Research Paper

Sustainable Management of Fall Armyworm, *Spodoptera frugiperda* (Lepidoptera: Noctuidae) in Maize Cultivation of Sri Lanka Through Local Natural Enemies

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Abstract

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) was first reported in Sri Lanka in 2018/19 *Maha* and caused a considerable foliage damage to the maize crop. A sustainable, ecologically, and economically viable, long-term solution adaptable to local conditions was sought to overcome the situation. Investigations were carried out to identify natural enemies and their potential for use in FAW management through their conservation and introductive/augmentative release comparing with conventional practices. An island-wide survey revealed that eight species of parasitoids and eleven species of insect predators, one species of frog and five species of birds were actively involved in suppressing of FAW population in maize crop in Sri Lanka. One Hymenoptera egg parasitoid, *Telenomus remus* which showed 80% parasitism and two unidentified species of Dipteran larval parasitoids, together showing 80% parasitism, belonging to Lonchaedae and Chloropidae were identified as the most prominent parasitoids of FAW. Several species of lady beetles and spiders, Staphilinid beetles, and ants were among the main predators of FAW. Farmer field demonstrations indicated that FAW damage of small scale maize cultivations (< 2 ha) could be successfully managed more profitably by implementing CBM without application of synthetic pesticides when compared with the practice of pesticide application. The main components of the proposed Community Biodiversity Management (CBM) practices include conservation of natural vegetation within the system, regular field scouting, supplementary introduction of egg parasitoid, *T. remus,* and application of a neem-based botanical insecticide only on early detected hot-spots of FAW.

Keywords: Conservation Management, Maize cultivation, Natural enemies

Introduction

The fall armyworm (FAW), *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) is a fast-spreading alien invasive pest having a broad range of hosts (Goergen *et al*., 2016). The pest was first reported in Sri Lanka during 2018/19 *Maha*, which is the main maize cultivation season of Sri Lanka. Maize is the second-largest cereal crop grown in Sri Lanka and its annual cultivation extent and production in 2018 were 70,895 ha and 270,041 mt respectively (Anon, 2019). The main districts of maize cultivation in descending order of cultivation extent are Anuradhapura, Monaragala, Ampara, and Badulla. The majority of maize farmers own 1-2 ha homeland; although in some areas, the cultivation extent exceeds 5-10 ha of the upland crop in the Dry zone. The crop was considered as a low input crop and farmers used to apply only chemical fertilizers with rare use of insecticides only to manage stem borers (Anon, 2015). However, the new pest caused a considerable foliage damage to the maize crop creating a panic situation among farmers, compelling them to apply insecticides. The use of insecticide in an inappropriate manner destabilized the prevailing stable maize agroecosystem by eliminating natural enemies, resulting in aggravation of the problem causing environmental and health hazards, and increased the cost of production affecting the farmer's economy. Therefore sustainable, environmentally safer, and economically viable management technologies adaptable to local conditions were required to overcome the problem. The use of parasitoids for conservation biological management (CBM) of FAW has previously been reported (Abang *et al*., 2021; Cave, 2000). Therefore, a research project was initiated in early 2019 focusing on the utilization of available natural enemies for the management of FAW in maize crops through conservation and activity enhancement.

Materials and Methods

Survey on natural enemies

An Island-wide survey was carried out during 2019-2020 to identify natural enemies of FAW. Egg masses and larvae of FAW were collected from non-pesticide sprayed maize fields most of which had been abandoned due to FAW damage. and they were separately reared in ventilated transparent insect rearing cages in the Entomology laboratory at Horticultural Crops Research and Development Institute (HORDI), Peradeniya, Sri Lanka. The larvae were fed with maize foliage and when pupated they were transferred to oviposition cages with potted maize seedlings for emerging adults to oviposit. Egg masses and larvae of FAW which failed to develop into the next stage within the stipulated time period were suspected to be parasitized and they were transferred to bigger ventilated plastic cages. After the adult parasitoids emerged, they were fed with diluted sugar solution (10%), water and various stages of host pest (FAW egg masses and larvae) to enable oviposition and feeding. The emerging adult parasitoids were used for identification and biological and multiplication studies. Mass rearing methodologies were attempted only for the most predominant parasitoids to

study their potential efficacy to be used in biological management of the pest. The FAW larvae emerged from the non-parasitized eggs were transferred back to the FAW culture. Representative samples of adult parasitoids preserved in 70% alcohol solution were send to Centre for Agriculture and Bioscience International (CABI), UK for their taxonomical identification, and reference specimens were deposited in the Entomology Museum, HORDI.

Mass production of egg parasitoid, *T. remus* on FAW eggs

All biological and mass production studies were conducted under prevailing room conditions (27-32 °C & 66-88 % RH) in the laboratory. One-day old egg masses of FAW were detached from the maize leaf and placed on egg card prepared by pasting a piece of maize leaf using gum arabica on to a piece of cardboard (6 × 3 cm). These FAW egg cards were exposed to adult egg parasitoids in a transparent plastic rearing cage (1 L) fixed with a screen for oviposition. After 24 h, the exposed egg cards were transferred to similar cages for the emergence of adults or stored in a refrigerator at 10 °C for up to 2 weeks prior to field release. Separate experiments were carried out to determine the appropriate age of FAW egg for oviposition of the parasitoid, developmental period of the parasitoid in FAW egg, adult life span under laboratory conditions and the optimum host egg density in relation to parasitoid density using different batches for replication.

Field release of egg parasitoid, *T. remus*

Transparent plastic bottles containing parasitized egg cards and emerging adults were transferred to maize fields and released by opening the lid and mounting egg cards on maize plants with the help of a cotton thread.

Effect of neem insecticides on FAW and on the egg parasitoid, *T. remus*

Preliminary evaluation of efficacy of neem insecticides was carried out in one-month old maize field of the Seed Certification Service, DOA, Gannoruwa, Peradeniya in the 2018/19 *Maha* season. The heavily infested field with FAW was divided into two plots (each 250 m^2) and initial FAW and parasitoid populations were estimated (FAO, 2018). One plot was sprayed two times with a registered and commercially available neem insecticide at the time of experiment (Azadirachtin 7.5 EC) at 4 mL L^{-1} concentration in one-week interval and the other plot was sprayed with DOA recommended insecticides, spinetoram 25 WG followed by chlorantraniliprol 20 SC. FAW population and their damage and the number of adult egg parasitoids and infested egg masses were estimated one week after each spray.

Studies on Conservation Biological Management (CBM) of FAW

The effectiveness of CBM on FAW in maize was evaluated in farmer fields in three main maize cultivating districts, Badulla, Monaragala, and Anuradhapura during 2019-2020 period. In each location, CBM practices were employed in one ha of maize field and its impact was compared with one ha of conventional field managed by farmers in the same *yaya*. The first CBM evaluation was conducted at Meegahakuwla in Badulla district with four replications in 2019 *Yala* season and the crop was

established in paddy fields after the *Maha* paddy harvest. The second and third evaluations were respectively carried out at Alayapaththuwa, Anuradhapura district with four replications and in Kenagallanda, Monaragala where the crops were established in uplands with two replications in 2019/20 *Maha* season. Evaluations were carried out by the research staff, HORDI with the participation of the extension staff of respective provincial DOAs and farmers. Farmers involved in CBM evaluations were encouraged to implement environmentally friendly cultivation practices throughout the cultivation period and advised not to use weedicides and insecticides. However, no restrictions were made on fertilizer application. They were given practical training on identification of different life stages of FAW, the damage they caused and on associated natural enemies (NEs) of the pest and conservation techniques which enhance the activities of the NEs. The main conservation techniques included the preservation of natural vegetation (flowering plants) in the surroundings which provide food and shelter for the inhabited NEs. This process had to be started before land clearing and farmers were advised not to control such weeds in the cropping area. Farmers were instructed to earthing up at top dressing to suppress competitive weeds at the young stage of the maize crop. They were instructed to make frequent field visits for scouting of FAW and associated NEs in their fields and carry out ecosystem analysis as a decision-making tool for action. Laboratory mass-reared egg parasitoid, *T. remus* was released in these demonstrations on 2-3 occasions at the rate of 1,500 - 2,000 adults ha^{-1}, firstly at the one-month-old crop stage and thereafter in two-week intervals (Plate 1). The early detected hot-spots of were treated with a registered, commercially available neem insecticide (Azadirachtin 1 EC) at 4 mL L^{-1} concentration which has been recommended by DOA for controlling a related species, *S. litura*. FAW population, their damage and the presence or absence of parasitoids and predators in 50 randomly selected maize plants were periodically recorded (FAO, 2018). Yield and other data were recorded from the respective farmers. Simultaneously, Similar data were also recorded in 1 ha of conventional field in the same area (*yaya*) for comparison. Means were compared using T-test using SAS computer software.

Results and Discussion

Survey on natural enemies

Eight (8) parasitoids, eleven (11) predators, and two (2) species of pathogens infested FAW were collected from maize fields (Table 1). Of them, the egg parasitoid, *Telenomus remus* Nixon (Hymenoptera: Platyastidae) which was collected from the SCS field, Gannoruwa (Plate 1 a & b) in late 2018/19 *Maha* contributed to 80-90 % parasitism of FAW eggs. However, this parasitoid could not be found in the major maize-growing dry zone districts. The survey also revealed that two species of dipteran parasitoids contributed to around 80% of parasitism of FAW larvae in unsprayed fields and they were available in maize fields throughout the country. However, their identity could be made only up to family level by CABI.

Plate 1a. *T. remus* infested FAW egg mass

Plate 1b. *T. remus* adult (enlarged)

Plate 2. Larval parasitoid Lonchaedae

Plate 3. Larval parasitoid Chloropidae

Plate 4. Remains of parasitized FAW larvae

Plate 5. Metarizium and NPV infested larvae

The smaller parasitoid (2 mm in length) had pink eyes (Plate 2) belonging to the Lonchaeidae contributed to around 70 % of the larval parasitism. Members of Family Lonchaeidae (lance flies) are reported to be an important pest of fruits especially of family Myrtaceae (Souza *et al*., 2019). However, this is the first report on some species of this family are shown to be efficient parasitoids of FAW larvae. The bigger species (3 mm in length) with a completely black body (Plate 3) belonged to family Chloropidae which showed only 10% larval parasitism. This family exhibits a large diversity in habitats and feeding types. It includes several important agricultural pests (fruit flies, gout flies), predators on egg masses of insects and spiders, as well as on scale insects and aphids, and ectoparasites of frogs (Nartshuk, 2014). A recent study indicated that *Anatrichus erinaceus* was a parasitoid of FAW in Ghana (Koffi *et al*., 2020). The present study shows that an unidentified species of Chloropida can be parasitic on the larvae of FAW in Sri Lanka. Observation of the remains of head capsules with dry residues of the body on maize foliage (Plate 4) was a characteristic sign of affected FAW larvae. Laboratory multiplication could not be achieved in both species. However, since they parasitized around 80% FAW larvae and occur naturally in sufficient numbers in most of pesticide free maize fields they could be considered as high potential candidates for CBM of FAW. In addition, a number of other larval parasitoids of FAW were also recorded in the survey (Table 1). *Paederus fuscipes* (Staphilinidae), *Ophionea nigrofaciata* (Carabidae), ants and spiders were the prominent predators (Table 2). Pathogenic microorganisms *Metarizium* spp. and NPV infested larvae were rarely observed (Plate 5).

Table 1. Parasitoids of fall armyworm, *S. frugiperda* collected from maize crop in survey

Location (District)	Number of parasitoids/50 plants (% parasitism)
Gannoruwa and Gampola (Kandy)	*Telenomus remus* (Platyastidae) 28 (85%), Lonchaedae 13 (70%), Cloropidae 4 (10%), *Microplitis manila* (Braconidae) 02 (1%), Tachinidae 12 (2%), *Campoletis flavicincta* (Ichneumonidae) 2 (0.05%), *Chelonus* spp. (Braconidae) 02 (0.04%),
Ambagaswewa and Medirigiriya (Polonnaruwa)	Lonchaedae 09 (65%), Cloropidae 02 (14%), *Microplitis manila* (Braconidae) 06 (2%),
Meegahakiula and Redeemaliyadda (Badulla)	Lonchaedae 07 (45%), Cloropidae 02 (15%), *Chelonus* spp. (Braconidae) 01 (0.01%), *Campoletis flavicincta* (Ichneumonidae) 01 (0.01%),
Alayapathtuwa, Galenbindunuwewa and Horowpathana (Anuradhapura)	Lonchaedae 13 (65%), Cloropidae 2 (04 %), Tachinidae 07 (03%)
Thenagallanda and Athimale (Monaragala)	Lonchaedae 07 (45%), Cloropidae 03 (21%), Tachinidae 02 (01%)
Bokkebedda, Lathugala (Ampara)	Lonchaedae 12 (43%), Cloropidae 01 (01 %),

Table 2. Predators of fall armyworm, *S. frugiperda* collected from maize crop in survey

Location (District)	Number of predators/50 plants)
Gannoruwa & Gampola (Kandy)	Spiders (19), *Paederus fuscipes* (Staphilinidae) (4), *Ophionea nigrofaciata* (Carabidae) (2), Lady Beetles (Coccinelidae) (11)
Ambagaswewa, Medirigiriya (Polonnaruwa)	Spiders (14), *Paederus fuscipes* (Staphilinidae) (7), Lady Beetles (Coccinelidae) (16), Ants (9), Dragon flies (Odonata) (4)
Meegahakiula & Redeemaliyadda (Badulla)	Spiders (29), *Ophionea nigrofaciata* (Carabidae) (13), Lady Beetles (Coccinelidae) (16), Ants (44), Dragon flies (Odonata) (6), Long legged flies (3), Staphilinidae (34), Tiger Beetles, (Cicindellidae) (7)
Alayapathtuwa, Galenbindunuwewa, Horowpathana (Anuradhapura)	Spiders (33), Lady beetles (24), Ants (37), Long legged flies (6), Staphilinidae (8), Ground beetles (8)
Thenagallanda & Athimale (Monaragala)	Spiders (23), Lady beetles (18), Ants (31), Staphilinidae (9) Frogs (5).
Bokkebedda, Lathugala (Ampara)	Spiders (21), Lady beetles (11), Ants (10), Long hone flies (3),

Mass Rearing of egg parasitoid, *T. remus*

Mass production of the egg parasitoid was successfully carried out under the laboratory on FAW eggs with 90-95% parasitisum rate. Adult egg parasitoids emerged in 8-10 days but a 1-2 weeks' delay in emergence was found under refrigeration at 10 °C.

Effect of neem insecticides on the egg parasitoid, *T. remus*

Comparative evaluation of insecticides (Neem and DOA recommended Spinetoram and Chlorantraniliprol) indicated that

the neem insecticide exerts no adverse effect on 80% parasitism whereas the two synthetic insecticides greatly reduced their population up to 10%.

Studies on Conservation Biological Management of FAW

Comparison of CBM demonstrations with conventional fields treated with insecticides in all three locations indicated that there was no significant difference ($p \leq 0.05$) in the number of egg masses, larvae, and damage of FAW between the two practices (Table 3). Conventional treatment involved two weedicide applications, for land clearing and for controlling under weed growth after crop establishment and 2-4 insecticide applications against FAW. There were no significant differences ($p \leq 0.05$) in yield at all three locations but cost of cultivation in two locations (Meegahakiula and Alayapaththuwa) was significantly lower ($p \leq 0.05$) in CBM fields when compared with conventional practices. As a result, CBM farmers obtained significantly higher ($p \leq 0.05$) profits than conventional farmers. Also, a significantly higher ($p \leq 0.05$) number of predator (spiders, Staphilinids and lady beetles) were observed in CBM demonstrations, than in conventional fields while, no significant differences ($p \leq 0.05$) were observed in the number of ants between the two practices. The soil inhabited behavior of ants which migrate to crop foliage for catching prey may reduce their potential contact with insecticides. The number of adult egg and larval parasitoids and number of parasitized FAW larvae were also significantly higher ($p \leq 0.05$) in CBM fields. However, no significant difference ($p \leq 0.05$) was observed between the two practices on the number of parasitized egg masses, probably due to the low number of egg masses recorded in sampling. *T. remus* has been reported in several counties of the Asian region and is used in the biological management of *Spodoptera* spp. particularly *S. litura* and *S. frugiperda* (Kenis *et al*., 2019; Cave, 2000; Laminou, *et al*., 2020). The present studies indicated that *T. remus* occurs naturally in the Kandy district of Sri Lanka and can be used effectively in the biological management of FAW.

Conclusions

A large number of parasitoids and predators actively contributed to suppress FAW in small-scale maize cultivations in Sri Lanka and pesticide applications significantly reduce their populations. One Hymenoptera egg parasitoid, *T. remus*, and two species of dipteran larval parasitoids (Lonchaeidae and Chlorapidae) were identified as predominant parasitoids. Farmer field demonstrations indicated that FAW damage in small scale maize cultivations (up to 2 ha) could be more profitably managed without synthetic pesticides by implementing CBM practices integrated with supplementary introduction of the egg parasitoid, *T. remus* and treatment of early detected hot-spots with neem-based botanical insecticides.

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Table 3. Comparison of conservation biological management (CBM) with conventional practice against fall army worm, *Spodoptera frugiperda* in small scale maize cultivations in Sri Lanka

Factor	Location								
	Meegahakiula, Badulla			Alayapaththuwa, Anuradhapura			Galketiyawa, Monaragala		
	Conservation	Conventional	P-value	Conservation	Conventional	P-value	Conservation	Conventional	P-value
FAW egg masses*	0.0	1.00±1.00	0.3559	0	1.00±0.71	0.1785	1.00±0.71	0	0.4226
FAW larvae*	5.00±1.73	1.75±1.03	0.1466	9.75±1.75	7.25±2.985	0.3890	7.00±3.535	6.364±3.182	0.7080
% Damaged plants	5.00±1.73	1.75±1.03	0.1460	14.00±1.825	14.25±5.72	0.8989	26.0±25.45	19.5±17.67	0.8727
Spiders*	33.25±7.43	3.50±1.32	0.0022	43.75±14	12.75±1.93	0.0344	28.50±12.82	3.00±1.414	0.0217
Staphilinids*	40.75±10.67	4.50±1.93	0.047	8.75±1.25	3.5±0.975	0.0144	1.5±1.41	1.0±2.12	0.8603
Lady beetles*	36.50±7.85	8.25±4.33	0.0148	24.00±3.11	6.25±1.65	0.0022	6.5±2.82	0.6±0.70	0.0420
Ants*	70.00±4.08	8.00±4.43	0.0663	37.50±8.83	27.25±4.80	0.2454	26.5±14.53	10.0±1.414	0.3527
Parasitized egg masses*	1.00	0	0.3559	0.25±0.25	0	0.3839	0	0	
Infested larvae*	6.50±0.50	0.75±0.75	0.0017	11.00±1.50	1.50±0.48	0.0119	4.0±2.657	0.5±0.107	0.0533
Egg parasitoid adults*	10±3.775	0	0.034	5.75±0.79	0.25±0.25	0.0541	4.5±2.12	0	0.0474
Larval parasitoid adults	27.5±6.65	14.25±6.14	0.0494	18.20±7.15	4.75±1.50	0.0153	18.485±6.22	9.899±3.31	0.0540
Yield kg ha^{-1}	3492±411.95	2973±52.85	0.1455	5987±898.95	4728±288.0	0.2267	4710±353.5	4,090±360.6	0.2126
Expenditure Rs ha^{-1}	85,895±4369.5	97,531±11935.5	0.2712	56,123±4,360	60,833±1,166.5	0.3431	41,000±1697	45150±2333	0.1789
Income Rs ha^{-1}	274,128±9,233	255,457±6,531	0.0039	229,831±13,817	176,683±14,947	0.0530	249,630±18738	215,445±19113	0.2126
Profit Rs ha^{-1}	188,233±6910	129,693±5,051	0.0001	171,081±22,446	113,350±10,180	0.0547	213,630±2750	187,595±2,032	0.05302

*Mean comparisons by T-test and Log transformed values of insect counts were used for analysis. * Values for 50 randomly selected maize plants*

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