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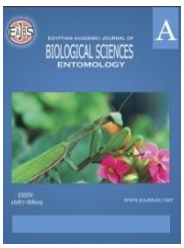

Entomophagous Insects of The Invasive Fall Armyworm, *Spodoptera frugiperda* (Nixon) in African and Asian countries

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ABSTRACT

The fall armyworm, *Spodoptera frugiperdais* a highly destructive pest of cereals and is native to the tropical and subtropical regions of North, Central and South America. The insect is polyphagous with a host range of 353 plant species in 76 families and was reported to cause 8.3 to 20.6 million tones losses in maize yield/year which represents 21 – 53% of the total production.

A total of 48 parasitoids (6 species of egg parasitoids, 4 species of egg-larval parasitoids, 34 species of larval parasitoids, 3 species of larval-pupal parasitoids and one pupal parasitoid) of *Spodoptera frugiperda* have been recorded in African countries since its invasion in 2016. In addition, 18 predator species have been found to be associated with this insect in maize and rice fields. In Asian countries, a total of 24 parasitoids (6 egg parasitoids, 2 egg-larval parasitoids and 16 larval parasitoids) have been recorded as well as 11 predator species. The most common egg parasitoid is *Telenomus remus* which is recorded in 8 countries of Africa as well as three countries of Asia (out of the 4 countries mentioned in Asia). The most common egg-larval parasitoid in Africa is *Chelonus bifoveolatus* as it is recorded in 8 countries whereas *Ch. formosanus* and *Ch. nr blackburni* are recorded in India (Asia). The most common larval parasitoids in Africa are *Coccygidium luteum* (7 countries), *Cotesia icipe* (6 countries) and *Charops* sp. (6 countries), whereas the most common one in India (Asia) is *Campoletis chlorideae.*

INTRODUCTION

The fall armyworm, *Spodoptera frugiperda*is (Nixon) is a highly destructive pest of cereals and is native to the tropical and subtropical regions of North, Central and South America (Kenis *et al*., 2019). It has been considered a risk to food security (Sagar et al., 2022). The insect is polyphagous with a host range of 353 plant species in 76 families (Montezano *et al*, 2018). It can cause 8.3 to 20.6 million tones losses in maize yield/year which represent 21 – 53% of the total production (Day *et al*., 2020). However, Baudron *et al*. (2019) and Kumela *et al*. (2019) recorded 11.6% and 32 – 47% yield losses, respectively.

As reported by Tending *et al*. (2019) the total life cycle of FAW averaged 25 days (22 – 28 days) at 25 ºC. The female can deposit 1500 – 2000 eggs during its life span which ranges from 7-10 days at 28 ºC (Kumar *et al*., 2022). Abd Elmageed *et al*. (2021) reported that the incubation period of the egg, larval and pupal periods were found to be 3.47, 20.93,

and 12.6 days, respectively, at 26 ºC and 55% R.H. whereas the total life cycle from egg to adult averaged 37.7 days.

The IPM of FAW has been carried out by agricultural control, chemical insecticides, sex attractants, bio-control agents (including parasitoids, predators and entomopathogens) as well as botanicals (Wan *et al*., 2021). The absence of diapause, the short generation time, the high fecundity and the resistance to at least 29 chemical insecticides including carbamates, organophosphorus and pyrethroids are the main factors that made *S. frugiperda* one of the most serious pests of crops mainly maize, rice and sorghum (Wan *et al*., 2021). In addition, *S. frugiperda* could develop resistance to *Bt* crops including corn and the first case of this resistance was observed in 2006 in Puerto Rico, USA after 3 years of planting *Bt* corn causing considerable losses of the yield that forced farmers to stop planting this crop (Abbas, 2016). Hence, the use of biological control agents seems to be a preferred method for its control providing high effectiveness as stated by Colmenarez *et al*., (2022).

A survey of parasitoids of FAW eggs, larvae and pupae carried out by Molina-Ochoa *et al*. (2003) revealed about 150 species of parasitoids and parasites from the Americas and Caribean basin. Among those, the egg-larval parasitoid, *Chelonus insularis* (Cresson) (Hym.: Braconidae) had the broadest natural distribution in the Americas. *Ch. insularis, Chelonus* sp. and *Euplectrus platyhypenae* (Howard) (Hym.: Eulophidae) were the most prevalent in North America. For South America, the most prevalent parasitoids were *Archytas incertus* (Macq.) (Dipt.: Tachinidae), *A. marmoratus* (Tens.), *Ch. Insularis* and *Meteorus laphygmae* (Vier.) (Hym.: Braconidae). *Diapitimorpha introita* (Cresson) (Hym.: Ichneumonidae) is the most important pupal parasitoid of FAW occurring mainly in North America. In addition, a survey of the parasitoids attacking *S. frugiperda* in sweet corn fields in Florida, USA, during 2010 – 2015 revealed that out of 8353 larvae of FAW collected during this period, 2365 larvae (28.3%) were parasitized with rates of parasitism ranging 1% to 91.7%. The two most common parasitoids obtained were *Cotesia marginiventris* (Cresson) (Hym.: Braconidae) and *Ch. insularis* whereas the other parasitoids were *Aleiodes laphygmae, Euplectrus platyhypenae, Meteorus* spp. and *Ophion flavidus* (Meagher et al., 2016). Tepa-Yotto *et al*. (2021) reported that the key parasitoids of *S. frugiperda* at a global scale are *Ch. insularis, Cotesia marginiventris, Eiphosoma laphygmae* and the egg parasitoids, *Telenomus remus* (Nixon) (Hym.: Scelionidae) and *Trichogramma pretiosum* (Riley) (Hym.: Trichogrammatidae). The egg parasitoid, *Tel. remus* has gained the most interest and has been mass released against this pest in the Americas for many years (Colmenarez *et al*.,2022).

S. frugiperda was first detected in the African continent starting from 2016 in West and Central Africa (Goergen et al., 2016, Ahissou *et al*.,2021a), Rwanda (Uzayisenga *et al.*, 2018), Senegal (Brevault *et al*., 2018), in Sudan (Ebadi, 2022), in Egypt (Youssif, 2021; Rashed *et al*., 2022), and over 44 African countries (Abang et al., 2020). The insect was also recorded in several countries in Asia including India, China, Korea, Japan, Viet Nam and Sri Lanka (Wu *et al*., 2021; Dao *et al*., 2020) as well as Syria, Jourdon and Israel (Pehlivan and Atakan, 2022). The insect successfully invaded Europe (Germany and the Netherlands, Agboyi *et al*.,2021, Jindal et al., 2021, Sun *et al*., 2021 and Turkey, (Pehlivan and Atakan, 2022) as well as Australia (Apirajkamol *et al*. 2022). Early *et al*. (2018) stated that the environmental requirements for this pest to establish itself permanently are present in large parts of Africa and Asia. *S. frugiperda* was recorded to have the potential to cause losses in maize yield reaching 8 – 20 tons per year equal to 13 billion USD per year in 12 African countries (Day *et al*., 2020).

Ahissou *et al*.(2021b) claimed that Africa may be more appropriate for FAW biological control than North America for two reasons: 1. small-scale production of maize

and other crops often closely cultivated, 2. chemical insecticides were rarely used in maize crops before the arrival of FAW in Africa. Both reasons probably make natural enemies easier to protect the crop.

A.The Recorded Entomophagous Insects of FAW in African Countries:

a.Parasitoids (Table 1):

As reported by Abang *et al*. (2020), the fall armyworm, *Spodoptera frugiperda*, has been detected in 44 African countries starting from 2016. However, according to literature, the survey of natural enemies of this pest has been carried out in only 17 countries up till now. Abang *et al*. (2020) recorded *Telenomus remus* (Nixon), (Hym.: Scelionidae) *Cotesia icipe* (Fernandez&Fiaboe) (Hym.: Braconidae) and *Procerochasmias nigromaculatus* (Cameron) (Hym.: Ichneumonidae) as egg, larval, and pupal parasitoids, respectively, of fall armyworm in Cameron. However, Abang *et al*., (2021) carried out a survey of parasitoids of FAW in maize fields that revealed the occurrence of two egg parasitoids and 4 larval parasitoids. The egg parasitoids were *Tel.remus* and *Trichogramma chilonis* (Ishi) (Hym.: Trichogrammatidae) whereas the larval parasitoids were the ichneumonids, *Charops* sp. and *Coccygidium luteum* Brulle and the braconids, *Cotesia icipe* and *C.sesamiae* (Cameron). *T. remus* was the most abundant egg parasitoid with a relative abundance of 93.1% compared to *T.chelonis* (7.7%). The most abundant larval parasitoid was *C. icipe* (65%), followed by *Charops* sp. (24.8%), *C.sesamiae* (7.3%) and *C.luteum* (2.9%). Through a survey of natural enemies of fall armyworm in maize fields in Zambia during 2018 – 2020, Durocher-Granger *et al*. (2020) could collect 4373 larvae and 162 egg masses and found that parasitism rates in 4 locations varied between 8.45% and 33.11%. Twelve parasitoid species were obtained including 2 egg-larval parasitoids; *Chelonus bifoveolatus* Szepligiti (Hym.: Braconidae) and *Ch. curvimaculatus (*Camerom); 9 larval parasitoids; the braconids, *Cotesia luteum*, *C. icipe*, *Parapanteles* sp., the ichneumonids, *Charops* sp., *Diadegma* sp., *Pristomerus* sp., *Enicospilus capensis* Thunberg, *Euplectrus laphygmae* (Ferr.), *Drino quadrizonula* (Thompson) and the tachinid larval-pupal parasitoid, *Metopius discolor* Tosquinet. Two of the 3 most abundant species, *Ch. bifoveolatus* and *C.luteum*, were also the most frequent species collected from Ghana, Benin, Senegal and Tanzania (Agboyi *et al*., 2020; Koffi et al., 2020). The 3rd abundant species, *D.quadrizonula*, was found in low numbers on FAW in Ghana and Benin (Agboyi *et al*., 2020).

Sisay (2018) surveyed natural enemies of FAW in Ethiopia and found 3 larval parasitoids; the braconid, *Cotesia icipe* with parasitism ranged 33.8 – 45.3%; the tachinid, *Palexorista zonata* (Curran) with 4.65 parasitism and the ichneumonid, *Charops ater* Szepligeti with 4.6% parasitism. However, Sisay et al. (2018) recorded the tachinid, *P. zonata* in Kenya with 12.5% parasitism and both *Ch. ater* and *Coccygidium luteum* in Kenya and Tanzania with parasitism ranging from 6-12% and 4- 8.3%, respectively. Tefera *et al*. (2019) could obtain *T. chilonis* from eggs of FAW collected from maize fields in Kenya.

In Ghana, Koffi *et al*. (2020) carried out a survey for natural enemies of FAW in 10 regions in Ghana in 2017. Among parasitoids recorded, 5 were braconids; *Ch. bifoveolatus*, *C. luteum*, *C. icipe*, *Meteorus testacea* (Granger), *Bracon sp.* and 2 tachinids*; Antarichus erinaceus* Loew and an unidentified one. The two most abundant parasitoids were *Ch. bifoveolatus* and *C.luteum* with parasitism rates of 1.04% and 0.85%, respectively. However, Issa *et al*. (2021) stated that a survey in maize fields in Ghana during 2018 – 2019 showed 5 larval parasitoids of *S. frugiperda*; the braconids, *C. luteum*, *Chilonus* sp. and *Cotesia* sp.; the ichneomonid, *Campoletis sonorensis* (Cameron) and the tachinid, *Exorista* sp. *C.luteum* was the dominant parasitoid with rates of parasitism of 6.4 – 10.7% and rates of parasitism with the other parasitoids ranged from 2.6 – 3.5%. Agboyi *et al*. (2020) conducted a survey of parasitoids attacking FAW in Ghana and Benin in 2019. Ten parasitoid species were

obtained; 2 egg parasitoids (*Tel.remus* and *Trichogramma* sp.), an egg-larval parasitoid (*Ch. bifoveolatus*), and 4 larval parasitoids (*C. luteum, C. icipe, Charops sp.* and *Drino quadrizonula* and 2 larval-pupal parasitoids (*Metopius discolour* Tosq. (Ichneumonidae) and *Meteoridea testacea* (Granger) (Braconidae). Parasitism rates in 3 Ghanian regions ranged from 0 to 75% between sites and 5 – 38% between regions. Shen *et al.* (2023) obtained the egg-larval parasitoid, *Ch. bifoveolatus* from larvae of *S. frugiperda* in Zambia. Ahissou *et al.* (2021b), in Burkina Faso, could obtain 3 species of parasitoids attacking larvae of FAW in maize fields during 2019 – 2020. The parasitoids were *Ch. bifoveolatus, C. luteum* and *Drino* sp. Abd El-Mageed *et al*. (2021) indicated that 3 parasitoid species could be found to parasitize *S. frugiperda* larvae in maize fields in Aswan governorate, South of Egypt. The parasitoids were the braconid, *Microplitis* sp. and the tachinids, *Exorista sorbillans* (Wied.) and *Pseudogonia ruffifrons* (Wied.) Also, Youssif (2021) obtained 5 parasitoid species from larvae of *S. frugiperda* in Sohag and Quena governorates (South of Egypt). The parasitoids were the pteromalid, *Dinarmus basalis* (Rondani), the braconids, *Cotesia ruficrus* (Haliday), *Microplitis rufiventris* (Kok.) and *Chelonus intermedius* (Thompson) and the tachinid, *Exorista larvarum* (L.).

Otim *et al*. (2021) reported that a survey of the natural enemies of FAW in different maize fields in Uganda during 2017 – 2019 revealed the occurrence of 13 parasitoid species belonging to 3 hymenopteran families and 2 dipteran tachinids. The parasitoids were the braconids, *Ch. bifoveolatus, Coccygidium* sp., *Cotisia flavipes* Cameron, *C. icipe, Diolcogaster* sp., *Meteorus* sp., *Charops diversipes* Roman and the two tachinids, *Sturmiopsis parasitica (*Curran) and *D. quadrizonula.* The most abundant parasitoids were *Coccigidium* sp. and *C.bifoveolatus* with parasitism rates ranging from 3.1 – 50% in 2017 and 0.8 – 33% in 2019. In a survey of FAW natural enemies in maize fields in Nigeria, Ogunfunmilayo *et al*. (2021) could obtain the egg parasitoid, *Tel.remus* and the larval parasitoid, *Euplectrus laphygmae* Ferriere (Hym.: Eulophidae) and rate of parasitism by *Tel.remus* was 100%. In maize fields in Mozambique, Canico *et al*. (2020) could collect 101 egg masses and 1444 larvae of FAW during 2018 – 2020. No egg parasitoids could be secured from the egg masses whereas 5 larval parasitoids could be obtained and among them, *C. luteum* and *D. quadrizonula* were causing maximum parasitism of 23.68% and 8.86%, respectively. Tendeng *et al*. (2019) obtained 2 parasitoid species from larvae of FAW collected from maize fields in Senegal; the ichneumonid larval parasitoid, *Campoletes* sp. and the egg-larval parasitoid, *Chelonus* sp. The average rate of parasitism by the 2 species was 1.2 and 10.9%, respectively. Ebadi (2022), in Sudan, could obtain the tachinid larval-pupal parasitoid, *Archytas* sp. from pupae of FAW collected from maize fields.

Amadou *et al*. (2018) reported that a survey of parasitoids of FAW in maize and sorghum fields in Niger during 2017 and 2018 revealed the occurrence of 7 parasitoid species attacking eggs and larvae. The egg parasitoids were *Telenomus* sp., *Trichogramma* sp. and T*richogrammatoidea* sp.; the egg-larval parasitoid *Chelonus* sp. and the larval parasitoids, *Cotesia* sp., *Charops* sp. and unidentified tachinid parasitoid. Rates of parasitism ranged from 5 – 34% by *Telenomus* sp.; 0.0 – 0.1% by *Trichogramma* sp.; 0.0 – 0.9 by *Trichogrammatoedea* sp.; 0.0 – 0.5 by *Chelonus* sp.; 0.0 – 1% by *Cotesia* sp.; 0.0 – 0.25% by *Charops* sp. and 0.0 – 3.3% by the unidentified tachinid parasitoid. Surveys of parasitoids of fall armyworm in maize fields in Kenya, Tanzania, and Nepal revealed the occurrence of the egg parasitoids, *T. mwanzai* Schulten &Fiejen in Tanzania, *T. chilonis* Ishii in Kenya and Nepal, and *Tel.remus* in Kenya, Nepal and Tanzania (Elibariki *et al*. (2020). Kenis *et al*. (2019) reported that *Tel. remus* was found parasitizing FAW eggs collected from maize and sorghum fields during 2017 and 2018 in Benin, Cote d'Ivoire, Kenya, Niger and South Africa. Over 30 larval parasitoids of FAW have been recorded in 17 countries in Africa as stated by Kenis *et al*. (2022). The most common ones are the braconids, *Ch. bifoveolatus,*

Ch. curvimaculatus, C. luteum and *C. icipe*. In addition, the FAW eggs are attacked mainly by *Tel.remus* and *Trichogramma* spp.

b.Predators (Table 3):

Koffi *et al*. (2020), in Ghana, reported that three predator species were observed to associate with FAW in maize fields; Pheidole *megacephala* (F.) ((Hym.: Formicidae), *Haematochares obscuripennis* Stal *and Peprius nodiulipes* (Sigroret) (both are Hete.: Reduviidae). However, Issa et al. (2021) stated that the predators found in maize fields in Ghana were the coccinellids, *Coccinella transversalis* (F.) and *Harmonia octomaculata* (F.). Ahissou *et al*. (2021b), in Burkina Faso, could obtain 6 predatory insects associated with FAW in maize fields; the dermapteran forficulids, *Diaperasticus erythrocephalus* (Olivier) and *Forficula senegalensis* (Serville), the carabid, *Calleida* sp., the reduviid, *Rhynocoris* sp., the formicid, *Ph. megacephala* and the coccinelid, *Cheilomenes sulphurea* (Olivier). In a survey of FAW natural enemies in maize fields in Nigeria, Ogunfunmilayo *et al*. (2021) could obtain the predatory mite, *Trombidium* sp. (Acari: Trombidiidae). Ebadi (2022), in Sudan, recorded 8 species of predacious insects associated with *S.frogiperda* in maize fields. They were the coccinellids, *Coleomegilla maculata, Cycloneda sanguinea, Eriopis* sp., *Hyppodamia* sp. and the carabid, *Calosoma granulatus*); 2 hemipteran: *Geocoris* sp. (Lygaeidae) and *Podisus* sp. (Pentatomidae) and a dermapteran, *Doru* sp. (Forfoculidae).

B.The Recorded Entomophagous Insects of FAW in Asian Countries:

According to literature, the survey of natural enemies of *S. frugiperda* in Asia has been carried out in only 4 countries up till now; India, China, Nipal and Indonesia.

a.Parasitoids (Table 2):

Jindal *et al*. (2021) reported that FAW larvae were collected during 2019 and 2020 from maize crops in India but no parasitoids could be observed in 2019. However, 2 parasitoid species could be obtained during 2020: *Campoletis* sp. and *Chelonus formosonus* Sonan. Parasitism rates were found to be 21.92 and 16.33% by the two species, respectively. A survey of natural enemies of *S. frugiperda* in South India in 2018 revealed the occurrence of 5 larval parasitoids: *Coccogidium melleum, Eriborus* sp., *Odontepyris* sp., *Campoletis chlorideae* Uchida *and Exorista sorbillans.* The first 3 species were recorded for the first-time parasitizing *S. frugiperda.* The average parasitism by *C. chlorideae* was 2-3% whereas the other parasitoids showed negligible parasitism (Sharanabasappa *et al*. (2019).

A survey of the natural enemies complex in maize fields in North India showed 80.46% larval mortality of *S. frugiperda*. The egg-larval parasitoid, *Chelonus* nr. *blackburni* was the predominant parasitoid causing 49.24% larval mortality followed by *Ch. formosanus*. The survey also revealed the occurrence of the ichneumonid parasitoid, *Temeluca* sp. for the first time parasitizing FAW larvae in the fields (Sagar *et al*.,2022). A survey was conducted during 2019 – 2020 at different locations in Tamil Nadu (India) for the natural enemies of *S. frugiperda* in maize fields (Anandhi and Saminathan, 2021). They obtained 4 parasitoid species namely: *Peribeae* sp. (Dipt.:Tachinidae), *Euplectrus sp.* nr. *Xanthocephalus* Girault and *Temelucha* sp. (Ichneumonidae) and the braconid, *Microplitis domolitor* Wilkenson for the first time in Tamil Nadu.

Shylesha *et al*. (2018), in a survey of FAW natural enemies in India, could obtain the egg parasitoids, *Telenomus* sp. and *Trichogramma* sp.; the larval parasitoids, *Glyptapanteles creatonoti* (Vier.), *Campoletis chlorideae* Uchida and an unidentified ichneomonid larval-pupal parasitoid. The parasitoid *Coccygidium transcaspicum* (Kokujev) (Hymenoptera: Braconidae) was obtained from fall armyworm *S. frugiperda* in maize fields in South India in 2019. It was the first report of *C. transcaspicum* as a parasitoid of *S. frugiperda* across the globe as mentioned by Gupta *et al*. (2020). Mallapur *et al*. (2022) carried out a survey of natural enemies of *S. frugiperda* in different maize fields in India, during 2019 and 2020 and obtained 2 parasitoids, *Campoletes chloridae* and *Chelonus*

formosanus.

Liao *et al*. (2019), in China, reported that 36 egg masses of FAW were collected from maize fields in 3 sites in China in 2019 out of which 11 egg masses (30.6%) were found to be parasitized by *Tel. remus*. *Megaselia scalaris* Loew (Dipt.: Phoridae) was reported as a parasitoid of *S. frugiperda* larvae and pupae for the first time in China as reported by Tang *et al*. (2021.

In Indonesia, a survey of egg parasitoids of *S. frugiperda* was carried out in 3 different corn fields by placing 323 egg masses (8-h-old) of *S. frugiperda* on the plants for 24 h. The results showed that two egg parasitoids could be obtained, *Telenomus* sp. and *Trichogramma* sp. with percent parasitism ranging from 55.7–100% by *Telenomus* sp. and 0.0 - 44% by *Trichogramma* sp. (Wahyuningsih *et al*., 2022). Also, Supeno *et al*. (2021), in Indonesia, recorded 3 larval parasitoids on *S. frugiperda; Apanteles sp.* (Hym.: Braconidae), *Eriborus* sp. (Hym.: Ichneumonidae) and *Exorista* sp. (Dipt.: Tachinidae). The average total rate of parasitism by the 3 parasitoids was 2.16%. The levels of parasitoids dominance were 67% (Tachinidae), 22% (Braconidae) and 11% (Ichneumonidae).

b.Predators (Table 3):

Sharanabasappa *et al*. (2019) recorded 3 predator species associated with FAW in maize fields in South India in 2018. The predators were *Forficula* sp., *Harmonia octomaculata* and *Coccinella transvirsalis*. Shylesha *et al*. (2018) obtained the dermapteran predator, *Forficula* sp. associated with *S. frugiperda* in maize fields in Tamil Nadu. In addition, Shylesha and Sravika (2018) reported that nymphs and adults of *Eocanthecona furcellata* (Wolf) and *Andrallus spinidens* (Fabr.) (Hemiptera: Pentatomidae) were found to associate with *S. frugiperda* in maize fields in India. Also, Keerthy *et al*. (2020) reported *E.furcellata* as an important predator of *S.frugiperda* in maize fields in India. The pentatomids, *Arma chinesis* (Fallou) (Tang *et al*.,2019a) and *Picromorus lewisi* Scott (Tang *et al*., 2019b) were recorded as predators of *S. frugiperda* in maize fields in China. Also, Abbas *et al*. (2022), in China, reported the earwig, *Doru luteipes* (Scudder) as a predator of *S. frugiperda* in maize fields. Zeng *et al*. (2021) reported the anthocorid, *Orius similis* Zeng (Hem.: Anthocoridae) as a native predator of *S. frugiperda* in China.

C.Laboratory and Field Studies on Parasitoids and Predators of *S. frugiperda*:

In Zambia, Sun *et al*. (2021) reported that the efficiency of the egg parasitoids, *T. mwanzai* and *Trichogrammatoidea lutea*, emerged from eggs of FAW in Zambia as compared to 3 species of *Trichogramma* native to China under laboratory conditions. The 3 species were *T.ostriniae, T.leucaniae* and *T.japonicum*. The results showed that *Trichogrammatoidea* was the best performing on FAW eggs among the 5 species and caused the highest rate of parasitism. Mohamed *et al*. (2021), in Kenya, found that *C. icipe* females accepted the 1st instar than the and 2nd instar larvae of *S. frugiperda* with parasitism levels of more than 60%, followed by the 3rd instar, while the 4th instar was the least accepted for oviposition. The 5th and 6th instars and pupal stages were not accepted for oviposition. In Kenya, over 140.000 wasps of each of *Tel.remus* and *T. chilonis* that parasitize FAW eggs; and 5000 wasps of *C. icipe* that parasitizes early larval instars of FAW have been released in maize fields in 5 counties. The initial post-release assessments revealed that rates of parasitism in FAW in the fields increased by 55, 50 and 38% for *T. chilonis, Tel.remus* and *C. icipe* , respectively (Anonymous, 2021).

Three releases (of 15,000 individuals, each) of *Tel. remus* were applied in maize plots of 0.5 ha in the major and minor rainy seasons of 2020, and compared to non-release control plots as well as to insecticide-treated plots in Ghana (Agboyi *et al*. (2021). No parasitism in egg masses was observed before the first release. Parasitism in egg masses after release reached 33% in the release plot of the major rainy season compared to 72 – 100% in the minor rainy season and during which pest densities were much lower. However, no

significant differences in egg parasitism were found among the release plots, the no-release control plots and the insecticide-treated plots. Similarly, no significant decrease in larval numbers or plant damage was found between the 3 treatments as well as no significant differences in cob damage or yield were noticed among the 3 treatments. The authors claimed that the lack of any significant differences between the 3 treatments might be attributed to the parasitoid dispersal during the 5 weeks of observation. The authors also mentioned that *Tel. remus* is able to parasitize the whole egg mass of *S. frugiperda* whereas *Trichogramma* spp. tend to parasitize only part of the egg mass. This is due to that the egg masses often consist of several layers and the female moth covers egg masses with scales that provide a barrier for *Trichogramma* females but not to *Tel. remus.* Similarly, Laminou *et al*. (2020), in Niger, reported that the egg parasitoids, *Tel. remus* and *Trichogrammatoidea* sp. were assessed in the laboratory for parasitizing egg masses of FAW. *Tel.remus* parasitized an average of 75% of the eggs, compared to 25% for *Trichogrammatoidea* sp. *Tel.remus* was able to parasitize egg masses that were fully covered with scales while, *Trichogrammatoidea* sp. parasitized only uncovered egg masses. In addition, releases of *Tel.remus* in sorghum fields caused up to 64% parasitism in FAW eggs. In this respect, in Egypt, we have never obtained *Trichogramma* from thousands of egg masses (which are covered with scales) of the cotton leaf worm, *Spodoptera littoralis* (Boisd) collected from the fields. Interestingly, we could obtain *T.evanescens* from 4 egg masses of *S.littoralis* (uncovered with scales) collected from a sugar cane field adjacent to a cotton field (Personal information). *T.evanescens* is an efficient egg parasitoid of the sugar cane borer, *Chilo agamemnon* (Bles.) in Egypt.

Shen *et al*. (2023) obtained the egg-larval parasitoid, *Ch. bifoveolatus* from larvae of *S. frugiperda* in Zambia. The laboratory studies revealed that the female parasitoid could accept FAW eggs at 0.0, 1 and 2-day old and completed development successfully. The rates of parasitism, pupal rate and emergence rate for the parasitoid at the tested ages of eggs were higher than 90%, 75% and 82%, respectively. Sharanabasappa *et al*. (2021) reported *Megaselia scalaris* as a parasitoid of *S. fugiperda* for the first time in India. In the laboratory, the female was found to deposit the eggs on the 6th larval instar or the pre-pupa and the adults emerge from the pre-pupa or the pupa. Evaluation of the efficiency of the egg parasitoids *T. chilonis, T.dendrolimi* and *T.pretiosum* for the control of *S.frugiperda* in maize fields in China was carried out by Yang *et al*. (2022). Release of *Trichogramma* wasps was done in cages (2x2x2 m) containing 20-25 maize plants each. 100 FAW eggs and 100 wasps were released in each cage 5 times at about 8 days intervals and rates of parasitism were assessed 48 h post-release. The results showed rates of parasitism ranged from 10.6 – 24.5, 17.9 – 31.4 and 16.6 – 30.2% by *T. chilonis, T.dendrolimi* and *T.pretiosum,* respectively. However, there were no significant differences among the 5 releases. Also in Indonesia, Sari *et al*. (2020) exposed each of the egg masses of *S. frugiperda* to a mated female of *Tel.remus* in a tube for 24 h. The rates of parasitism averaged 69.4% (35/50 eggs), the survival rates of emerged adults averaged 60% and the % of females was 74%. Ghosh et al. (2022), in India, reported that 3 releases of the larval parasitoid, *Bracon brevicornis* (Wesm.) in maize fields at a rate of 4000 adults/ha at weekly intervals caused a 54% average reduction in infestation by *S. frugiperda*.

Varshney *et al*. (2021), in India, designed a biocontrol-based integrated pest management (IPM) strategy for FAW in the field in the spring and autumn seasons (2018-2019). This strategy comprised the installation of FAW pheromone traps, 4 releases of *Trichogramma pretiosum* Riley, 2 sprays of neem oil, one spray of each of *Bacillus thuringiensis* (NBAIR-Bt 25) and *Metarhizium anisopliae* (NBAIR-Ma 35). The results showed reductions of 76 and 71 % in egg masses and 80 and 74% in larval populations at 60 days after application in spring and autumn seasons, respectively. In addition, cob yield/acre

was higher compared to farmers` practice (6 – 7 sprays of emamectin benzoate 5% SG in spring and autumn seasons). Also, Muniappan (2023) suggested an IPM program for *S. frugiperda* in maize fields in South Asia that involved seed treatment by insecticides, the release of the egg parasitoids, *T. pretiosum and Tel. remus,* pheromone traps, and the release of the larval parasitoids, *Bracon hebetor* Say and *B. brevicornis*.

Shylesha and Sravika (2018) found that nymphs and adults of *Eocanthecona furcellata* (Wolf) and *Andrallus spinidens* (Fabr.) (Hemiptera: Pentatomidae) were found preying on *S. frugiperda* effectively in maize fields in India. The authors mentioned that both species are being reared for potential an IPM program of FAW. Keerthy *et al*. (2020), in India, reported that the adult of *E.furcellata* was capable of feeding on 126, 88 and 69 2nd, 4th and 6th larval instars of FAW in the laboratory during its lifetime in the laboratory. Also, Abbas *et al*. (2022), in China, reported the earwig, *Doru luteipes* (Scudder) as a predator of *S. frugiperda* in maize fields and both the nymph and adult were found to consume 8 – 12 and 10 – 21 *S. frugiperda* larvae daily, respectively, in the laboratory. Adults of *Orius similis* Zeng (Hem.: Anthocoridae) were found to prey on eggs and only 1st instar larvae of *S. frugiperda* in the laboratory. The maximum daily consumption of females was 23.7 eggs or 26.2 larvae whereas the male consumed 22.5 eggs or 19.6 larvae (Zeng *et al*., 2021). Li *et al*. (2021) reported that 2nd and 3rd instar larvae of *Eupeodes corolla* (Dipt.: Syrphidae) preyed on 1st and 2nd instar larvae of FAW consuming a maximum of 54.5 and 83.3 larvae, respectively, over 24 h period. Interestingly, once *Spodoptera* larvae reached 3rd instar, they exhibited aggressive behavior and equally preyed on surphid larvae. The 5th and 6th instar larvae consumed 16.4 – 19,2, 6.0 – 19.6 and 6.7-8.3 of 1st, 2nd and 3rd instar *E.corolla* larvae/day, respectively.

Conclusion

A total of 48 and 24 parasitoids as well as 17 and 11 predators have been recorded, so far, as entomophagous insects of *S. frugiperda* in Africa and Asia, respectively. These different species of parasitoids and predators attacking the developmental stages of *S. frugiperda* can have a considerable role in the IPM strategy against this pest.

Table 1: Parasitoids of *Spodoptera frugiperda* in African countries

Parasitoid species	Country	Reference
Egg parasitoids		
Telenomus remus	Cameron	Abang *et al*. (2020, 2021)
,, ,,	Kenya	Anonymous (2021),
,, ,,	Kenya	Kenis *et al*. (2019)
,, ,,	Benin	Agboyi *et al*. (2020)
,, ,,	Ghana	Agboyi *et al*. (2021)
,, ,,	Niger	Lamino *et al*. (2020)
,, ,,	Nigeria	Ogunfunmilayo *et al*. (2021)
,, ,,	Cote d'Ivoire	Kenis *et al.* (2022)
,, ,,	South Africa	,,
Trichogramma chilonis	Cameron	Abang *et al.* (2021)
,, ,,	Kenya	Anonymous (2021), Elibariki *et al.* (2020)
Trichogramma mwanzai	Zambia	Sun *et al.* (2021)
,, ,,	Tanzania	Elibariki *et al.* (2020)
Trichogramma sp.	Ghana	Agboyi *et al*. (2020)
,, ,,	Niger	Amadou *et al*. (2018)
,, ,,	Kenya	Kenis *et al*. (2022)
Trichogrammatoidea lutea	Zambia	Sun *et al.* (2021)
Trichogrammatoidea sp.	Niger	Laminou *et al.* (2020)
Egg-larval parasitoids		
Chelonus bifoveolatus	Zambia	Durocher – Granger *et al.* (2020)
,, ,,	Ghana	Koffi *et al.* (2020)
,, ,,	Benin & Senegal	Agboyi *et al*. (2020)
,, ,,	Uganda	Otim *et al.* (2021)
,, ,,	Burkina Faso	Ahissou *et al.* (2021 b)
Chelonus curvimaculatus	Zambia	Durocher – Granger *et al.* (2020)
Chelonus intermedius	Egypt	Youssif (2021)
Chelonus sp.	Ghana	Issa *et a*l. (2021)
,,	Senegal	Tending *et al.* (2012)
,,	Niger	Amadou *et al.* (2018)
Larval parasitoids		
Cotesia icipe	Cameron	Abang *et al.* (2020)
,, ,,	,,	Abang *et al.* (2021)
,, ,,	Ethiopia	Sisay *et al.* (2018)
,, ,,	Ghana	Koffi *et al.*(2020)
,, ,,	Ghana & Benin	Agboyi *et al*. (2020)
,, ,,	Uganda	Otim *et al.* (2021)
,, ,,	Zambia	Durocher – Granger *et al.* (2020)
,, ,,	Niger	Amadou *et al.* (2018)
,, ,,	Kenya	Mohamed *et al.* (2021)
Cotesia sesamiae	Cameron	Abang *et al.* (2021)
Cotesia ruficrus	Egypt	Youssif (2021)
Cotesia flavipes	Uganda	Otim *et al.* (2021)
Cotesia sp.	Ghana	Issa *et al.* (2021)
Charops diversipes	Uganda	Otim *et al.* (2021)
Charops ater	Ethiopia, Kenya & Tanzania	Sisay *et al.* (2018)
Charops sp.	Cameron	Abang *et al.* (2021)
Charops sp. ,,	Ghana & Benin Mozambiqe	Agboyi *et al.* (2020) Canico *et al*. (2020)
,, ,,	Zambia	Durocker – Granger *et al*. (2021)
,, ,,	Cameron	Abang *et al*. (2021)

,, ,,	Niger	Amadou *et al.* (2018)
Coccygidium luteum	Cameron	Abang *et al.* (2021)
,, ,,	Kenya	Sisay *et al.* (2018)
,, ,,	Tanzaina	Sisay *et al.* (2018)
,, ,,	Ghana	Koffi *et al.* (2020)
,, ,,	Benin	Agboyi *et al.* (2020)
,, ,,	Burkina Faso	Ahissou *et al*. (2021 b)
,, ,,	Mozambique	Canico *et al.* (2020)
,, ,,	Zambia	Durocher – Granger *et al.* (2020)
Coccygidium sp.	Uganda	Otim *et al.* (2021)
Plaexorista zonata	Kenya	Sisay *et al.* (2018)
,, ,,	Ethiopia	,, ,,
Meteorus testaeea	Ghana	Koffi *et al.* (2020)
Meteorus sp.	Uganda	Otim *et al.* (2021)
Bracon sp.	Ghana	Koffi *et al.* (2020)
Antarichus erinaceus	,,	,, ,,
Drino quadrizonula	Ghana & Benin	Agboyi *et al*. (2020)
,, ,,	Uganda	Otim *et al.* (2021)
,, ,,	Zambia	Durocher - Granger *et al.* (2020)
,, ,,	Mozambique	Canico *et al.* (2020)
Drino sp.	Burkina Faso	Ahissou *et al*. (2021 b)
Microplitis rufiventris	Egypt	Youssif (2021)
Microplitis sp.	Egypt	Abd Elmageed *et al.* (2021)
Exorista sorbillans	Egypt	,, ,,
Exorista larvarum	Egypt	Youssif (2021)
Exorista sp.	Ghana	Issa *et al*. (2021)
Pseudogonia ruffifrons	Egypt	Abd Elmageed *et al*. (2021)
Dinarmus basalis	Egypt	Youssif (2021)
Diolcogaster sp.	Uganda	Otim *et al.* (2021)
Campoletis sonorensis	Ghana	Issa *et al.* (2021)
Campoletis sp.	Senegal	Tending *et al.* (2019)
Sturmipsis parasitica	Uganda	Otim *et al*. (2021)
Euplectrus laphygmae	Nigeria	Ogunfunmilayo *et al*. (2021)
,, ,,	Zambia	Durocher – Granger *et al.* (2020)
Parapanteles sp.	,,	,, ,,
Diadegma sp.	,,	,, ,,
Pristomerus sp.	,,	,, ,,
Enicospilus capensis	,,	,, ,,
Larval – pupal parasitoids		
Meteoridea testacea	Ghana	Agboyi *et al.* (2020)
Metopius discolor	,,	,, ,,
,, ,, ,, ,,	Zambia Mozambique	Durocher – Granger *et al.* (2020) Canico *et al.* (2020)
Archytas sp.	Sudan	Ebadi (2022)
Pupal parasitoids		
Procerochasmias nigromaculatus	Cameron	Abang *et al.* (2020)

Table 2: Parasitoids of *Spodoptera frugiperda* in Asian countries

Parasitoid species	Country	Reference
Egg parasitoids		
Telenomus remus	Nipal	Elibariki *et al*. (2022)
,, ,,	Indonesia	Sari *et al*. (2020)
Telenomus sp.	,,	Wahyuningsih *et al*. (2022)
Trichogramma sp.	,,	,, ,,
Telenomus remus	China	Liao *et al*. (2019)
Trichogrumma pretiosum	,,	Yang *et al*. (2022)
T. chilonis	,,	,, ,,
T. dendrolimi	,,	,, ,,
Egg- larval parasitoids		
Chelonus formosonus	India	Jindal *et al*. (2021)
	,,	Sagar *et al*. (2022)
	,,	Mallapur *et al*. (2022)
Chelonus nr blackburni	,,	Sagar *et al*. (2022)
Larval parasitoids		
Campoletis sp.	India	Jindal *et al*. (2021)
Campoletis chlorideae	,,	Sharanabasappa *et al*. (2019)
,, ,,	,,	Shylesha *et al*. (2018)
,, ,,	,,	Mallapur *et al*. (2022)
Coccygidium melleum	,,	Sharanabasappa *et al*. (2019)
Coccygidium transcaspicum	,,	Gupta *et al*. (2020)
Eriborus sp.	,,	Sharanabasappa *et al*. (2019)
,,	Indonesia	Supeno *et al*. (2021)
Exorista sorbillans	India	Sharanabasappa *et al*. (2019)
Exorista sp.	Indonesia	Supeno *et al*. (2021)
Temeluca sp.	India	Sagar *et al*. (2022)
Temeluca sp.	,,	Anandhi and Saminathan (2021)
Euplectrus nr xanthocephalus	,,	,, ,,
Microplitis domolitor	,,	,, ,,
Peribiae sp.	,,	,, ,,
Bracon brevicornis	,,	Ghosh *et al*. (2022)
*Odontepyri*s sp.	India	Sharanabasappa *et al*. (2019)
Glyptapanteles creatonoti	,,	Shylesha *et al*. (2018)
Apanteles sp.	Indonesia	Supeno *et al*. (2021)
Megaselia scalaris	India	Sharanabasappa *et al*. (2019)
,, ,,	China	Tang *et al*. (2021)

Table 3: Predators associated with *Spodoptera frogiperda* in the fields in African and Asian countries

Predator species	Country	Reference
a- In Africa		
Pheidole megacephala	Ghana	Koffi *et al*. (2020)
Hematochares obscuripennis	,,	,, ,,
Perprius modiulipes	,,	,, ,,
Diaperasticus crythrocephalus	Burkina Faso	Ahissou *et al.* (2021 b)
Furficula senegalensis	,,	,, ,,
Callida sp.	,,	,, ,,
Cheilomenes sulphurea	,,	,, ,,
Coccinella transvirsalis	Ghana	Issa *et al*. (2021)
Harmonia octomaculata	,,	,, ,,
Coleomegilla maculata	Sudan	Abadi (2022)
Cycloreda sanguinea	,,	,, ,,
Eriopis sp.	,,	,, ,,
Hippodamia sp.	,,	,, ,,
Calosoma granulatus	,,	,, ,,
Geocoris sp.	,,	,, ,,
Podisus sp.	,,	,, ,,
Doru sp.	,,	,, ,,
b- In Asia		
Furficula sp.	India	Sharanabasappa *et al*. (2019)
Furficula sp.	,,	Shylesha *et al*. (2018)
Harmonia octomaculata	,,	Sharanabasappa *et al.* (2019)
Coccinella transvirsalis	,,	,, ,,
Eocanthecona furcellata	,,	Shylesha and Sravika (2018)
Andrallas spinidens	,,	,, ,,
Eupeodes corolla	China	Li *et al.* (2021)
Arma chinesis	,,	Tang *et al.* (2019 a)
Picromerus lewisi	,,	Tang *et al.* (2019 b)
Doru luteipes	,,	Abbas *et al*. (2022)
Orius similis	,,	Zeng *et al*. (2021)

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