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Research Article
Indigenous Natural Enemies Attacking Fall Armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Ghana

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Abstract

Background and Objective: The Fall Armyworm *Spodoptera frugiperda* (Lepidoptera: Noctuidae) is a novel invasive pest in Africa but has established as a major pest of maize. Maize fields across six ecozones were surveyed for indigenous natural enemies of *S. frugiperda* in Ghana. **Materials and Methods:** Fifty maize plants showing signs of *S. frugiperda* infestation were sampled from three farms in each of the forty-eight districts blocked within all the six agro-ecological zones of Ghana. Collected *S. frugiperda* eggs and larvae were cultured in a laboratory for parasitoid emergence and percent parasitism determined. **Results:** Five species of egg and larval natural parasitoids comprising three Braconidae *Coccygidium luteum* Brullé, *Chelonus* sp. and *Cotesia* sp., one Ichneumonidae *Campoletis sonorensis* (Cameron) and one Tachinidae *Exorista* sp were identified. Among the predators recorded were coccinellids (*Harmonia octomaculata* [F.] and *Coccinella transversalis* [F.]) (Coleoptera: Coccinellidae), earwigs and spiders. *C. luteum* was the dominant natural parasitoid and also exhibited the highest field parasitism level, 6.38-10.71%. Parasitism levels of the other parasitoids ranged between 2.56-3.45%. The seemingly low field parasitism observed could be attributed to the high application of broad-spectrum insecticides which inadvertently is inimical to their development. **Conclusion:** Some indigenous parasitoids are adapting to *S. frugiperda*. Further exploration and protection of natural enemies through ecofriendly practices in a comprehensive IPM program is imperative for sustainable management of *S. frugiperda*.

Key words: Natural enemy, parasitoid, predator, maize, fall armyworm, invasive pest

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Fall armyworm (J.E. Smith 1797) (Lepidoptera: Noctuidae) has been the greatest threat to food security, besides climate change, to sub-Saharan Africa since the pest was officially recorded in the continent in 2016[1-3]. This is because of the conductive tropical African environment for its survival and preference for maize, which is an important commodity and widely cropped in sub-Saharan Africa. It is a prime staple crop for many smallholder farmers but also an important cash crop for all categories of farmers[4,5]. In Ghana, maize is an important staple food for human consumption, in poultry feed production and in the brewery industry. It accounts for 62% of local cereal production[4,6,7] and contributes 3.3% to total agricultural production value[8,9]. Estimated mean yield loss of maize attributed to *S. frugiperda* in 2018 was 470 000 t amounting to US$177.3 million compared to years prior to the invasion[3].

To salvage the wanton destruction by the pest at the height of the invasion, rapid response strategy mainly by the use of chemical insecticides was employed[10]. Locally available insecticides, mainly broad-spectrum chemical insecticides were found to be the antidote and were mass applied albeit health and environmental implications. Although this turn out to be effective at the onset, it is not the best option for the long term due to the possibility of the pest developing resistance to a broad spectrum of insecticides, issue of residues especially in fresh corn, killing of beneficial insects and other non-target organisms. For these reasons, alternative methods with less deleterious effects are imperative in the development of Integrated Pest Management (IPM) strategies to contain the pest. Viable alternatives include the use of biorationals, natural enemies and habitat manipulation such as the push-pull.

In the Americas where the *S. frugiperda* is indigenous, several natural enemies have been identified, with a substantial number assessed for their effectiveness in suppressing the pest[11,12]. It is believed that the natural enemies, particularly natural parasitoids did not come to Africa alongside the pest hence population explosion, with its attendant destruction, soon after its arrival[13]. It is in this vein that conscious effort to explore sustainable alternative management options that a study to identify natural enemies is being carried out in Ghana by Crops Research Institute. This study has two components: scouting for indigenous natural enemies and Laboratory and field behavioral assessment of efficiency of the identified natural enemies as part of an integrated management strategy against *S. frugiperda*. This report, however, covers the scouting aspect.

MATERIALS AND METHODS

Study areas: The survey was conducted in all sixteen regions of Ghana, from June, 2018 to August, 2019. The entire country was first zoned into six broad areas based on ecological considerations (Coastal Savanna, Tropical Rainforest, Semi-Deciduous Rainforest, Forest-Savanna Transition, Guinea Savanna and Sudan Savanna). These were further blocked such that all ecological zones within each of the 16 political regions were covered. Thus, three districts per region and three maize farms were randomly selected from major maize growing areas within the regions (Fig. 1). Coordinates and elevation of sampled farms were taken and later marked on Ghana map using, ArcGIS Release 10.6. Maize farms that had not been sprayed since planting and those that had not been sprayed for at least 3 weeks were the benchmarks for selecting a farm for sampling. This was based on farmers' assertions on insecticide spraying timelines.

Sampling for natural enemies: Sampling for fall armyworm larvae in maize was conducted in all the sixteen regions during the major cropping season (June-August) in the transitional to the coastal ecological zones in the south. That of the Guinea and Sudan Savanna zones was in July-August. Fifty maize plants showing signs of *S. frugiperda* infestation (frass, window panes, maize leaf blades showing characteristic chewing signs) were then randomly sampled from each farm. Eggs were collected by cutting sections of the maize leaves with egg masses and put into labelled 1 litre plastic jars and the open end covered with fine nylon mesh fastened with rubber bands.

The type of predators and their activities such as capturing of larva of *S. frugiperda* at the time of examining infested maize plants was also observed.

Both alive and dead *S. frugiperda* larvae of different instars were also collected from randomly selected infested maize (i.e., signs of fresh frass, leaves with holes/window panes). Larval lengths were measured and categorized into different instars: < 1 cm (1st-2nd instar), 1-2 cm (3rd-4th instar) and >2 cm (5-6th instar). Each specimen was put into a separate 350 mL disposable plastic cup and covered as in the jars.

Rearing immature fall armyworm for natural parasitoids: Samples were taken to and kept in the laboratory at 28-30°C, pending emergence of natural parasitoids from eggs, larvae and pupae. The live *S. frugiperda* larvae were fed with fresh-cut young maize leaves daily until they pupated or died. Larval droppings were cleaned every other day. Set up was

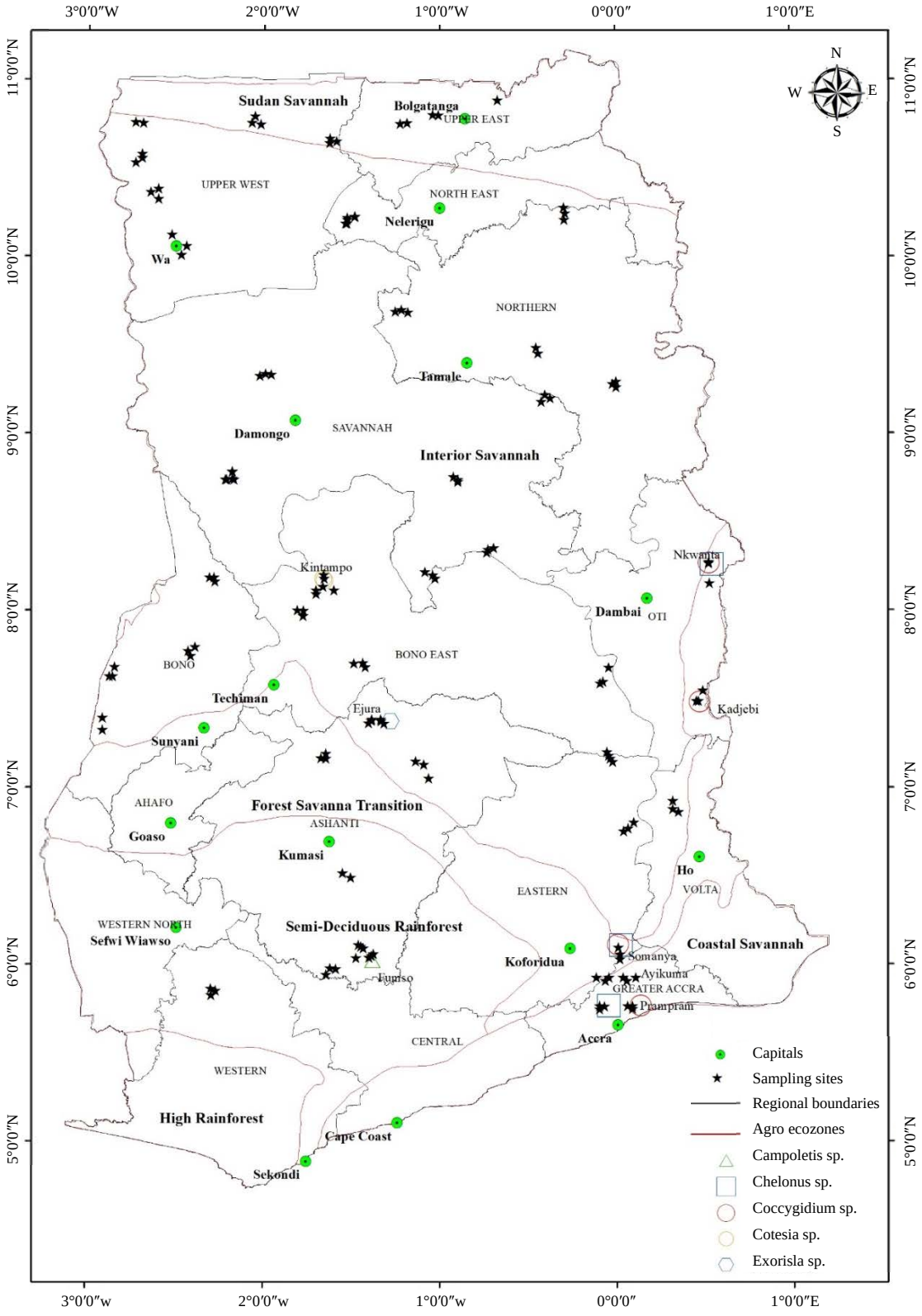

Fig. 1: Map of surveyed areas and locations where natural parasitoids were collected

observed daily, observing any changes in the *S. frugiperda* larvae/pupae as well as the collection of emerged parasitoids. The parasitoids that emerged from the eggs or larvae were recorded every 24 hrs until pupation. Samples of the parasitoids preserved in 70% ethanol were sent to the University of Ghana and CABI-Ghana for identification. The percentage parasitism of each parasitoid was calculated based on the proportion of parasitoids that emerged from the total number of *S. frugiperda* larvae per farm[14]:

$$\text{Parasitism (\%)} = \frac{\text{Number of parasitoids}}{\text{Number of larvae collected}} \times 100$$

RESULTS AND DISCUSSION

Natural parasitoids: Five natural parasitoid species belonging to three insect families, which include Braconidae, Ichneumonidae and Tachinidae emerged from the cultured *S. frugiperda* collected from the field. One species, *Chelonus* sp. is an egg parasitoid while four species, comprising *Coccygidium luteum* Brullé, *Cotesia* sp., *Campoletis sonorensis* (Cameron) and *Exorista* sp. are larval parasitoids. The natural parasitoids identified in the study and brief descriptions of their attributes as natural enemies are presented in Table 1.

The distribution of the parasitoids, as shown in Fig. 1, data indicated they were more predominant in the eastern corridor of the country. These hotspots are predominantly characterized by Coastal and Transitional ecological conditions. These ecological zones are moderately dryer compared to the forest zones but comparatively wetter than the Guinea savanna. Nevertheless, the observed pattern probably reflects the direction from where the pest entered Ghana and first established. Based on the evidence that *S. frugiperda* moved in from the eastern part of West Africa (possibly Nigeria)[2] and probably colonized these areas earlier, affirmed by the first official report in Ghana coming from Eastern Region (Fig. 1)[10]. Subsequent surveys over time in the mid to western parts of the country are therefore expected to produce more natural parasitoids.

The highest parasitism, ranging between 6.38-10.71% was recorded for *C. luteum*. The parasitism levels of 2.56-3.45, 2.86, 2.17 and 2.35 for the other four natural parasitoids *Chelonus* sp., *C. sonorensis*, *Exorista* sp. and *Cotesia* sp., respectively were relatively very low (Table 2). The relatively high parasitism exhibited by *C. luteum* compared to the rest of the collected natural parasitoids in the field coupled with a wide distribution in Ghana, of this natural parasitoid makes it a promising candidate for the management of *S. frugiperda* in Ghana.

The most widely distributed natural parasitoid was the *Coccygidium luteum* Brullé (Fig. 1 and Table 2). The *C. luteum* has recently been reported to be associated with *S. frugiperda* in Ethiopia, Sisay *et al.*[15] as well as in Ghana and Benin[23] with high parasitism level and a significant reduction in *S. frugiperda* population. *Coccygidium* spp.

Table 1: Identified natural parasitoids of fall armyworm

Species	Order/Family	Attributes
Coccygidium luteum Brullé	Hymenoptera: Braconidae	Larval parasitoid of noctuid moths including *Spodoptera* sp.[15,16]
Chelonus sp.	Hymenoptera: Braconidae	An egg-larval parasitoid. Lays eggs in host eggs and completes development in the host larvae. Single egg per host but superparasitization may occur, in which case only one parasitoid emerges. After emerging, females are ready to oviposit eggs, whether mated or not[17]
Cotesia sp.	Hymenoptera: Braconidae	Gregarious endoparasitic larval parasitoids attacking Lepidoptera. Adults lay eggs alongside its symbiotic polydnavirus and some venom into larva of the host. This halts development of the larvae[18]
Campoletis sonorensis (Cameron)	Hymenoptera: Ichneumonidae	An arrhenotokous oligophagous larval endoparasitoid of noctuid moths including *S. frugiperda* and several major pest species. It is a generalist parasitoid; prefer 2nd and 3rd instar *S. frugiperda* larvae[12,19,20]
Exorista sp.	Diptera: Tachinidae	A gregarious and polyphagous parasitoid that attacks a number of lepidopteran pests, particularly noctuid larvae. Females lay eggs on last instar host larvae. The first instar larvae emerge and penetrate the host integument after incubating for 4 days, resulting in death of host. Females are said to be attracted to odours from infested maize plants[21,22]

Table 2: Levels of fall armyworm parasitization by natural parasitoids in the field

Parasitoid	*S. frugiperda* parasitized (%)	Number of farms with parasitized larvae/pupae
Coccygidium luteum Brullé	6.38-10.71	6
Chelonus sp.	2.56-3.45	3
Campoletis sonorensis (Cameron)	2.86	1
Exorista sp.	2.17	1
Cotesia sp.	2.35	1

have been found to attack several *Spodoptera* species including *S. frugiperda*, *S. exigua*, *S. exempta* and *S. litura* in several countries from West to Southern Africa[16] and India as well as parts of Middle East[24].

The generally low parasitism levels of *S. frugiperda* by the recorded natural parasitoids could be due to the excessive use of broad-spectrum insecticides in surveyed areas (Table 2). While some farmers indicated they have not yet sprayed their farms at the time of sampling, the majority had at least once applied insecticides prior to the collection of specimens although farms that had not been sprayed for at least 3 weeks were purposively selected. A survey reported by Groote *et al*.[3], who indicated that there is widespread and high use of broad-spectrum insecticides in all maize growing areas in Ghana. Repeated field trials without application of insecticides in the hot spots are expected to record higher parasitism levels among all the parasitoids identified in this study.

Chelonus sp. and *Cotesia* sp. are two other Braconid parasitoids that were found attacking *S. frugiperda* in this study. Although their distribution and parasitism levels were limited in the studied areas, particularly *Chelonus* sp., they are known to be effective generalist parasitoids of agricultural importance. *Cotesia sesamiae* (Cameron) has been known to parasitize noctuid stemborers in Africa with the capability of expanding its host range[25,26].

Another important parasitoid in our collection worth considering is *Campoletis sonorensis* though its distribution was not widespread in this survey. *C. sonorensis* have been identified as a major parasitoid of *S. frugiperda* in Mexico[12,26] where both maize and the pest originated. Another species from the Genus have also been recorded in India, where the pest recently invaded[18,27]. High parasitism level (30-35%) of *Campoletis* on *S. frugiperda* were recorded by Barreto-Barriga *et al*.[12] in Mexico but the 3% by *C. chlordideae* recorded by Sharanabasappa *et al*.[24] in India was very low, probably due to the limited area surveyed by the latter. The importance of *Campoletis* in the suppression of *S. frugiperda* is the evidence suggesting that it is attracted to the plant of its host even if the host is present or absent[19]. Adoption of good management practices in maize fields will inadvertently help the colonization of this natural parasitoid.

Exorista sp. is the only parasitoid of the order Diptera recorded in the current survey and was found in only one location in the middle belt. The parasitism level was low and similar to the other natural parasitoids, except *C. luteum*. Sissay *et al*.[15] observed *Palexorista zonata* (Curran) (Diptera: Tachinidae) to attack *S. frugiperda* with appreciable parasitism levels in Kenya and Ethiopia but not in Tanzania.

Predators: A number of predators were also observed attacking *S. frugiperda* on infested maize. They included coccinellids (*Harmonia octomaculata* [F.] and *Coccinellatrans versalis* [F.]) (Coleoptera: Coccinellidae), earwigs *Forficula* sp., wasps, a wide range of spiders and the millipede eating ants *Plectoctena* sp.

Sharanabasappa *et al*.[24] suggested *H. octomaculata* and *C. transversalis* and *Forficula* sp. might be of great importance against early larval instars of *S. frugiperda* in India. This is because high numbers of these predators, which are known to prey on eggs and larvae of lepidopterans, were encountered in maize fields infested with *S. frugiperda*.

According to Schatz *et al*.[28] workers of *Plectoctena minor*, mainly prey on millipedes but have the tendency to prey on other soft-bodied arthropods, including termites and larvae of beetles. Late instar *S. frugiperda* larvae that drop to the ground ostensibly to pupate were preyed upon in fields where *Plectoctena* sp. was abundant. All these predators are critical to the management of *F. frugiperda.* The actual impact of these predators in suppressing *S. frugiperda* needs to be assessed further.

CONCLUSION

Some indigenous parasitoids of lepidopterans have been identified to attack the invasive *S. frugiperda* in Ghana. It can be concluded that the dominant parasitoids are from the Hymenoptera family, particularly the order Braconidae. The most predominant parasitoid recorded in this survey with great potential for the management of the *S. frugiperda* is the *Coccygidium luteum* Brullé followed by *Campoletis sonorensis* Cameron. The parasitism levels of *C. luteum* amidst heavy insecticide usage were highly appreciable. Further on-field insecticide exclusion studies at different ecological zones need to be undertaken before meaningful integrated pest management strategies involving the natural enemies can be developed.

SIGNIFICANCE STATEMENT

This study discovered five indigenous natural parasitoids and some predators that can be beneficial for the management of the new invasive pest, fall armyworm in Ghana. This study will help researchers to uncover the critical areas of natural enemy dynamics that many researchers were not able to explore. Thus a new theory on the spate of how natural enemies adapt to new pests may be arrived at.

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