours. Entomopathogenic nematodes fit perfectly into insect pests' IPM programmes (Shapiro-Ilan et al., 2012).

First report of entomopathogenic nematodes in Ghanaian soils was reported by Danso et al. (2019). In that study, sweet potato rhizosphere soils were sampled to extract entomopathogenic nematodes using the insect baiting technique (Bedding and Akhurst, 1975) with Greater wax moth, *Galleria mellonella* (Athropoda: Pyralidae) from the Eastern, Central and Volta regions of Ghana. It was an effort to use entomopathogenic nematodes to manage sweet potato weevils *Cylas* species infestation for increased sweet potato crop productivity. Since then, entomopathogenic nematodes research activities have progressed steadily and has been applied to manage the FAW on maize with funding support provided by AGRA (2017GH006) and KAFACI (KAB20200106). Under the AGRA FAW project in 2018, soils were sampled from maize farms across Ghana N07°11'.637'W01°24.806'; N07°11'.637'W01°24.806'; N06°42'.508'W03 °04.086';N05°07'.369'W01°15.698'; N06°36'. 049'W01°52.608';N05°38'.501'W00°07.555'; N06°00'.438'E00°37.028'; N10°50'.822'W00°10.861'; N10°50'.820'W01°59.739; and N09°04'.842' W01° 46.446' to extract entomopathogenic nematodes (Danso et al., 2023). Entomopathogenic nematodes were found in 75% of the 200 maize farms sampled across Ghana. These beneficial nematodes were extracted from the soil samples using the insect baiting technique (Bedding and Akhurst, 1975) and modified White (White, 1927) traps with *G. mellonella* and FAW larvae.

Entomopathogenic nematodes have been identified using morphometric and molecular markers. General nematodes DNA extraction kit was provided by CLEARDECTIONS® (Wageningen, the Netherlands). Molecular markers were synthesized and supplied by METABION® International (Germany). The PCR products were sequenced by GENEWIZ® Inc. (USA) to identify the entomopathogenic nematodes. In 2020 under the KAFACI FAW project, entomopathogenic nematodes mixed populations were tested against FAW on maize under greenhouse conditions. In that study, entomopathogenic nematodes performed creditably compared to emamectin benzoate (Danso et al., 2021). There was no significant difference between Steinernematidae and Heterorhabditidae entomopathogenic nematodes in protecting maize in subsequent pure culture studies. Currently, field studies are being conducted to assess the efficacy of entomopathogenic nematodes in maize.

Entomopathogenic fungi: *Spodoptera frugiperda* larvae are susceptible to entomopathogenic fungi (EPF) (Molina-Ochoa et al., 2003; Ríos-Velasco et al., 2010). Entomopathogenic fungi live in soil and infect insects by penetrating their cuticle to their bodies to eventually kill and feed on them (Dara, 2017). Although they are mainly isolated from arthropod carcasses, their natural habitat is soil (Behie and Bidochka, 2014). These fungal pathogens are important contributors to insect population dynamics in soil. EPF are classified into the divisions Ascomycota, Zygomycota, Deuteromycota, Oomycota, Chytridiomycota (Esparza-Mora et al., 2017). They are also considered important biocontrol agents against economically important pests in crops such as maize and other cereal staples. It has been estimated that over 750 species of fungi belonging to more than 90 genera have entomopathogenic qualities (Rajula et al., 2020; Roy et al., 2010). These identified species have close association with more than 1800 insect species in field and mostly kill wide range of insect population under favorable conditions (Jankevica, 2004).

The infectious properties of EPF, the infectious process (Skinner et al., 2014; Lacey et al., 2015; Mascarin and Jaronski, 2016), and the use of these pathogenic organisms in large scale preparations as biopesticides (Jaihan et al., 2016; Rıos-Moreno et al., 2016) have been studied. Indigenous strains of entomopathogenic fungi as alternative to chemical insecticides have to be evaluated against *S. frugiperda.* Among the various genera and species, some fungi appear as non-selective pathogens while others are host-specific (Vukicevich et al., 2020). EPF, among other advantages, can infect their hosts through contact and they do not need consumption or digestion by the host to cause infection. They are environmentally safe, high host specificity, negligible effect on non-target organisms and easy mass production. EPF are reported to be non-lethal to humans and animals and have no residual effect on harvested farm produce (Siti Ramlah et al., 1994; James and Lighthart, 1994; Moslim et al. (2006).

In Ghana, various research works into the efficacy of EPF in the management of insect pests have been conducted. The potential of indigenous EPF for the management of the diamondback moth (DBM) has been studied (Anaisie et al., 2011). *Aspergillus* sp, *Penicillium* sp. and *Fusarium* sp. were isolated from cadavers of DBM collected from field and identified. That study showed that the fungi isolate have potential as biological control agents in the management of the DBM in Ghana. Adu-Mensah (2000) also reported the susceptibility of two grasshopper species to strains of *Metarhizium* with respect to humidity. Boafo et al. (2014) conducted bioassay to ascertain the pathogenicity of indigenous EPF *Aspergillus* sp, *Metarhizium* sp, *Paecilomyces* sp, *Penicillium* sp isolated from cadavers of *C. lameensis* on adults of *C. lameensis* oil palm leaf miner in Ghana. Gabuin, (2021) also evaluated EPF (*Aspergillus* sp.) against larvae of the cotton bollworm *Helicoverpa armigera* under laboratory conditions. García et al. (2011) reported 96.6 and 78.6% mortality with (*B. bassiana* and *M. anisopliae* strains, respectively on 2nd instar larvae of FAW at a concentration of 1 x 10^9conidia/ ml. Aktuse et al. (2019) reported that *M. anisopliae* isolates showed 92 and 97% mortality on FAW eggs and neonate larvae, respectively, whereas only *B. bassiana* showed 30% mortality on 2nd instar larvae of FAW in Kenya. Cruz-Avalos et al. (2019) reported that, *M. anisopliae* and *B. bassiana* isolates showed 19 and 100% mortality on FAW eggs and neonate larvae, respectively.

In Ghana, a number of fungi were collected across different Agro-ecological zones. These fungal pathogens were isolated from sampled soils and FAW larvae cadavers. Based on known colony characteristics, suspected EPF were selected. These EPFs were grouped based on literature and colony characteristics, particularly colour. Selected samples from each group were used to conduct DNA sequencing. EPFs identified included; *T. atroviride, T. harzianum, Trichoderma ghanense, Beauveria bassiana, Fusarium equiseti* and *Aspergillus terreus.* Even though the six identified fungi have been confirmed by literature as potential EPF for management of various organisms, *Beauveria bassiana* and *Trichoderm*a *ghanense* are the well-known and efficient EPFs for the management of insects including FAW. An i*n-vivo* study was done to evaluate selected indigenous EPFs on the various developmental stages of *S. frugiperda* on maize. Larvae of *S. frugiperda* were exposed to spores or conidia suspension of EPF and mortality assessed under screen house conditions. Indigenous EPF *B. bassiana* and *T. ghanense*, a commercial insecticide Emamectin benzoate (positive control and distilled water (negative control) were used for the screen house experiment. Initial results show that *B. bassiana* and *T. ghanense* compare favourably with that of the positive control, emamectin benzoate. *B. bassiana* and *T. ghanense* were successfully isolated from mummified FAW larvae cadavers to complete Koch's postulate test. The implication is that the spore suspensions of *B. bassiana* and *Trichoderma* sp. applied on the FAW larvae caused mortality invading host cells, thus, EPF (*Beauvaria* sp and *Trichoderma* sp.) can infect their hosts through contact and they do not need consumption or digestion by the host to cause infection. Also, *Beauvaria* sp and *Trichoderma* sp re-isolated from cadaver FAW larvae sprayed with the spore suspension according to Koch's postulate test indicates that the spore suspension of EPF was the cause of mortality to the FAW larvae.

CONCLUSIONS

The fall armyworm is in Ghana, and to a larger extent, Africa to stay. There is need for sustainable management to ensure stable production of maize and alternative host crops such as sorghum, millet, rice, cabbage to ensure that the already deteriorating food security situation in Africa is not worsened. This review has shown that, there is inconsistent prevalence rate of FAW in Ghana probably as a result of disjointed effort in managing the pest. While government has withdrawn the wholesale supply of conventional insecticides to farmers, probably due to unsustainable financing, there is need to sensitize farmers to take FAW management on their farms in their own hands. It is worth noting that, some farmers grow maize without any FAW management plan in mind. Such farms tend to harbour and multiply FAW for further spread to adjourning farms; a practice that should be discouraged. It is refreshing to note that several indigenous predators and parasitoids attack FAW and efforts are underway to mass-rear and release these natural enemies. There is need to ensure judicious use of pesticides to reduce the negative impacts on such chemicals on these important natural enemies to enhance biological control of FAW. Activities towards obtaining entomopathogens should also be encouraged to obtain ecologically friendlyFAW management across the country and the continent.

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AUTHOR CONTRIBUTION STATEMENT

All authors contributed equally.

CONFLICT OF INTEREST

No conflict of interest.

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