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Diversity of parasitoids associated with fall armyworm *Spodoptera frugiperda* (J.E. Smith) in various maize ecosystems

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Abstract
The field experiment was carried out during *Kharif* and *Rabi* season of 2022-2023 at Agricultural and Horticultural Research Station, Bavikere, Keladi Shivappa Nayaka University of Agricultural and horticultural Sciences, Shivamogga, Karnataka, India. A total of 6 hymenopteran parasitoid species *viz*., *Campoletis chlorideae* Uchida, *Chelonus formosanus* Sonan, *Cotesia ruficrus* (Haliday), *Trichogramma chilonis* Ishii, *Telenomus* sp. and *Eurytoma* sp. representing 5 families and 6 subfamilies were recorded on fall armyworm from three different maize ecosystems. Among different ecosystems, both the number of families and species of hymenopteran parasitoids were found higher in organically grown maize than those found in other ecosystems. *Trichogramma chilonis* was dominant during *Kharif* season with a total relative frequency of 85.00% whereas, during *Rabi* season, *Telenomus* sp. was dominant with a total relative frequency of 60.50%. Organically cultivated maize had the highest diversity of parasitoids, followed by naturally grown and farmers' practice.

Keywords: Maize, fall armyworm, parasitoids, diversity, ecosystems

Introduction
Maize (*Zea mays* L.) is one of the utmost significant cereal crops in the global agriculture economy equally as food and fodder for man and animals, having a greater yield potential called as "Queen of cereals". It is being cultivated both in the tropical and subtropical climatic conditions of the world. Maize seeds are consumed as human food, as feed stuff for poultry birds and for cattle, and also used in production of starch, glucose and edible oil from industry. At present, the average yields of cereal grains are lower in India due to variety of factors, among which, the insect pests have been considered as one of the most important constraints. The fall armyworm, *Spodoptera frugiperda* (J.E. Smith) (Noctuidae: Lepidoptera) has become a serious pest on maize in India and elsewhere. The pest has been very recently reported on maize from Karnataka for the first time in India (Sharanabasappa *et al*., 2018) [9]. The rapid spread of this pest in Indian states and Asian countries is due to its efficient ability to travel and migrate long distances in short time. In general, about 66 percent of all successful biocontrol programmes have involved parasitoids which play an important role in regulating the population of their hosts through effective biological control (Halder *et al*., 2018) [5]. Till now, around 30-40 parasitoids on fall armyworm have been reported all over the world. Ichneumonoids and chalcidoids are major parasitic group reported on fall armyworm along with tachinid fly. Egg and larval stages are more prone to parasitism. Sharanabasappa *et al*. (2019) [11] recorded larval parasitoids *viz*., *Coccygidium melleum* (Roman), *Odontepyris* sp., and *Eriborus* sp. from Karnataka. In *Kharif* 2019, the activity of two egg parasitoids *viz*., *Trichogramma* sp. and *Telenomus remus* were recorded from Shivamogga and Davanagere districts of Karnataka (Sharanabasappa *et al*. 2020) [10]. Indiscriminate use of insecticides causes the loss of biodiversity of beneficial organisms. Recently, biodiversity in agricultural land has received growing attention because it plays a significant role in agro-ecosystem function. For example, beneficial organisms like parasitoids serve agro-ecosystem function by regulating pest populations. If the use of insecticides is to be reduced through Integrated Pest Management, then the consequent reduction in pest control has to be augmented in some way and no doubt, parasitoids are the best alternatives to pesticides. To aid this means of pest control, it is essential that the diversity of parasitoids needs to be studied (Daniel and Ramaraju, 2017) [1].

Present research study was conducted to know the diversity of parasitoids associated with fall armyworm, *S. frugiperda* in various maize ecosystems.

Materials and Methods

The present field experiment was carried out in maize ecosystems of naturally grown, organically grown and grown using farmers' practice with respect to pest management at Agricultural and Horticultural Research Station (AHRS), Bavikere, Keladi Shivappa Nayaka University of Agricultural and horticultural Sciences (KSNUAHS), Shivamogga, Karnataka, India (Fig. 2). Bavikere is situated in transition tract of southern Karnataka (Zone 7) at 75^0 51' E longitude and 13^0 42' N latitude with 667.51 m above MSL and annual rainfall of 1104.2 mm (Fig. 1). Maize (P 3304) crop was sown in *Kharif* and *Rabi* season of 2022-2023 in an area of 100 square meters with 60×30 cm for each ecosystem as mentioned above. For naturally grown maize ecosystem, neither plant protection measures nor nutrient application was taken up, while for farmers' practice, standard POP of UAS, Bangalore was followed. In case of organically grown maize, only FYM application and neem oil (Neemasol @ 5 ml/l of water) spray were taken. Different host stages (Egg, larva and pupa) were sampled randomly from 50 plants per ecosystem at fortnightly interval and reared for parasitoid emergence under laboratory condition. The emerged parasitoids were stored in 70% alcohol and morphologically identified and labelled. Data on species distribution and species richness were recorded and compared. Alpha diversity of individual site was calculated using the Simpson's Diversity Index (SDI) $D = \Sigma n(n-1)/N(N-1)$; where 'N' represents the total number of individuals of all species and 'n' is the total number of individuals of a particular species (Simpson, 1949) [13]. SDI is computed by deducting the Simpson's index value from one. The value ranges between 0 to 1, with 0 indicating no diversity and 1 indicating infinite diversity. The SDI considers both the relative abundance of each species and the total number of species present.

Fig 1: Study area (AHRS, Bavikere, Karnataka, India)

Fig 2: Different maize ecosystems

Results and Discussion

The current field study involved different maize ecosystems that were developed naturally, organically, and through farmers' practice during *Kharif* and *Rabi*, 2022-2023. A total of 6 hymenopteran parasitoid species were recorded on fall armyworm from different maize ecosystems which represent 5 families and 6 subfamilies. These six hymenopteran parasitoids representing 6 genera *viz*., *Campoletis chlorideae*, *Chelonus formosanus*, *Cotesia ruficrus*, *Trichogramma chilonis* and unidentified species of genera *Telenomus* and *Eurytoma* (Table 1) were documented on fall armyworm, each genera representing one species. Shylesha *et al*. (2018) [12], Gupta *et al*. (2020) [4] and Deshmukh *et al*. (2021) [2] also documented hymenopteran parasitoid species on fall armyworm in Karnataka, India.

The binary data of parasitoids in different ecosystems were given in Table 2. The two braconids *viz*., *Chelonus formosanus* and *Cotesia ruficrus* were collected during *Kharif* season only in organically grown maize and were absent during *Rabi* season, whereas, *Telenomus* sp. and *Eurytoma* sp. were collected during *Rabi* season in all the ecosystems and were absent *Kharif* season. However, *Campoletis chlorideae* and *Trichogramma chilonis* were present in both the seasons. Both the number of families and species of hymenopteran parasitoids found in organically grown maize were higher (5 and 6, respectively) which includes *Campoletis chlorideae*,

Chelonus formosanus, *Cotesia ruficrus*, *Trichogramma chilonis*, *Telenomus* sp. and *Eurytoma* sp. than those found in naturally grown and grown using farmers' practice (4 in each) which includes *Campoletis chlorideae*, *Trichogramma chilonis*, *Telenomus* sp. and *Eurytoma* sp. (Table 2). These results are in partial agreement with Daniel and Ramaraju (2017) [1] who reported the diversity of chalcidid parasitoids of three different rice ecosystems of Tamil Nadu, where the Cauvery delta zone was the most diverse and the high rainfall zone being the least. Similar results were recorded in coffee plantations of Aceh Tengah district, Indonesia (Husni *et al*., 2021) [6].

During *Kharif* season, in organically grown maize highest (4) number of parasitoid species *viz*., *Campoletis chlorideae*, *Trichogramma chilonis*, *Chelonus formosanus* and *Cotesia ruficrus* were recorded, followed by naturally grown (1 species, *Trichogramma chilonis*) and there were no record of any parasitoids from farmers' practice. Abundance wise also organically grown maize stood first with the total collection of 30 individuals, followed by naturally grown (10 individuals). During *Rabi* season, all the maize ecosystems equally represented four numbers of species *viz*., *Campoletis chlorideae*, *Trichogramma chilonis*, *Telenomus* sp. and *Eurytoma* sp. whereas, abundance wise organically grown maize stood first with the total collection of 125 individuals, followed by naturally grown and farmers' practice with 59 and 39 individuals, respectively. *Trichogramma chilonis* was dominant during *Kharif* season with a total relative frequency of 85.00%, followed by *Campoletis chlorideae* (10.00%) whereas, *Chelonus formosanus* and *Cotesia ruficrus* equally recorded a least total relative frequency of 2.50%. During *Rabi* season, *Telenomus* sp. was dominant with a total relative frequency of 60.50%, followed by *Trichogramma chilonis* (30.94%) and *Eurytoma* sp. (5.83%) whereas, *Campoletis chlorideae* recorded a least total relative frequency of 2.70% (Table 3). These findings partially corroborate those of Inclan *et al*. (2015) [7] who found higher abundance and species richness of tachinid parasitoids on organic than on conventional farms. Similarly, Dinesh *et al*. (2018) [14] who reported that organic rice ecosystem supported a greater diversity of birds and beneficial insects than the conventional one.

The Simpson's Diversity Index (SDI) was higher (0.35) in organically grown maize indicating higher diversity during *Kharif* season, followed by naturally grown (0.00) and farmers' practice (0.00). During *Rabi* season also, SDI of organically grown maize was higher (0.55), followed by naturally grown (0.54) and farmers' practice (0.50) (Fig. 3). These findings are in partial agreement with Gnanakumar *et al*. (2012) [3] who reported Simpson's diversity index of hymenopteran egg parasitoids was higher in organic ecosystem compared to conventional paddy ecosystem in Palakkad, Kerala. Similarly, the species evenness and heterogeneity of Simpson index for useful insects (predators, parasitoids, pollinators, and decomposers) were found higher in organic rice ecosystems (Ovawanda *et al*., 2016) [8].

Table 1: List of parasitoids associated with fall armyworm in maize

Sl. No.	Scientific position of the parasitoid	Host Stage
1	*Campoletis chlorideae* (Hymenoptera: Ichneumonidae)	Larva
2	*Chelonus formosanus* (Hymenoptera: Braconidae)	Egg-Larval
3	*Cotesia ruficrus* (Hymenoptera: Braconidae)	Larva
4	*Trichogramma chilonis* (Hymenoptera: Trichogrammatidae)	Egg
5	*Telenomus* sp. (Hymenoptera: Scelionidae)	Egg
6	*Eurytoma* sp. (Hymenoptera: Eurytomidae)	Larva

Table 2: Binary (presence/absence) data for fall armyworm parasitoids in maize ecosystems

Sl. No.	Family	Parasitoid	Naturally grown		Organically grown		Farmers' practice	
			Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
1	Ichneumonidae	*Campoletis chlorideae*	-	+	+	+	-	+
2	Braconidae	*Chelonus formosanus*	-	-	+	-	-	-
3	Braconidae	*Cotesia ruficrus*	-	-	+	-	-	-
4	Trichogrammatidae	*Trichogramma chilonis*	+	+	+	+	-	+
5	Scelionidae	*Telenomus* sp.	-	+	-	+	-	+
6	Eurytomidae	*Eurytoma* sp.	-	+	-	+	-	+

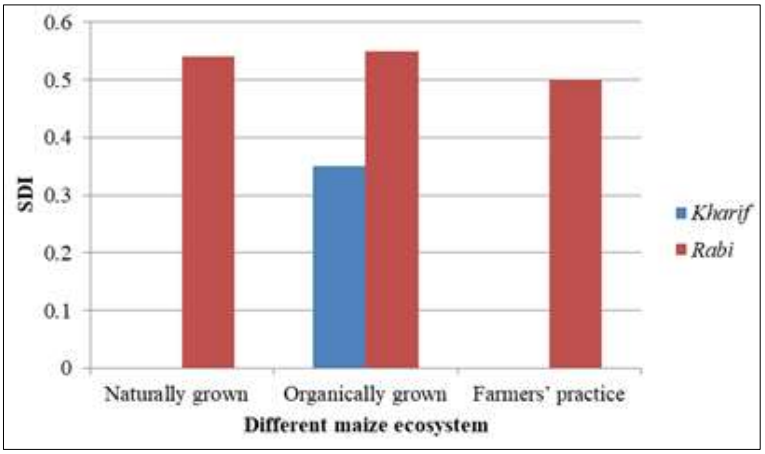

Fig 3: Alpha diversity indices for fall armyworm parasitoids in maize ecosystems

Table 3: Abundance, richness and relative frequency of parasitoids associated with fall armyworm in various maize ecosystems

Sl. No.	Parasitoid	Naturally grown		Organically grown		Farmers' practice		Total	
		Abundance	Relative Frequency (%)	Abundance	Relative Frequency (%)	Abundance	Relative Frequency (%)	Abundance	Relative Frequency (%)
***Kharif* season (2022-23)**									
1	*Campoletis chlorideae*	0	0.00	4	13.33	0	0.00	4	10.00
2	*Chelonus formosanus*	0	0.00	1	3.33	0	0.00	1	2.50
3	*Cotesia ruficrus*	0	0.00	1	3.33	0	0.00	1	2.50
4	*Trichogramma chilonis*	10	100.00	24	80.00	0	0.00	34	85.00
5	*Telenomus* sp.	0	0.00	0	0.00	0	0.00	0	0.00
6	*Eurytoma* sp.	0	0.00	0	0.00	0	0.00	0	0.00
	Total individuals	10		30		0		40	
	Species richness	1		4		0		4	
***Rabi* season (2022-23)**									
1	*Campoletis chlorideae*	1	1.70	3	2.40	2	5.12	6	2.70
2	*Chelonus formosanus*	0	0.00	0	0.00	0	0.00	0	0.00
3	*Cotesia ruficrus*	0	0.00	0	0.00	0	0.00	0	0.00
4	*Trichogramma chilonis*	16	27.11	43	34.40	10	25.64	69	30.94
5	*Telenomus* sp.	37	62.71	72	57.60	26	66.67	135	60.53
6	*Eurytoma* sp.	5	8.47	7	5.60	1	2.57	13	5.83
	Total individuals	59		125		39		223	
	Species richness	4		4		4		4	

Conclusions

During this study, it was concluded that parasitoids species diversity was more in organically grown maize (6) which includes *Campoletis chlorideae*, *Chelonus formosanus*, *Cotesia ruficrus*, *Trichogramma chilonis*, *Telenomus* sp. and *Eurytoma* sp., followed by naturally grown and farmers' practice (4 and 4, respectively) which includes *Campoletis chlorideae*, *Trichogramma chilonis*, *Telenomus* sp. and *Eurytoma* sp. A total of six parasitoids *viz*., *Campoletis chlorideae*, *Trichogramma chilonis*, *Chelonus formosanus*, *Cotesia ruficrus*, *Telenomus* sp. and *Eurytoma* sp. were recorded during the study period. The total relative frequency of *Trichogramma chilonis* was higher in *Kharif* (85.00%), followed by *Campoletis chlorideae* (10.00%) and during *Rabi*, *Telenomus* sp. was higher (60.53%), followed by *Trichogramma chilonis* (30.94%) and *Eurytoma* sp. (5.83%). Overall, the organically grown maize ecosystem increased species richness, abundance, and relative frequency of parasitoids on fall armyworm.

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