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Impact of the invasive pest, *Spodoptera frugiperda* (J.E. Smith) (Lepidoptera: Noctuidae) on the ecological niche of maize and sorghum stem borers.

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Abstract

The Fall Armyworm (FAW), originally native to the Americas, transformed into a devastating global pest following its invasion of Africa in 2016. This pest has since spread rapidly to regions such as Asia, the Middle East, and Oceania, resulting in substantial economic losses, particularly in maize production. *S. ferugiperda*'s strong migratory abilities, rapid reproduction rates, and preference for staple crops have exacerbated its impact. Before *S. ferugiperda*'s arrival, lepidopteran stem borers were the primary constraint on cereal crop production in Ethiopia, leading to significant yield losses. Both invasive species, like *S. ferugiperda*, and native pests compete for the same resources, particularly in cereal crops, including maize and sorghum. The interactions within these insect communities can shape the composition of pest complexes that attack crops and influence their natural enemies, which play a crucial role in pest population regulation. The effects of an invasive species such as *S. ferugiperda* on the abundance of resident stem borers are not well understood. To explore this issue, pest surveys were conducted following the *S. ferugiperda* invasion, focusing on sorghum and maize fields in fourteen Woredas across the central Rift Valley of Ethiopia during the main growing season. Data were meticulously collected at two critical growth stages: the vegetative and tassel initiation stages. The survey results indicated a significant decline in stem borer populations in both maize and sorghum crops after the invasion of *S. ferugiperda*. In addition, the infestation levels of stem borers were notably low in mixed maize and sorghum cropping systems throughout the surveyed areas. However, significantly higher populations of *S. ferugiperda* were recorded in all surveyed woredas. These findings raise important questions about the ecological dynamics between *S. ferugiperda* and stem borers, suggesting a potential displacement of stem borers to other cereal crops as they adapt to the changing pest landscape. This situation underscores the need for integrated pest management strategies that consider the evolving interactions between invasive pests and native species to safeguard cereal crop production in Ethiopia. Understanding these dynamics will be essential for developing effective agricultural practices and policies to mitigate the impact of both *S. ferugiperda* and stem borers in the future.

Keywords: *Spodoptera ferugiperda, Busseola fusca, Sesamia calamistis, Chilo partellus*

1. Introduction

Maize is one of the most widely grown crops, with good adaptability in various agro-climatic regions of Ethiopia. However, various stress factors hinder maize production, including insect pests. As many as 141 insect pests cause varying degrees of damage from sowing to harvest (Sigh et al. 2018; Reddy et al. 2008). Among the lepidopteran pests, spotted stem borer, *C. partellus*, pink stem borer (PSB), *Sesamia inferens*, oriental armyworm, *Mythimna separata*, maize cob borer, *Helicoverpa armigera*, maize leaf folder, *Marasmia trapezalis,* and tobacco caterpillar, *Spodoptera litura* are common in major maize-producing areas of the world, including Ethiopia (Reddy et al. 2008).

Almost ten years ago, an invasive polyphagous pest, *S. frugiperda*, was recorded for the first time in the southern parts of the country, and it has since invaded all maize- and sorghum-producing areas of Ethiopia. Before the report of *S. frugiperda on* maize in Ethiopia, the major lepidopteran pests infesting the crop were stem borers: *C. partellus, B. fusca, and S. calamistis,* which are native to the country. These pests are known to attack all the aerial parts of the maize plant, viz., leaf whorl, stem, tassel, and cob, and cause parallel rows of oblong holes on leaves and dead hearts by boring into the stem (Reddy *et al*.,2003; Baldhiya et al. 2018). Although considered a leaf-feeding insect, *S. frugiperda* is known to attack other parts of the maize plant, such as the whorl, tassel and earhead (Tippannavar et al. 2019). The major symptoms caused are shot holes, skeletonised leaves and heavily windowed whorls with frass, and boring into the cob (Goergen *et al.*, 2016; Prasanna *et al.*, 2018). The competition for resources and space is an obvious phenomenon among intraguild feeders. Maize stem borer is prevalent in Ethiopia and attacks maize and sorghum crops during the early stages of growth to harvest, infesting cobs as well. Similar to *S. frugiperda*, stem borers remain in the whorl up to the third instar before boring into the stem (Deole et al. 2018) and continue to occur in the cob, where all developmental stages of both species have to compete. Hence, *S. frugiperda* and stem borers have identical ecological niches, i.e., both species belong to the same guild, thus competing for the same resources such as leaf/ whorl, tassel, and cob. According to Gause's (1934) principles, no two species with similar ecological niches can coexist in a stable equilibrium, meaning that when two species compete for the same requirements, one will be slightly more efficient than the other and will reproduce at a higher rate as a result. The fate of the less efficient species is local extinction. Sokame et al. (2021) indicated that the introduction of *S. frugiperda* was significantly correlated with the reduction of the abundance of the resident communities of maize stem borers and parasitoids in maize fields; moreover, the decrease in stem borer density after the arrival of *S. frugiperda* occurred mostly at both reproductive and senescent maize stages. It also suggests a possible displacement of stem borers by *S. frugiperda* elsewhere,

for example, to other cereals. Similarly, Girma et al. (2021) indicated that infestation of stem borer started significantly declining in 2016, suggesting an early arrival of *S. frugiperda* in Uganda and indicating a possible displacement of stem borer from maize onto sorghum.

The present study involves an understanding of the relative incidence of different lepidopteran pests in maize and sorghum through a field survey to study intraguild competition and its effect on the survival and fitness of intraguild species, viz. *S. frugiperda*, *C. partellus, B. fusca,* and *S. calamistis*.

1.2. Specific Objective:

- To assess and determine the impacts of invasive exotic *S. frugiperda* on the maize and sorghum stem borer ecological niche.
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3. Materials and Methods

3.1. Description of the Study Areas

The survey was conducted in 14 major maize and sorghum growing districts located in three regional states (Oromia, Sidama, and Southern Nations, Nationalities, and Peoples (SNNP)) in the central Rift Valley of Ethiopia, encompassing seven zones (Fig.1). These zones include East Hararghe, featuring the districts of Deder and Babile; West Hararghe, which includes Miesso and Bordode; East Shoa with Meki (Dugda districts) and Adami Tulu Jido Kombolcha disricts; West Arsi, comprising Negele Arsi and Aje; Sidama, represented by Dore and Wendogenet; Wolaita, consisting of Damote and Humbo; and Gamo, which consists of Arbaminch Zuria and Mirab Abaya. These diverse areas exhibit both unimodal and bimodal rainfall patterns, resulting in annual precipitation ranging from 500 mm to 2800 mm. Additionally, the altitudes in these regions vary significantly, ranging from 1500 meters to 2800 meters above sea level. This variation in climate and geography plays a crucial role in shaping the agricultural practices and ecological dynamics of the regions, making the study essential for understanding local environmental conditions and their impacts on livelihoods.

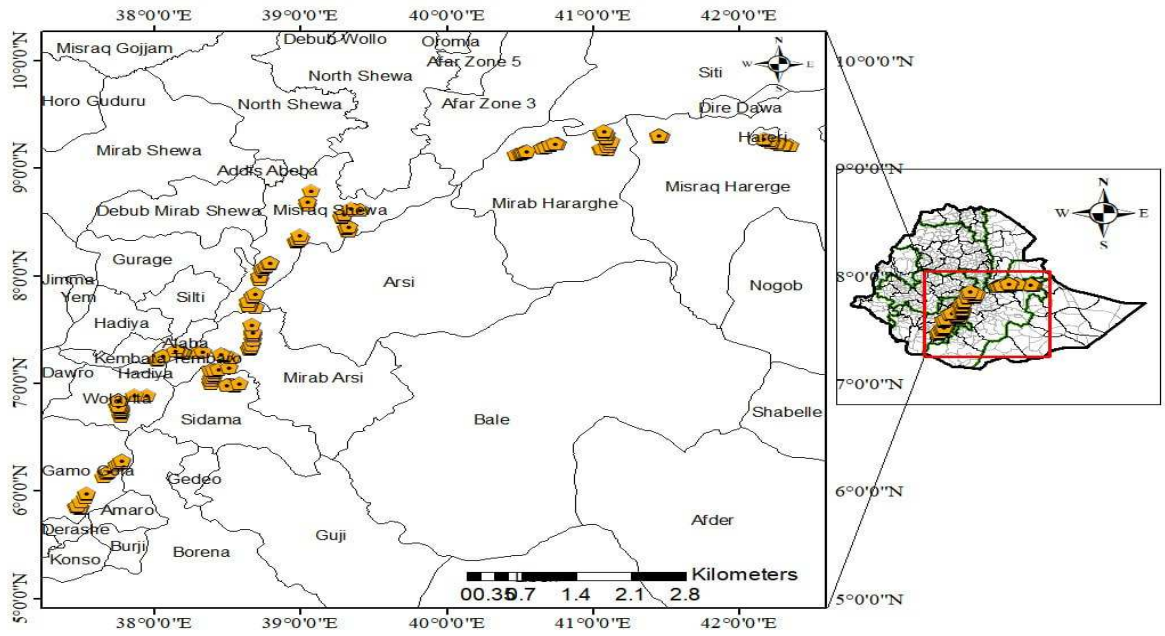


Figure 1. Surveyed areas in the central rift valley of Ethiopia

3.2. Sampling procedure and data collection

Seven major sorghum and maize-producing zones in Ethiopia were chosen purposively for the study: East Hararghe, West Hararghe, East Shoa, West Arsi, Sidama, Wolaita, and Gamo. In the East and West Hararghe zones, two districts were selected purposively from each zone. From each district, 20 farmers were chosen, comprising 10 who practised mixed maize and sorghum cropping, 5 who focused solely on sorghum, and 5 who cultivated only maize. For the East Shoa, West Arsi, Sidama, Wolaita, and Gamo zones, the approach was similar. Two districts were selected in each zone, followed by the selection of five villages randomly from each district. From each village, two farmers' fields were randomly selected, and within each field, four quadrants were randomly established, each measuring 12 square meters, for analysis.

Each quadrant contained four rows, and about 5 plants per row were selected. The location of the quadrants and scoring were fairly representative of the farm. Data were collected from four cell quadrants demarcated within a plot, each measuring 3 m × 4 m, where 20 plants were randomly selected per quadrant and examined for signs and symptoms of infestation by *S. frugiperda* and cereal stem borers. Signs and symptoms were used to distinguish infestation by *S. frugiperda* and cereal stem borers. *S. frugiperda* infestation was distinguished by the presence of larvae and whitish excrement as well as a leaf-feeding pattern. Infestation due to cereal stem borers is characterized by circular holes on the leaves and the absence of whitish,

sawdust-like excrement. Infestation by cereal stem borers and *S. frugiperda* was recorded as presence (1) and absence (0) without destructive sampling. Infestation scoring was conducted at 6 and 8 weeks after planting (WAP) by examining each of the 20 marked plants per quadrant for signs of injury during both inspections. The plants were examined for new signs of infestation by one of the two insect types (stem borers and *S. frugiperda*). The sampled plants were tagged during the initial data collection, and the second data collection was conducted using those tags.

S. frugiperda and stem borer damage severity was recorded at different stages of the plant based on the rating scale described by Davis et al. (1992) and Williams et al. (2007). The scale (1-9), 1= only pin-hole damage on leaves, 2 = pin-hole and shot hole damaged to leaf, 3 = small elongated lesions (5-10mm) on 1-3 leaves, 4 = mid-sized lesions (10-30mm) on 4-7 leaves, 5= large elongated lesions (>30mm) or small portions eaten on 3-5 leaves, 6 = elongated lesions (>30mm) and large portions eaten on 3-5 leaves, 7 = elongated lesions (>30cm) and 50% of leaf eaten, 8 = elongated lesions (30cm) and large portions eaten on 70% of leaves, 9 = most leaves with long lesions and complete defoliation was observed. Rating data were taken at an interval of 30 days, starting from 30 days after the emergency for each sampled plant. Leaf damage rating data were taken up to the flowering stage.

To identify the species of collected larval parasites, ten *S. frugiperda* and five stem borer larvae were collected from each participating farmer in the surveyed districts and brought to the laboratory. The *S. frugiperda* larvae were fed fresh maize leaves, sourced in accordance with their age, while young fresh sorghum and maize stalks were provided to the maize stem borers every 24 hours until the larvae pupated. Observations for parasitoids were conducted every 12 hours, at 7 AM and 5 PM.

To assess the number of holes and tunnel lengths, five stalks were examined, each from maize and sorghum plants collected from 10 farmers in each district. The number of existing holes was counted on each stalk and subsequently dissected using sickles and knives. The tunnel lengths observed were measured with rulers. In addition, questionnaires were developed to understand the farmers' perception of *S. frugiperda* and stem borers in the surveyed areas.

3.3. Statistical analysis

The binary data on presence (1) and absence (0) of infestation of *S. frugiperda* and stem borers were analyzed using a generalized linear mixed model (GLMM) with a random intercept, assuming a binomial error distribution to evaluate the effect of crop (maize and sorghum) on the presence/absence of infestation of maize stem borers (MSB) and *S. frugiperda*, respectively. The GLMM was fitted using the lme4 package (Bates et al. 2015). The sampling date and crop were used as fixed factors, while the quadrant and plant were random factors. The significance of the fixed factors was determined using the Satterthwaite approximation, as implemented in the R library lmerTest (Kuznetsova et al. 2017). Where significant differences were obtained, pairwise comparisons were made using the least-squares means and the adjusted Tukey multiple-comparison procedure ($\alpha = 0.05$) in the ls-means and Multcomp packages, respectively. All statistical analyses were carried out using SPSS software.

4. Results

4.1. Effects of *S. frugiperda* and stem borer interaction on infestation and damage level in sorghum and maize mixed cropping systems in selected districts of East and West Hararghe, Ethiopia.

The number of egg colonies, the number of larvae, and damage scales of *S. ferugiperda* were recorded in mixed maize cropping systems, and the results depicted that significantly higher numbers ($P < 0.05$) of egg colonies and larvae were recorded in mixed maize across all selected districts. In comparison, significantly ($P < 0.05$) lower numbers of *S. frugiperda* were recorded in mixed sorghum in all selected districts. Regarding damage severity, the highest damage scale values were recorded in mixed maize at Miesso, followed by the mixed maize systems of the other districts (Table 1).

Similarly, stem borer infestation percentages were evaluated in both mixed sorghum and maize across the selected districts, and the results showed that the highest stem borer infestation levels were recorded in mixed sorghum at Deder, followed by mixed sorghum in Babile, Miesso, and Bordode. In contrast, mixed maize across all selected districts showed significantly lower stem borer infestation levels ($P < 0.05$). Egg-colonies and larval counts for stem borers were significantly higher ($P < 0.05$) in mixed sorghum cropping systems across all selected districts of East and West Hararghe, whereas minimal values were recorded in mixed maize cropping systems. Damage scale assessments similarly indicated significantly greater ($P < 0.05$) damage in mixed sorghum cropping systems compared with mixed maize cropping systems (Table 1).

Table 1. Impacts of *S. frugiperda* and stem borer interaction on percentages of infestation and damage level in sorghum and maize mixed cropping systems of selected districts of East and West Hararghe zones during the rainy season of 2024, Ethiopia.

No	Districts (Cropping system)	Percentage of infestation by *S. frugiperda*	Number of *S. frugiperda* egg colonies recorded	Number of *S. frugiperda* larvae recorded	*S. frugiperda* damage score (0-9)	Percentage of infestation by SB	Number of SB egg colonies recorded	Number of SB larvae recorded	SB damage score (0-9)
1	Deder (MS)	9.26 ± 1.02cd	1.84 ± 0.90d	9.25 ± 2.51d	3.16± 0.10bc	40.57± 2.19a	2.13± 0.68bc	18.4 ± 3.71b	4.76± 0.12a
2	Deder (MM)	42.86 ± 2.20b	6.40 ± 1.59bc	49.28 ± 2.88b	3.78± 0.13b	5.43± 1.64d	0.34± 0.34cd	4.00 ± 1.78 c	1.41± 0.28e
3	Babile (MS)	7.57 ± 1.27cd	2.10 ± 0.74d	14.88 ± 2.75d	2.21± 0.20bc	21.57± 0.98c	3.54± 0.91ab	31.20± 4.63a	3.22 ± 0.13b
4	Babile (MM)	39.61 ± 2.86b	9.54 ± 0.91a	45.44 ± 3.20b	3.81± 0.13b	1.90± 0.89de	0.00± 0.00d	4.00 ± 2.52c	0.43± 0.23f
5	Miesso (MS)	11.70 ± 0.57c	3.91 ± 0.89cd	24.34 ± 2.49c	2.87± 0.22bc	26.20± 1.07b	4.64± 1.70a	35.20± 4.96a	1.95± 0.13d
6	Miesso (MM)	53.98 ± 2.41a	7.57 ± 0.84ab	68.21 ± 2.61a	6.78± 2.71a	1.67± 1.20de	0.00± 0.00d	2.40 ± 1.60c	0.39± 0.24f
7	Bordode (MS)	5.99 ± 1.29d	1.76 ± 0.49d	15.76 ± 2.49d	0.91± 0.27c	23.43± 2.58bc	2.29± 0.34bc	32.80± 5.27b	2.50± 0.24c
8	Bordode (MM)	40.27 ± 0.69b	6.61 ± 1.03abc	43.00 ± 1.32b	3.31± 0.11bc	0.00 ± 0.00e	0.00 ± 0.00 d	0.00± 0.00c	0.00± 0.00f
LSD		4.84	3.01	7.58	2.82	4.19	2.02	10.45	0.49

Key: Means followed by the same letter in the column are not significantly different (P<0.05).**MS**: Mixed sorghum, **MM**: Mixed maize, **FAW**: fall armyworm or *S. frugiperda,* **SB**: stem borer

4.2. Impact of *S. frugiperda* and stem borers interaction on infestation and damage level in sole sorghum and maize cropping systems in selected districts of East and West Hararghe, Ethiopia.

Although *S. frugiperda* infestation percentages were significantly higher in sole-maize than in sole-sorghum fields in Babile, Miesso, and Bordode, rates in Deder were nearly identical between the two crops, showing no significant difference. Within sole-sorghum fields*, S. frugiperda* infestation was the highest in Miesso, followed by Babile and Bordode (Table 2).

In addition, the number of egg colonies of *S. ferugiperda* was generally high across districts; although differences were mostly non-significant (P < 0.05), lower egg-colony counts were recorded in sole sorghum at Deder. *S. ferugiperda* larval counts were recorded for both sole maize and sole sorghum: significantly higher numbers were found in Deder and Babile in sole maize, and in Miesso in sole sorghum, with other districts showing lower counts in their respective cropping systems. *S. ferugiperda* damage scales, assessed in both sole maize and sole sorghum, showed

significantly more serious damage in Deder (sole maize) and Babile (sole sorghum), whereas the remaining districts' cropping systems exhibited significantly lower damage scales (Table 2).

Furthermore, the percentage infestation of stem borers assessed in both sole maize and sole sorghum cropping systems in the selected districts of East and West Hararghe also indicated that significantly higher stem borer infestations ($P < 0.05$) in sole sorghum at Deder and Babile, followed by Miesso and Bordode. In general, the percentage of stem borer infestation was significantly lower in sole maize compared to sole sorghum. Besides, counts of stem borer egg colonies and larvae showed significantly higher values at Babile, Miesso, and Bordode in sole sorghum cropping systems, followed by Deder's sole sorghum. Stem borer damage scales, evaluated in both sole sorghum and sole maize across the selected districts, were the highest in sole sorghum at all selected districts, followed by sole maize (Table 2)

Table 2. Impacts of the interaction between *S. frugiperda* and stem borers on infestation rate and damage levels in sole sorghum and maize cropping systems in selected districts of East and West Hararghe zones during the rainy season of 2024, Ethiopia.

No	Districts (Cropping system)	Percentage of infestation by *S. frugiperda*	Number of *S. frugiperda* egg colonies counted	Number of *S. frugiperda* larvae counted	*S. frugiperda* damage score (0-9)	Percentage of infestation by SB	Number of SB egg colonies counted	Number of SB larvae recorded	SB damage score (0-9)
1	Deder (SS)	32.93± 1.32e	4.37 ± 0.83c	49.80 ± 2.48bc	3.00 ± 0.25cd	16.40± 1.81a	0.80± 0.53c	25.60± 2.03ab	2.34± 0.12a
2	Deder (SM)	28.49± 2.720e	4.67 ± 1.46bc	63.07 ± 6.33a	4.56 ± 0.36a	4.11 ± 0.58c	0.26± 0.26c	1.60 ± 0.97c	0.80± 0.28b
3	Babile (SS)	46.74± 2.13c	7.57 ± 1.29ab	49.70 ± 1.24bc	4.11± 0.05ab	13.87± 1.69a	4.90± 0.65a	32.80± 6.37a	1.87 ± 0.13a
4	Babile (SM)	69.36 ± 1.83a	8.52 ± 1.27a	64.26 ± 3.95a	3.31± 0.25cd	2.88 ± 1.16c	0.63± 0.32c	6.64 ± 2.40c	0.95± 0.23b
5	Miesso (SS)	50.20± 1.76c	6.89 ± 0.52ab	52.79 ± 5.35ab	3.67± 0.19bc	5.53 ± 0.35c	2.76± 0.56b	21.60± 1.60b	1.84± 0.13a
6	Miesso (SM)	58.09± 1.67b	6.62 ± 1.24ab	46.90 ± 4.59bc	2.85± 0.32d	4.88± 0.29c	0.72 ± 0.44c	2.60 ± 0.50c	1.03± 0.24b
7	Bordode (SS)	38.17± 0.76d	9.46 ± 0.87a	49.28 ± 3.97bc	3.01± 0.13cd	10.73± 0.44b	2.88± 0.51b	19.20± 4.96b	1.81± 0.24a
8	Bordode (SM)	49.27± 2.07c	7.35 ± 0.73ab	38.68 ± 3.05c	3.25± 0.13cd	5.90 ± 1.17c	2.35 ± 0.19b	21.60± 0.97c	1.66± 0.00a
LSD		5.15	2.93	12.14	0.69	4.19	1.37	9.04	0.62

Key: Means followed by the same letter in the column are not significantly different (P<0.05). SS: Sole sorghum, SM: Sole maize, FAW: fall armyworm, SB: stem borer

4.3. Effects of *S. frugiperda* and Stem borer interaction on infestation and damage level in the sole maize cropping system of selected districts of East Shoa, West Arsi, Sidama, Wolaita and Gamo zones, Ethiopia.

In addition, the survey results indicated that significantly (P<0.05) higher numbers of egg colonies, larvae, and damage scale were recorded for *S. frugiperda* than for the stem borer. Furthermore, *S. frugiperda* infestations varied among districts, with significantly higher levels observed in Damote, Mirab Abaya, and Arbaminch Zuria than the other districts (Table 3). Besides, the infestations of stem borer were evaluated in all the surveyed districts by comparing them with *S. frugiperda*, and the results indicated that significantly lower values (P < 0.05) were observed in all districts. In addition, the infestations of stem borer in some districts were recorded as nil, and extremely low values were observed (Table 3).

Table 3. Impacts of *S. frugiperda* and stem borer interaction (Mean ± SE) on damage and infestation level in the sole maize cropping system across selected districts of the central and southern parts of Ethiopia during the rainy season of 2024**.**

No	Districts	Percentage of infestation by *S. frugiperda*	Number of *S. frugiperda* egg colonies recorded	Number of *S. frugiperda* larvae recorded	*S. frugiperda* damage score (0-9)	Percentage of infestation by SB	Number of SB egg colonies recorded	Number of SB larvae recorded	SB damage score (0-9)
1	Meki (SM)	52.73 ± 1.34e	10.06 ± 0.75de	47.93 ± 1.96ef	3.19 ± 0.22ef	6.31 ± 1.78b	4.28± 0.57b	8.80± 3.25cd	1.12± 0.33b
2	Jido kombolch (SM)	43.38 ± 1.35f	7.46 ± 0.39f	28.05 ± 1.91g	3.25 ± 0.17ef	4.65 ± 0.71bc	1.46± 0.47c	5.60 ± 2.16d	0.66± 0.15cd
3	Negele Arsi (SM)	47.40± 1.28f	15.99 ± 0.98ab	77.43 ± 2.98c	3.71± 0.11cd	9.42 ± 0.56a	5.65 ± 0.76a	32.80± 2.96a	2.02 ± 0.17a
4	Aje (SM)	58.84± 1.72d	12.22 ± 0.93cd	58.85 ± 4.99de	3.59± 0.12de	9.05 ± 0.83b	3.74± 0.58b	16.80 ± 3.71b	1.75± 0.14a
5	Dore (SM)	47.05± 2.31f	12.09 ± 1.42cd	58.68 ± 5.08de	3.75± 0.13cd	2.99 ± 1.01c	1.35± 0.48c	10.00± 2.40bcd	0.82± 0.19bc
6	Wondo genet SM)	34.23± 1.62g	8.00 ± 1.01ef	48.96 ± 3.39ef	2.90± 0.14f	0.00 ± 0.00d	0.00 ± 0.00d	12.80± 2.96bcd	0.00± 0.00e
7	Damote (SM)	84.47± 1.66 a	17.84 ± 0.84a	119.58 ± 7.01a	5.40± 0.13a	0.43 ± 0.29d	0.00± 0.00d	15.60± 3.39bc	0.07± 0.67e
8	Humbo (SM)	72.40± 1.59b	13.61 ± 0.88bc	100.04 ± 5.24b	4.91± 0.21b	0.00 ± 0.00d	0.00 ± 0.00d	17.20± 1.89b	0.00± 0.00a
9	Arbaminch Zuria (SM)	64.83 ± 0.85c	9.25 ± 0.86ef	65.52 ± 2.44 d	4.06 ± 0.12c	0.67 ± 0.37d	0.00 ± 0.00d	6.80 ± 1.69d	0.33 ± 0.11de
10	Mirab Abaya (SM)	67.72 ± 1.78b	10.00 ± 0.59de	42.92 ± 1.68f	3.89 ± 0.17cd	0.00 ± 0.00d	0.00 ± 0.00d	7.20 ± 2.13d	0.00 ± 0.00d
LSD		4.55	2.56	11.36	0.44	1.98	1.18	7.67	0.39

Key: Means followed by the same letter in the column are not significantly different (*P*<0.05). **SS**: Sole sorghum. **SM**: sole maize, **FAW**: fall armyworm, **SB**: stem borer

4.4. Parasitoid species recorded in surveyed districts of the eastern, central and southern Ethiopia

A diverse assemblage of parasitoid species was recovered from larval samples collected across the surveyed woredas, reflecting both spatial variation in parasitoid communities and broad host-parasitoid interactions within the agricultural landscape. To ensure representative sampling, larvae were collected from multiple fields and crop types at each district during different crop growth stages; these standardized collection protocols increased confidence that the observed parasitoid diversity reflects true field patterns rather than sampling bias.

Overall, both the numerical abundance of parasitoids and the proportion of larvae found to be parasitised were substantially higher in *S. frugiperda* larvae than in the stem borer larvae. This pattern likely reflects a combination of biological and ecological factors: *S. frugiperda* is highly abundant and mobile, providing a plentiful and predictable host resource; its feeding behaviour and exposed feeding sites on leaves may also increase encounter rates with searching parasitoids; and some parasitoid species may preferentially attack *S. frugiperda* because of host suitability for larval development. The greater parasitism of *S. frugiperda* suggests that natural enemies are already exerting measurable regulatory pressure on this invasive pest in the study area, although the observed parasitism levels alone are unlikely to suppress outbreaks without integration with other management tactics. Across nearly all surveyed locations, dipteran parasitoids, principally tachinid flies, dominated the parasitoid assemblage in both frequency and absolute numbers. Tachinids were recorded from a wide range of habitats and host plants, and their prevalence likely stems from life-history traits such as broad host ranges, effective host-searching behaviour, and the production of numerous mobile larvae or eggs that can encounter hosts in exposed feeding sites (Table 4 and Fig. 1).

Among hymenopteran parasitoids, the braconid *Cotesia marginiventris* was consistently the second-most abundant species. Found across districts and host plants, its moderate-to-high occurrence suggests it is an important larval parasitoid (specialist or generalist) that can help suppress lepidopteran pests, especially where tachinids are less active or when host densities favour hymenopteran attack. In contrast, *Chelonus bifoveolatus* (Braconidae: Cheloninae), an egg-larval parasitoid, was the least frequently encountered (Table 4). In addition, the percentage of parasitism was also evaluated for both stem borer and *S. ferugiperda*, and the results showed that significantly ($P<0.05$) it was higher in *S ferugiperda* than the stem borer (Fig. 1).

Table 4. Parasitoids recorded on *S. frugiperda* and stem borer larvae species across selected districts of eastern, central and southern parts of Ethiopia, during the rainy season of 2024.

Maize and sorghum pests	Parasitoid species	Surveyed districts													
		Meki	Aje	Babile	Jido Kombolcha	Deder	Bordode	Arbaminch zuria	Mirab Abaya	Miesso	Negele Arsi	Dore	Damote	Humbo	Wondogenet
Spodoptera ferugiperda	*Diptera (Tachinids)*	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Cotesia marginiventris (Cresson)	x	x	x	x	x	x	x	x	x	x	x	x	x	x
	Chelonus bifoveolatus (Cameron) *(%)*	x			x	x	x	x	x	x		x	x	x	x
Busseola fusca	*Diptera (Tachinids)*	x	x	x	x	x	x	x			x				
	Cotesia marginiventris (Cresson)	x				x			x		x	x	x	x	x
	Chelonus bifoveolatus (Cameron) *(%)*			x									x		
Chilo partellus	*Diptera (Tachinids)*	x	x		x	x	x	x		x				x	
	Cotesia marginiventris (Cresson)	x			x	x		x		x	x		x	x	
	Chelonus bifoveolatus (Cameron) *(%)*					x									
Sesamia calamistis	*Diptera (Tachinids)*	x					x		x	x			x		
	Cotesia marginiventris (Cresson)	x	x			x		x			x			x	x
	Chelonus bifoveolatus (Cameron) (%)							x					x		

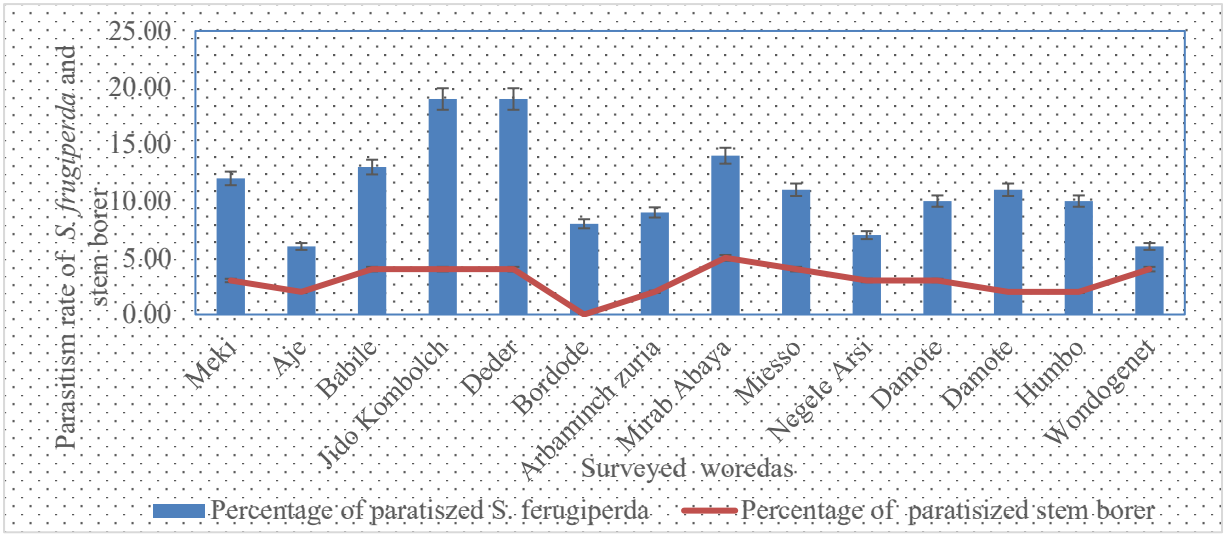
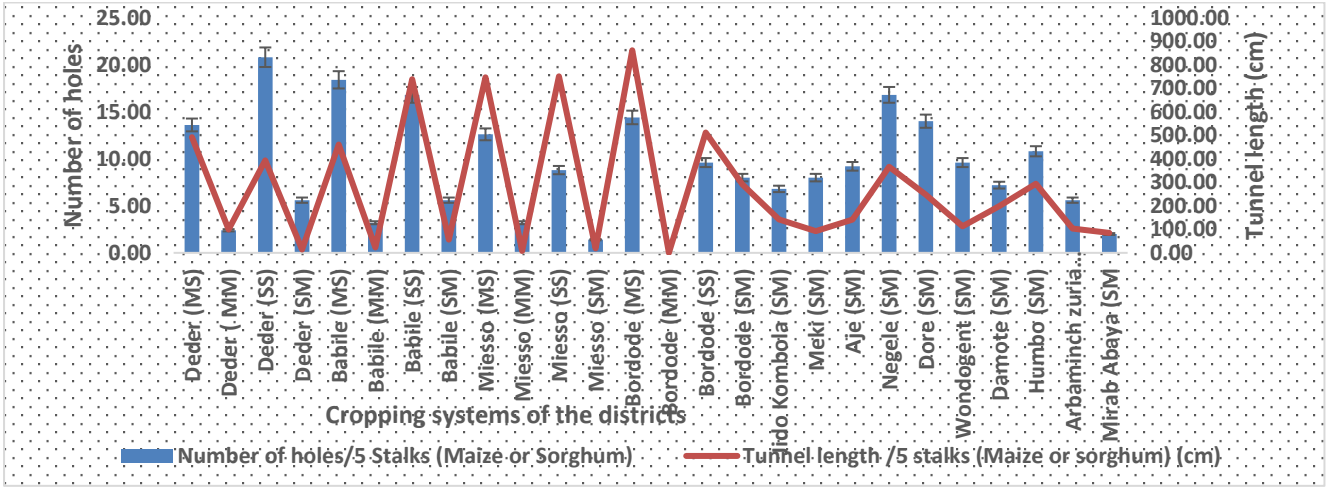


Figure 1. Abundances of parasitoids recorded on the collection of *S. frugiperda* and the stem borer larvae in the surveyed districts of eastern, central and southern parts of Ethiopia during the rainy season of 2024.

4.5. Impact of *S. frugiperda* and stem borer interaction on the number of holes and tunnels length of the maize and sorghum stalks

The evaluation of number of holes and tunnel lengths in both mixed and sole cropping systems for maize and sorghum revealed that significantly higher numbers of holes and tunnel lengths were found in the mixed and sole sorghum systems compared to the sole maize systems. Notably, this trend was consistent across most locations, except for sole maize cropping systems in Negele Arsi and Sidama districts (Fig. 2).



Figures 2. Effects of *S. frugiperda* and stem borer interactions on tunnel length and number of holes of maize and sorghum stalks in eastern, central and southern Ethiopia during the rainy season of 2024. Key: MS: mixed sorghum, MM: mixed maize, SS: sole sorghum, SM: sole maize.

4.6. Farmers' perceptions

In both the East and West Hararghe zones, a detailed survey involving ten farmers from each selected woreda revealed that over 90% of the respondents engage in mixed cropping of maize and sorghum. This practice not only enhances land utilisation but also offers benefits such as improved pest management through increased biodiversity. Furthermore, more than 70% of the farmers reported using row cropping methods, while 30% opted for broadcasting techniques. These diverse planting strategies highlight the adaptability of farmers in optimizing their crop yields. Similarly, in the East Shoa, West Arsi, Sidama, Wolaita, and Gamo zones, over 95% of farmers utilize row cropping for their maize, demonstrating a strong preference for organized planting arrangements.

The primary pests affecting both sorghum and maize are the stem borer and *S. frugiperda*. Historically, the stem borer was recognized as the major pest; however, the recent emergence of *S. frugiperda* has shifted the balance, making it the primary threat to both crops. This shift illustrates the evolving challenges faced by farmers and underscores the need for adaptive pest management strategies. Regarding pest control, over 80% of interviewees reported using chemical methods to manage *S. frugiperda* infestations, indicating a proactive approach to protecting their crops. However, it is concerning that more than 70% of the respondents do not implement any management practices for stem borers.

Furthermore, more than 90% of the farmers identified *S. frugiperda* as the current major obstacle to the successful cultivation of sorghum and maize. This consensus emphasizes the critical need for effective strategies to mitigate the impact of this invasive pest. Interestingly, over 70% of the interviewees acknowledged that both the *S. frugiperda* and stem borer feed on their crops, illustrating the complexity of pest interactions and the challenges farmers face in maintaining healthy fields. Among the farmers surveyed, more than 90% confirmed that maize serves as the primary host for the *S. frugiperda*. This finding suggests that focusing pest management efforts on maize could be crucial in controlling the spread of the *S. frugiperda* and protecting both maize and sorghum crops.

Overall, these insights highlight not only the immediate challenges posed by invasive pests but also the resilience and adaptability of farmers in the region. There is a clear need for collaborative efforts among agricultural extension services, research institutions, and farmers to develop sustainable pest management strategies. By enhancing farmers' knowledge and

providing access to effective control measures, it will be possible to alleviate the pressures from both the fall armyworm and stem borers, ultimately securing food production and improving livelihoods in these agricultural zones.

5. Discussions

The resurvey results revealed that the percentage of infestations of *S. frugiperda* in maize and sorghum mixed cropping system fields was significantly higher in maize crops compared to sorghum crops. This trend aligns with previous studies indicating that maize provides more favourable conditions for *S. frugiperda* larvae, including an optimal nutritional profile that supports faster growth and development. Interestingly, the percentage of stem borer infestation was significantly higher in sorghum under maize and sorghum mixed cropping systems, highlighting the complexity of pest interactions in diverse cropping systems. The study also indicated that under mixed maize and sorghum crops, *S. frugiperda* infestation is significantly higher in maize than in sorghum. But, the infestation of stem borers was significantly higher in sorghum than in maize. This is in line with Shinde et al. 2025), who showed that *S. frugiperda* larvae exhibit a stronger preference for maize over sorghum. The same authors also revealed that *S. frugiperda* larvae display a stronger response to maize, with higher feeding preference index values. In choice tests, *S. frugiperda* larvae feed more on maize plants, leading to higher damage rates compared to sorghum (Zhao et al.2025). In addition, Ntiri et al. *(*2019) indicated that maize registers higher values for nutritional indices like Consumption Index (CI), Consumption Rate (CR), Growth Rate (GR), and Approximate Digestibility (AD) for *S. frugiperda*, indicating better nutritional suitability compared to sorghum. Female *S. frugiperda* moths show a preference for laying eggs on maize plants compared to sorghum (Shinde et al. 2025). Besides, Chatterjee et al. (2023) showed that sorghum produces secondary metabolites that can defend against *S. frugiperda* attacks, making it less palatable. Moreover, the same authors recorded that flavonoids present in sorghum have been shown to increase mortality and reduce the body weight of *S. frugiperda* larvae. Introducing genes that produce flavonoid precursors from sorghum into maize can increase the resilience of maize plants against *S. frugiperda* (Chatterjee et al. 2023). In addition, Chatterjee et al. (2023) revealed that stem borers may prefer sorghum due to its stem characteristics.

The survey demonstrated that, when examining sole crops, both the percentage of infestations of *S. frugiperda* and the number of egg colonies were significantly elevated in maize and sorghum compared to stem borer infestations. According to Hailu et al. (2021), the competitive

dynamics between existing stem borers and invasive *S. frugiperda* are exacerbated by *S. frugiperda's* aggressive feeding habits, adaptability, and notably, its cannibalistic behaviour. This predatory nature enables *S. frugiperda* to thrive at the expense of native stem borers, resulting in a reduction in their populations and altering their host preferences (Sokame et al. 2023). Sokame et al. (2021) also indicated that the introduction of *S. frugiperda* significantly correlated with the reduction in the abundance of resident communities of maize stem borers and parasitoids in maize fields; moreover, the decrease in stem borer density after the arrival of *S. frugiperda* occurred mostly at both reproductive and senescent maize stages. It also suggests a possible displacement of stem borers by *S. frugiperda* elsewhere; for example, to other cereals (Sokame et al. 2021).

The study also indicated that, under the sole cropping system of both maize and sorghum, the number of *S. frugiperda* was significantly ($P<0.05$) higher than in the intercropping system. However, the percentage of stem borer infestation was higher in sole sorghum compared to sole maize. This is attributed to the stem borer's life cycle, where larvae tunnel into the stem, causing the plant to weaken. Sorghum's physical and chemical attributes may make it more attractive to certain stem borer species (Shinde et al. 2025). Similarly, Chatterjee et al. (2023) indicated that Sorghum has certain defence mechanisms against *S. frugiperda*, including chemical compounds that can reduce larval development. Flavonoids in sorghum have shown promising results in combating *S. frugiperda* larvae (Zhao *et al.*, 2025). Field observations suggest that the aggressiveness of *S. frugiperda* and its higher larval populations can lead to a marked decline in stem borer activity. This displacement may force stem borers to shift from preferred host plants like maize to alternative cereals such as sorghum, potentially disrupting local agroecological balances. Moreover, Bonoukpoe et al. (2021) documented instances of *S. frugiperda* larvae preying on stem borer larvae, which provides *S. frugiperda* with a significant competitive edge. Research suggests that interspecific competition is stronger among stem borer species themselves than between *S. frugiperda* and stem borers, further indicating the effectiveness of *S. frugiperda* in dominating these interactions. The cannibalistic nature of *S. frugiperda*, combined with its rapid habitat occupancy, is a critical factor that enables the competitive displacement of native stem borers from their preferred environments (Sokame et al. 2022). These dynamics underscore the broader implications for pest management strategies in agricultural systems, necessitating a more integrated approach to address the challenges posed by invasive species like *S. frugiperda* (Sokame et al. 2023).

Field studies have shown that higher larval populations of *S. frugiperda* can result in a significant decline in stem borer activity, effectively displacing these native pests from their preferred hosts, such as maize, to less suitable options like sorghum. This shift not only impacts the population dynamics of stem borers but also alters the ecological balance within cropping systems, as the competition for resources intensifies (Sokame et al. 2022. This cannibalistic nature is an additional factor that exacerbates the decline of stem borer populations, allowing *S. frugiperda* to outcompete them effectively (Hailu et al. 2021). The rapid habitat occupancy of *S. frugiperda*, coupled with its aggressive feeding behaviour and adaptability, plays a crucial role in its ability to displace native stem borers. Studies have documented this phenomenon, emphasising the need for integrated pest management strategies to address the impacts of *S. frugiperda* on agricultural systems extensively. According to Hailu et al. (2021), results of the intraspecific interaction indicated that *S. frugiperda* exhibited cannibalism to a larger degree than the stemborer species, especially at the late instars. The higher cannibalism trait in *S. frugiperda*, however, became a competitive advantage, as it led to a higher degree of intraguild predation when it cohabited with stemborer species and allowed *S. frugiperda* to achieve a greater relative growth rate (Bonoukpoe et al. 2021). Overall, interactions with *S. frugiperda* are detrimental for stemborer species and may be an important factor to explain the invasive success of *S. frugiperda*. Such knowledge is essential for understanding the mechanisms underlying ecological interactions among pests with overlapping niches in the field and for designing successful integrated pest management strategies.

Divya et al. (2021) demonstrated that *S. frugiperda* survival was reduced under intra-specific competition compared to inter-specific competition. However, stem borer survival was significantly reduced under interspecific competition due to intraguild predation by *S. frugiperda*. Fitness cost analysis of stem borer pupae surviving in competition with *S. frugiperda* larvae indicated that they were negatively affected by reduced pupal weight rate (Bonoukpoe et al. 2021). Low field incidence of stem borer and its lowest survival in the presence of an intraguild competitor, i.e. *S. frugiperda*, proves that stem borer might get displaced from the maize ecosystem in the near future (Divya et al. 2021). Intraspecific and interspecific interactions among insects are significant biotic factors that determine the ultimate outcomes of invasive–native species interactions by influencing ecological distribution, abundance, and evolution of insects in an ecosystem (Ntiri et al. 2019).

Moreover, the data were consistent with the idea that maize can act as a more suitable host for fall armyworm larvae, owing to higher compatibility of plant quality and nutritional characteristics that support faster growth and development (e.g., improved larval performance and survival on maize relative to less preferred hosts) (Shinde et al. 2025). Such host-driven advantages can create a host preference and/or larval performance advantage that effectively concentrates *S. frugiperda* pressure in maize microhabitats, even when both crops coexist in the same field.

At the same time, stem borer infestation was significantly higher in sorghum than in maize under maize–sorghum mixed cropping. This contrasts with the *S. frugiperda* pattern and indicates that pest responses in mixed systems are not simply a matter of "more vegetation equals more pests," but rather reflect species-specific ecological requirements and how those requirements map onto crop architecture, plant chemistry, and microhabitat structure (Zhao et al.2025). In mixed systems, pest communities may therefore reorganize in a way that appears as niche compression: one pest species (here, *S. frugiperda*) is disproportionately associated with maize, while another pest group (stem borers) becomes disproportionately associated with sorghum.

A key question for explaining this niche compression is whether it is driven primarily by direct larval interactions (cannibalism, predation, or other antagonistic interference), versus vegetative niche exclusion, in which the presence of a more competitive plant/crop (or the activity of larvae) disrupts the physical habitat required by the other pest or shifts the availability of key feeding/oviposition micro-sites (Chatterjee et al. 2023). The current results can be interpreted through both mechanisms, but they suggest that vegetative niche exclusion (including whorl-structure disruption) is a plausible, possibly dominant contributor, while direct larval antagonism may act as an additional, but less consistently detectable, driver.

Where direct larval antagonism is important, one would expect stronger suppression of *S. frugiperda* performance in sorghum if larvae moved or aggregated there, or if the probability of cannibalism/predation increases under maize-to-sorghum spillover. However, the observed data show a clear segregation of *S. frugiperda* toward maize, which fits host suitability rather than necessarily requiring direct larval interference to explain lower infestation in sorghum. Cannibalism can certainly occur within *S. frugiperda* under crowded conditions, and predation can reduce survival when larvae are exposed to natural enemies or are concentrated in restricted microhabitats (Sokame et al. 2021). Still, for cannibalism/predation to be the primary

mechanism behind niche compression in the present system, additional evidence would be needed, such as comparable larval densities in both crops (indicating that larvae are present in sorghum but being suppressed), or behavioral/biological observations showing frequent larval-to-larval antagonism that differs between maize and sorghum microhabitats (Chatterjee et al. 2023). Without such evidence, direct larval cannibalism/predation cannot be ruled out, but it is less directly supported as the main explanatory pathway.

In contrast, vegetative niche exclusion provides a mechanism that can produce niche compression even when pest movement between crops is limited. Maize and sorghum differ strongly in canopy architecture and the persistence/availability of vertical feeding sites (such as whorl-like structures used by many stem/borer-associated larvae and early instars). If larval feeding on maize more effectively damages or eliminates the vertical structural microhabitats that would otherwise favour other pests (or other developmental stages), then larvae can indirectly force community reassembly by altering the spatial and structural availability of resources. In such a scenario, niche compression would emerge because the effective "habitat niche" becomes unavailable in one crop type, not because larvae directly kill each other, but because the plant architecture required by a given guild becomes disrupted (Chatterjee et al. 2023). This is particularly relevant given that many lepidopteran pests use within-whorl or within-stem niches during early development, making them vulnerable to structural changes and feeding-mediated damage.

Furthermore, the results that stem borer infestation is higher in sorghum under mixed cropping may reflect that sorghum preserves (or offers) vertical/within-plant niches that are less compromised than those in maize, or that the structural traits of sorghum better fit stem borer ecology even when maize is present (Zhao et al.2025). Thus, maize could be "absorbing" *S. frugiperda* into a maize-favoured niche, while sorghum remains comparatively favourable for stem borers effectively generating a crop-partitioning of pest guilds through habitat suitability and structural constraints.

Overall, the combined pattern of higher *S. frugiperda* in maize and higher stem borer infestation in sorghum supports the interpretation that niche compression is being shaped by differential crop suitability and microhabitat structure, consistent with a vegetative niche exclusion / habitat-availability framework (Zhao et al. 2025; Chatterjee et al. 2025). Direct cannibalism/predation may still contribute to within-species and between-guild suppression, especially under local crowding (Sokame et al. 2021), but the observed segregation is equally

and perhaps more parsimoniously explained by crop-driven differences in plant quality and structural microhabitat availability.

6. Conclusions and Recommendations

In conclusion, this study demonstrates a marked reduction in the incidence and survival of native stem borers following the establishment of *Spodoptera frugiperda* in Ethiopia. This temporal association suggests that the arrival and rapid establishment of *S. frugiperda* may have altered the existing pest community and contributed to changes in the population dynamics of native stem borers. From an ecological perspective, such changes can arise through interspecific competition, particularly when two herbivores exploit similar host plants, feeding sites, or other limiting resources. Under conditions of strong niche overlap, competition may reduce the abundance and fitness of the less competitive species, potentially resulting in competitive displacement.

However, the observed decline in native stem borers may not necessarily result from direct resource competition alone. Herbivore–herbivore interactions can also occur indirectly through plant-mediated effects and shared natural enemies. Feeding by *S. frugiperda* may modify host-plant quality, induce plant defensive responses, or alter the availability of suitable tissues for subsequent herbivore colonization. Similarly, changes in predator and parasitoid communities associated with the establishment of *S. frugiperda* could influence the survival of native stem borers. These mechanisms illustrate that invasive species can restructure agricultural communities through both direct and indirect ecological interactions.

The observed reduction in native stem-borer survival may therefore represent an ongoing process of community restructuring rather than simple competitive exclusion. Ecological theory suggests that species with overlapping resource requirements may either compete strongly or reduce competition through niche differentiation. Consequently, native stem borers may respond to the presence of *S. frugiperda* through changes in host-plant selection, feeding location, seasonal activity, or other aspects of resource utilization. Such host shifts and niche partitioning could facilitate coexistence, whereas persistent and strong resource overlap could ultimately contribute to local displacement of the weaker competitor.

These interactions have important implications for pest management in Ethiopia. A decline in native stem-borer populations should not necessarily be interpreted as an overall reduction in pest pressure, because *S. frugiperda* may occupy ecological space previously used by native

pests and compensate for their decline through increased abundance or broader host utilization. Therefore, sustainable pest management should consider changes in the composition, abundance, and interactions of the entire pest community**,** rather than focusing on individual pest species in isolation.

Further research is needed to determine the mechanisms responsible for the apparent decline of native stem borers following the establishment of *S. frugiperda*. Long-term field observations and controlled experiments should examine resource overlap, host-plant responses, feeding-site selection, seasonal phenology, natural-enemy interactions, and possible host shifts. Such studies would help distinguish direct competition from indirect ecological effects and clarify whether the observed pattern represents competitive displacement, niche partitioning, or broader changes in the agroecosystem.

Overall, the interaction between *S. frugiperda* and native stem borers highlights the ecological complexity associated with invasive pests and the challenges they pose to agricultural production. Understanding these interactions is essential for predicting future changes in pest communities and for developing integrated and sustainable management strategies. A better understanding of competition, host shifts, niche partitioning, and indirect ecological interactions will ultimately contribute to protecting crop productivity while improving the resilience and sustainability of Ethiopian agroecosystems.

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Consent for publication

This manuscript does not contain any person's data in any form (including individual details, images, or videos), and therefore, consent for publication is not applicable.

Competing interests

The authors declare that they have no competing interests.

Data Availability

The data generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

Authors' Information

All authors have approved the submitted manuscript and agree to be accountable for all aspects of the work, including ensuring that questions related to the accuracy and integrity of the research are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

This study involved field research on insect pests and crops and did not involve human participants or vertebrate animals. Therefore, ethical approval and consent to participate were not applicable.

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