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Assessing interactions between wild host plants and stemborer species in East Africa

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Research Article

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Abstract

Lepidopteran stemborers are among the most destructive pests of maize, sorghum, and sugarcane in Africa. Yet, data on their species composition and host range in Rwanda remain limited. This study provides the first comprehensive assessment of stemborer diversity, seasonal dynamics, and altitudinal distribution across eastern (low altitude), central (mid-altitude), and northern (high altitude) Rwanda. Surveys were conducted during both the rainy (maize growing) and dry seasons of 2023–2024, targeting infested maize fields and surrounding wild vegetation. A total of 2691 stemborer individuals were recovered from nine host plants, with 1474 (54.8%) from wild and fodder vegetation and 1217 (45.2%) from maize plantations. Species richness was highest in the mid-altitude zone, while overall abundance peaked at low altitudes. *Busseola fusca* was the most abundant in the high-altitude zone, *Chilo partellus* in the low altitude, and *Sesamia* spp. was concentrated in the mid-altitude. Seasonal variation significantly influenced population dynamic, with the highest abundance (1251; 46.4%) recorded during the dry season. Notably, *Pennisetum purpureum* (Napier grass) hosted 1156 (42.9%) of all specimens, highlighting its role as a key refugium during maize off-seasons. These findings underscore the ecological importance of wild vegetation in sustaining stemborer populations and suggest that wild vegetation, altitudinal, and seasonal factors must be considered in designing integrated lepidopteran stemborer pest management strategies.

Introduction

The ecological and agricultural significance of lepidopteran stemborers lies not merely in their presence but also in the extent of their impacts on crop productivity across diverse environments (Assefa *et al.* 2010; Goftishu *et al.* 2017; Ntirenganya *et al.* 2025). They tunnel and cloaked inside the host plant's stems and feed on the internal cavity of the plant (Assefa 2006; Goftishu *et al.* 2017; Overholt *et al.* 2001), making them very difficult to control (Ntirenganya *et al.* 2025; Overholt *et al.* 2001). More effort has been devoted to understanding stemborers' ecological habitats and their relationships with host plants (Goftishu *et al.* 2018; Midega *et al.* 2015; Ntirenganya *et al.* 2025; Overholt *et al.* 2001). However, the interactions between crop and wild stemborer hosts remain poorly understood, limiting our ability to develop integrated management strategies that effectively address both pests and the full range of their host plants.

Over the past 20 years, assessments of stemborer species and their host plants were conducted (Assefa 2006; Goftishu *et al.* 2018; Le Rü *et al.* 2006a, 2006b; Moolman *et al.* 2014; Ntirenganya *et al.* 2025; Otieno *et al.* 2008; Overholt *et al.* 2001). From these studies, more than 150 lepidopteran stemborer species (families Crambidae, Noctuidae, Pyralidae, and Tortricidae) were reported (Assefa *et al.* 2010; Goftishu *et al.* 2018; Kfir 1992; Khan *et al.* 1997; Le Rü *et al.* 2006a), of which more than 21 species having major effects on agricultural yield, attacking maize, sorghum, wheat, rice, sugarcane, and related cereal crops across tropical and subtropical regions (Overholt *et al.* 2001; Sokame *et al.* 2019). The remaining species occur primarily in wild plants under the Poaceae, Cyperaceae, Typhaceae, and related vegetation families, where they play an important ecological roles as native herbivores. These vegetation serve as reservoirs for pest stemborers (Goftishu *et al.* 2018; Le Rü *et al.* 2006b; Sokame *et al.* 2022; Tefera 2004).

In Sub-Saharan Africa, Noctuids *Buseola fusca* Fuller, 1901 and *Sesamia calamistis* Hampson, 1910, crambids *Chilo partellus* Swinhoe, 1885, *Chilo orichalcociliellus* Strand, and the pyralid *Eldana saccharina* Walker, 1865 are key stemborers widely distributed (Assefa 2006; Assefa *et al.* 2010; Ntirenganya *et al.* 2025; Overholt *et al.* 2001). With the exception of *C. partellus*, which is native to Asia (Asmare *et al.* 2014; Kfir 1992; Kfir *et al.* 2002), other species are native to Africa (Kfir 1992; Khan *et al.* 1997; Maes 1998). *Sesamia calamistis* Hampson, 1910,

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Sesamia nonagrioides Lefèbvre, 1827, and other *Sesamia* species are widely distributed across sub-Saharan Africa, including West, Central, East, and Southern Africa, and extending to Indian Ocean islands (Madagascar, Réunion) predominantly in humid to sub-humid agroecosystems (Kanya *et al.* 2004; Le Rü *et al.* 2006a, 2006b; Moolman *et al.* 2014). Studies of dynamics of these species in their habitats reported the influence of altitude, temperature, humidity, and cropping systems, with seasonal fluctuations affecting their community structure (Gounou *et al.* 2009; Ntirenganya *et al.* 2025; Régnier *et al.* 2023).

Phylogeographical studies have indicated that African maize stemborer, *Busseola fusca*, is natively adapted to higher altitudes commonly above 1500 m (Asmare *et al.* 2014; Calatayud *et al.* 2014). With climate change and variation, this species was also observed expanding its range to mid and low altitudes of less than 1500 m in East Africa (Calatayud *et al.* 2014; Goftishu *et al.* 2017; Mutamiswa *et al.* 2017). Similarly, recent surveys conducted in Ethiopia indicated that *Chilo partellus,* naturally adapted to low altitude with warmer temperature, has widened its agroecological distribution to high altitude of 2084 m.a.s.l (Asmare *et al.* 2014; Goftishu *et al.* 2018). In contrast, a reasonable number of *Sesamia calamistis* was continuously reported across all altitudes in Ethiopia (Goftishu *et al.* 2017, 2018; Melaku *et al.* 2006; Tefera 2004; Wale *et al.* 2007), with a relative increase in mid-altitude of most parts of East Africa (Kaçar *et al.* 2023; Le Rü *et al.* 2006a, 2006b).

Despite decades of research on lepidopteran stemborers, critical gaps persist in our understanding of their ecology, particularly regarding interactions with host plants, species-specific seasonal dynamics, and adaptive responses to climatic variability. Ecological role of wild vegetation surrounding farmlands remains contested. Some studies suggested the low stemborers abundance in wild habitats (Kankonda *et al.* 2017; Le Rü *et al.* 2006a, 2006b; Ong'amo 2005), while others reported active crop–wild vegetation exchange that challenge traditional assumptions about stemborer habitat specialization and pest emergence (Assefa *et al.* 2010; Goftishu *et al.* 2018; Khan *et al.* 2007; Midega *et al.* 2015).

Emerging evidence also suggests that non-economic stemborer species may evolve into significant pests under changing land use and climatic conditions (Gounou *et al.* 2009; Mutamiswa *et al.* 2022; Régnier *et al.* 2023). These dynamics underscore the need for localized ecological assessments, particularly in understudied regions such as Rwanda, where information on stemborer community structure and agroecological functioning is limited. Addressing these knowledge gaps is essential for developing climate-resilient and ecologically informed pest management strategies.

This study aims to address critical gaps in the ecology of lepidopteran stemborers in Rwanda by (i) conducting the first assessment of stemborer species diversity and abundance across different altitudinal zones, (ii) evaluating seasonal variation in infestation patterns, and (iii) determining the role of wild host plants' persistence of stemborers populations. We hypothesize that higher altitudes support fewer stemborers due to cold microclimates, while lower altitudes may exhibit higher overall richness driven by warmer temperatures and continuous cropping systems (Mutamiswa *et al.* 2022; Mwalusepo *et al.* 2018). Mid-altitude zone with moderate temperatures may facilitate co-existence of multiple stemborer species (Mwalusepo *et al.* 2015, 2018).

Seasonal variation is expected to influence stemborers community dynamics by switching from maize to alternative host plants during the dry season when maize is absent (Khan *et al.* 2007; Ntiri *et al.* 2019; Van Den Berg *et al.* 1991). Conversely, maize plantations are expected to show peak infestation levels during the long rainy season, with the availability of preferred host plants, and favourable humidity that support rapid larval development. Wild host plants such as *Pennisetum purpureum* (Napier grass) could serve as persistent reservoirs that sustain stemborer populations across seasons (Moolman *et al.* 2014; Ong'amo 2005). Understanding these interactions is essential for developing climate-smart, and site-specific pest management strategies. The findings contribute to improved resilience in smallholder farming systems while supporting broader goals of biodiversity conservation and sustainable agriculture intensification.

Materials and methods

Study zones characteristics

The study was conducted from 2023 to 2024 in three ecologically distinct zones of Rwanda: Eastern, Southern, and Northern provinces, each representing unique biogeographical zones and unique vegetation types (MINAGRI 2021; SANBI *et al.* 2022). Kayonza district (1°51′04″ S, 30°39′04″ E; ~1324 m a.s.l.) represented eastern province. The district lies within the low altitudinal zone of Akagera sub-humid savanna region, part of the eastern savannah corridor, characterized by *Cyperus papyrus*, hippo grass (*Vossia cuspidata*), and swamp forest vegetation along floodplains and wetland valleys (Ruticumugambi *et al.* 2024; SANBI *et al.* 2022). Kamonyi district (2°00′15″ S, 29°54′19″ E; ~1661 m a.s.l.) represented southern province. The district is located in mid altitudinal zone in montane forest region extending to the Albertine Rift, dominated by upper montane forests, and grasses (Lillesø *et al.* 2024; SANBI *et al.* 2022). Burera district (1°28′26″ S, 29°50′05″ E; ~2182 m a.s.l.) represented northern province. The district is located in high-altitude zone encompassing Afroalpine mountain ecosystems with extensive wetlands dominated by Poaceae (*Miscanthidium* and *Pennisetum*), Typhaceae, and Cyperaceae families (Nsengimana *et al.* 2025; SANBI *et al.* 2022) (Figure 1).

Although the sampled areas of southern and central regions of Rwanda exhibit overlapping altitude ranges with parts of the eastern region due to similar geomorphological processes, they are classified into distinct altitudinal zones based on differences in elevation gradients (Table 1), vegetation structure, and microclimatic conditions (Lillesø *et al.* 2024; MINAGRI 2021; SANBI *et al.* 2022), which are key ecological factors influencing stemborers community structure (Mutamiswa *et al.* 2022; Mwalusepo *et al.* 2018; Tamiru *et al.* 2007).

Sampling design

Data were collected during the dry (June–August), long rainy (September–February), and short rainy (March–May) seasons in 2023 and 2024 (National Institute of Statistics of Rwanda (NISR) 2024). In each altitudinal zone, nine maize farms were selected, resulting in a total of 27 sampled farms, equally distributed across three selected sectors from representative districts. Farms were eligible for inclusion if they contained at least 0.5 hectares of maize and were separated from one another by a minimum distance of 3 km. Each farm was subdivided into five 3 m × 3 m sampling quadrants, and all maize stems within these quadrants were systematically examined for the presence of stemborer infestation. Wild vegetation was surveyed in natural habitats along the margins

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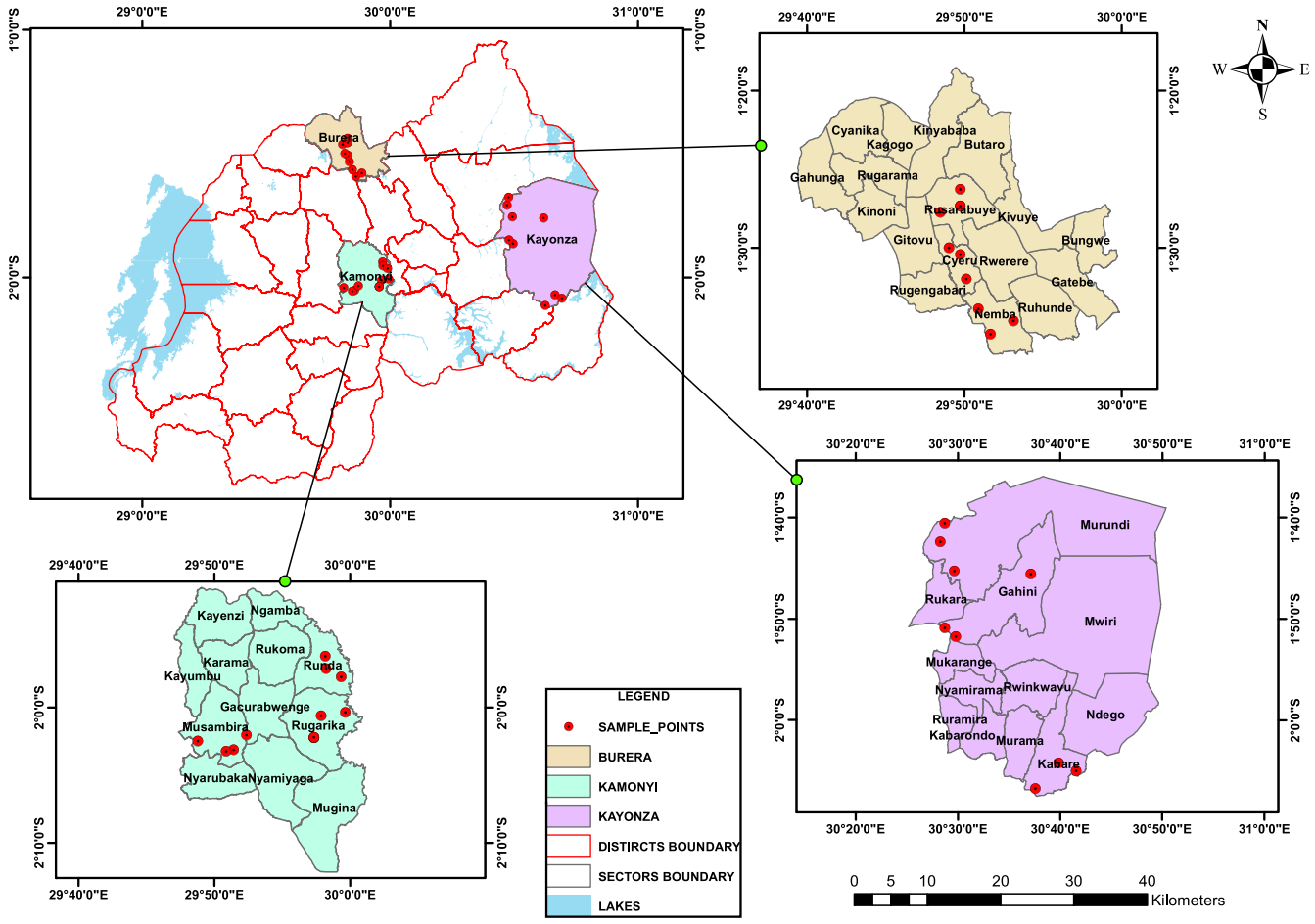

Figure 1. Map of Rwanda showing the sampling sites. The yellow colour indicates the sites located at a high-altitude zone in the northern province; the light green indicates the sampling sites at a mid-altitude zone of the southern province, the light purple colour indicates the sampling sites located at low-altitude zone of the eastern province. The map was generated from the metadata available at the Rwanda Biodiversity Information System (RBIS) using ArcGIS, 10.8.2.

of maize farms, with sampling sites located within a maximum distance of 50 m from each sampled cultivated field.

Sampling was guided by a targeted selection of vegetation families known to host stemborers or closely related taxa. This purposive sampling strategy, rather than purely random selection, was adopted based on recommendations from previous studies that reported low stemborer population densities in wild vegetation (Goftishu *et al.* 2018; Kanya *et al.* 2004; Otieno *et al.* 2008). The method aimed to increase the likelihood of detecting stemborers by focusing on vegetation with higher ecological relevance to the pest.

Collection and rearing of stemborers

At each locality, both cultivated maize and farm margin's wild vegetation were carefully checked for stemborer infestation symptoms such as wilting leaves, dry leaves, dead hearts, holes bored on stems, and fresh frass (Goftishu *et al.* 2018; Moeng *et al.* 2018). For wild vegetation, special consideration was given to species belonging to the Poaceae, Cyperaceae, and Typhaceae families with known records to host stemborers in cultivated and wild ecosystems (Goftishu *et al.* 2018; Otieno *et al.* 2008). Infested plants were cut, dissected, and carefully checked for the presence of stemborers. Recovered larvae were transferred to artificial diets in plastic vials (7.5 × 2.5 cm) closed with cotton and kept in the laboratory until pupation (Devi and Kaur 2015; Goftishu *et al.* 2018; Overholt *et al.* 2001). Recovered pupae and egg colonies were kept separately in plastic vials (15 × 7 cm) closed with cotton wool until their emergence (Moeng *et al.* 2018).

Sample processing and laboratory identification

Identification of stemborers to genus and species levels was done using microscopic observations, following established morphological keys. Primary identification followed the guide for stemborers identification developed by the International Centre of Insect Physiology and Ecology (ICIPE) (Overholt *et al.* 2001), the recently published *Sesamia* species identification key (Le Rü *et al.* 2022), and the insect identification platform of Lucid Central (https://www.lucidcentral.org). To ensure taxonomic accuracy, identifications were further validated in consultation with stemborer specialists from ICIPE. Voucher specimens were deposited at the zoology laboratory, biology department, College of Science and Technology, University of Rwanda, under the stemborers collection (access code: WS2023 and WS2024).

Statistical data analysis

Stemborer communities were analysed by comparing their abundance and diversity across three altitudinal zones (low, mid, and high), seasonal conditions (dry season, long rainy season, and

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Table 1. Geographical description of sampled sites and their respective altitudes and the nature of the landscape

Location	GPS-coordinates	Altitude (m)	Landscape
Burera-Cyeru-Ndongozi	S1°32′0″; E29°50′6″	2010.9	Highland
Burera-Cyeru-Butare	S1°30′26″; E29°49′44″	2019	Highland
Burera-Cyeru-Ruyange	S1°30′0″; E29°49′0″	2080	Highland
Burera-Nemba-Kavumu	S1°35′30″; E29°51′39″	2097	Highland
Burera-Nemba-Rubona	S1°34′40″; E29°53′7″	2020	Highland
Burera-Nemba-Rushara	S1°33′53″; E29°50′53″	2030	Highland
Burera-Rusarabuye-Kabona	S1°26′17″; E29°49′43″	2274	Highland
Burera-Rusarabuye-Ndago	S1°27′44″; E29°48′27″	2018	Highland
Burera-Rusarabuye-Ruhanga	S1°27′20″; E29°49′43″	2234	Highland
Kamonyi-Musambira-Buhoro	S1°27′20″; E29°49′43″	1699	Midland
Kamonyi-Musambira-Kivumu	S2°2′29″; E29°48′47″	1713	Midland
Kamonyi-Musambira-Cyambwe	S2°3′8″; E29°51′26″	1581	Midland
Kamonyi-Runda-Gihara	S1°56′15″; E29°58′10″	1684	Midland
Kamonyi-Runda-Muganza	S1°57′9″; E29°58′14″	1567	Midland
Kamonyi-Runda-Ruyenzi	S1°57′46″; E29°59′20″	1508	Midland
Kamonyi-Rugalika-Kigese	S2°0′38″; E29°57′53″	1501	Midland
Kamonyi-Rugalika-Nyarubuye	S2°2′14″; E29°57′20″	1624	Midland
Kamonyi-Rugalika-Nyarubuye	S2°2′14″; E29°57′20″	1624	Midland
Kayonza-Gahini-Kahi	S1°45′35″; E30°37′8″	1435	Lowland
Kayonza-Gahini-Kagarama	S1°51′45″; E30°29′48″	1456.8	Lowland
Kayonza-Gahini-Jambo Beach	S1°50′54″; E30°28′43″	1485.2	Lowland
Kayonza-Kabare-Mubumba	S2°4′12″; E30°39′52″	1497	Lowland
Kayonza-Kabare-Gashiru	S2°4′59″; E30°41′34″	1314	Lowland
Kayonza-Kabare-Gituku	S2°6′44″; E30°37′34″	1482	Lowland
Kayonza-Murundi-Buhabwa	S1°45′17″; E30°29′37″	1428	Lowland
Kayonza-Murundi-Karambi	S1°42′26″; E30°28′17″	1385	Lowland
Kayonza-Murundi-Ngugu	S1°40′34″; E30°28′42″	1355	Lowland

Note: (MINAGRI 2021; SANBI *et al.* 2022).

short rainy season), and host plant species. Abundance was quantified by counting the number of individual adult heads rather than using mean estimates. For egg colonies, each colony was considered as a single individual after adult emergence, as all individuals within a colony originated from the same oviposition event. To compare diversity across altitudes and seasons, we calculated multiple diversity indices (Shannon diversity, Simpson, and Pielou's Evenness) and created rarefaction curves at 95% confidence intervals using bootstrap methods in iNEXT package (Morris *et al.* 2014). Chi-square test was used to assess independence or differences in proportions, and when the assumptions of normality were not met, the non-parametric Kruskal–Wallis test was applied as an alternative.

To test the influence of altitude and season on species assemblages, we performed permutation multivariate analysis of variance (PERMANOVA) and non-metric multidimensional scaling (NMDS) to demonstrate and visualize compositional differences, providing complementary insights into community structure beyond richness alone (Hsieh *et al.* 2016). To test whether seasonal variation reflected stemborer movement between maize and alternative hosts, we analysed community dispersion by using marginally significant permutation dispersion (PERMDISP, $p = 0.055$) (Anderson 2017). All statistical data analyses were performed in R Statistics software version 4.4.0 at significance of 0.05 for all tests (R Core Team 2025).

Results

General abundance of stemborers

A total of 2756 stemborer individuals were collected during the study period. Of these, 2691 (97,6%) were successfully identified to species or genus levels, while 65 individuals were classified only to the family level. These unidentified individuals were included in the analyses restricted to developmental stages. Across developmental stages, the larvae were overwhelmingly abundant

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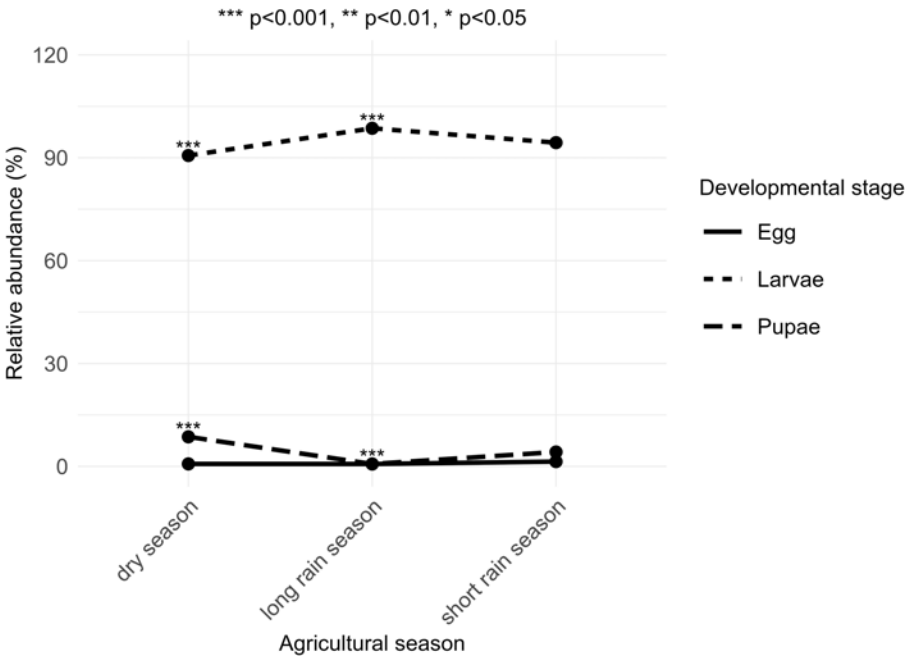

Figure 2. Relative abundance and distributions of stemborers developmental stages where ***$p < 0.001$, **$p < 0.01$, *$p < 0.05$ show the level of significances.

Table 2. Distribution and abundance of stemborers across different altitudinal gradients (0 = Absence) where abbreviations represent genera of stemborers

		Low altitude			Mid-altitude			High altitude			
No	Species	Dry season	Short Rain season	Long rainy season	Dry season	Short rainy season	Long rainy season	Dry season	Short rainy season	Long rainy season	*p*-value
1	*Busseola fusca*	69	18	41	86	38	90	462	97	167	0.045
2	*Chilo partellus*	330	158	217	55	74	82	3	0	0	0.003
3	*Sesamia calamistis*	76	28	87	114	73	239	0	0	0	0.008
4	*Sesamia nonagrioides*	9	2	18	37	0	11	0	0	0	0.007
5	*Eldana saccharina*	1	0	0	8	0	0	0	0	0	0.028

($n = 2604$; 94.5%), followed by pupae ($n = 131$; 4.7%) and egg colonies ($n = 21$; 0.8%) (Figure 2). Species-level abundance patterns showed that *Busseola fusca* was the most abundant species ($n = 1068$; 39.68%), followed by *Chilo partellus* ($n = 919$; 34.15%), *Sesamia calamistis* ($n = 617$; 22.92%), *S. nonagrioides* ($n = 77$; 2.8%), and the least represented was *Eldana saccharina* ($n = 9$; 0.45%).

Abundance varied across altitudinal zones. Higher abundance ($n = 1076$; 39.2%) was recorded in low altitude, followed by mid-altitude ($n = 942$; 34.1%) and high-altitude ($n = 738$; 26.7%) zones. Seasonal variations also had a notable effect: the dry season exhibited the highest abundance ($n = 1302$; 47.2%), compared to the long rainy season ($n = 956$; 34.7%) and the short rainy season ($n = 498$; 18.1%). The significant chi-square test ($\chi^2 = 67.52$, df = 4, $p < 0.001$) confirms a strong seasonal pattern in stemborer developmental stages distribution. Larvae dominated samples during the long rainy season, whereas pupae were mainly sampled during the dry season.

Stemborers abundance across altitudinal gradients

Analysis of the effect of altitude on stemborer species revealed that *Busseola fusca* was the most abundant species at high-altitude ($n = 726$; 26.97%), compared to the mid-altitude ($n = 214$; 7.95%) and low-altitude ($n = 128$; 4.75%) zones. In contrast, *Chilo partellus* species showed an opposite pattern with highest abundance at low altitude ($n = 705$; 26.2%) followed by mid-altitude ($n = 211$; 7.84%), and only three individuals were recorded at higher altitude zones. *Sesamia sp.* was the most numerous in mid-altitude ($n = 474$; 17.6%) compared to low altitude ($n = 220$; 8.17%). As expected for a species that is not strongly associated with maize cultivation, *Eldana saccharina* was rarely encountered, represented by eight individuals at mid-altitude and a single individual at low altitude (Table 2). Kruskal-Wallis test analysis revealed a significant difference in species distribution across the altitudinal gradients ($\chi^2 = 185.99$, df = 10, $p < 0.05$).

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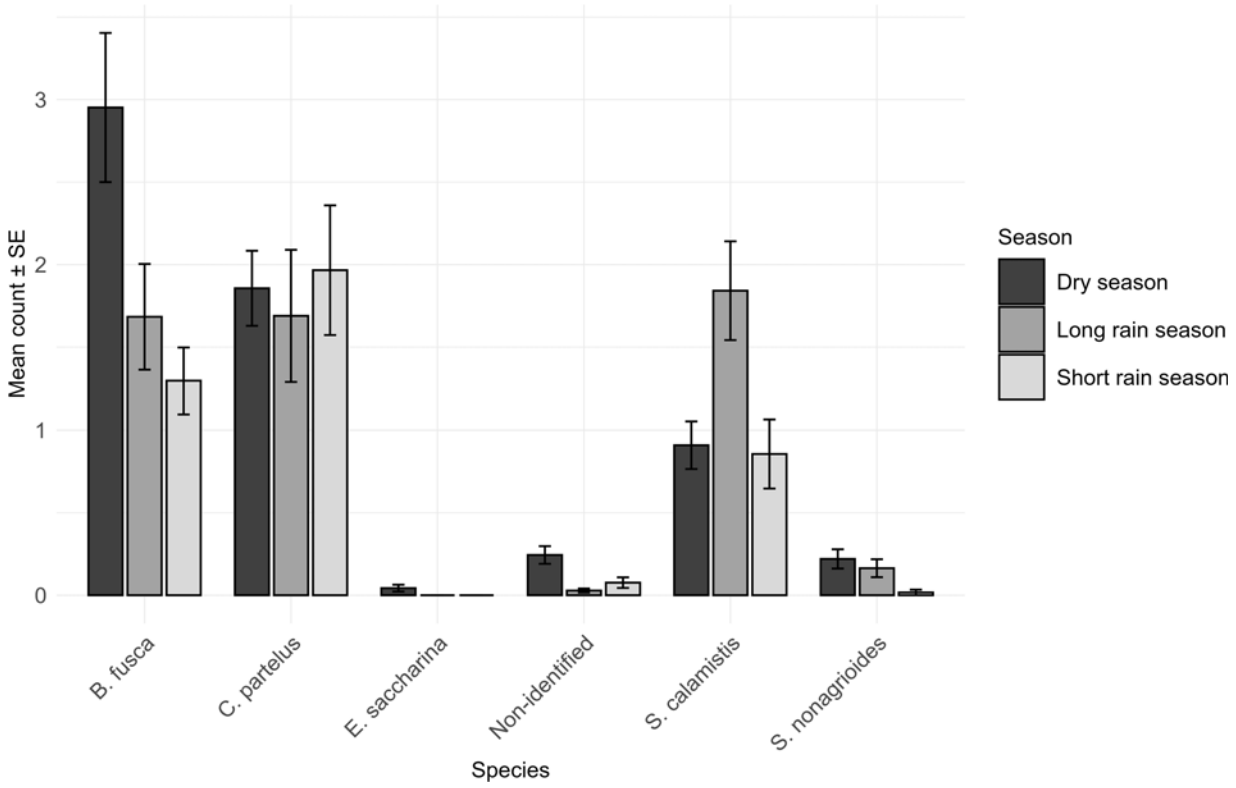

Figure 3. Comparative analysis of seasonal population dynamics of Stemborers where *B: Busseola*, *C*: *Chilo*, *E*: *Eldana*, *S*: *Sesamia* (genera names of stemborers).

Stemborers abundances across seasons

Seasonal patterns showed a clear and significant influence on stemborer abundance. Overall, dry season showed a higher number of identified stemborer individuals ($n = 1251$; 46.48%), followed by the long rainy season ($n = 951$; 35.4%) and the short rainy season ($n = 498$; 18.5%). Species-level responses further highlighted distinct ecological preferences. *Busseola fusca* peaked with 617 (49.3%) individual species during the dry season. *Chilo partellus* maintains relatively stable populations across dry season ($n = 388$; 31%) and long rain season ($n = 298$; 31.3%) but declines during the short rainy season ($n = 153$; 16%). *Sesamia calamistis* was abundant in long rainy season ($n = 329$; 34.6%). In contrast, *Eldana saccharina* and *S. nonagrioides* remain consistently low across seasons with limited association to maize plantation (Figure 3). Statistically, Kruskal-Wallis test of species abundance across agricultural seasons shows that all species exhibit a significant population variation over seasons where p-values of statistical analysis of individual species response to seasonal variation are provided in Table 2.

Stemborers abundances across host plants

Stemborer species abundance analysis in relation to the host plants revealed nine plants serving as alternative hosts, of which seven species belong to Poaceae family, while the Cyperaceae and Typhaceae were represented by a single species (Table 3). In a total of 2691 stemborer individuals recorded, maize and Napier grass emerged as the predominant host plants (maize – 1217 individuals, 45.2%; Napier grass – 1156 individuals, 42.9%). The remaining 318 individuals (11.9%) were distributed among other wild host plants. Statistical analysis revealed a significant difference in species distribution across host plant types ($\chi^2 = 194.28$, df = 14, $p < 0.05$). Notably, an accelerated increase in stemborer abundance on wild vegetation was observed during periods when maize was absent, particularly in high- and low-altitude zones (Table 3).

Stemborers diversity and richness

Rarefaction curves have reached asymptotes and sample coverage exceeded 95% across all assemblages, indicating adequate sampling effort to capture the majority of stemborer species present. Sample-based rarefaction confirmed a significant difference in species richness among altitudinal gradients (Figure 4a) and indicated seasonal variation as potential regulator of stemborer community structure (Figure 4b). Diversity metrics further supported these patterns. The mid-altitude zone exhibited the highest Shannon Diversity Index ($H' = 1.239$), Simpson Index ($D = 0.675$), and Pielou's Evenness ($J' = 0.770$). In comparison, the low-altitude zone showed moderate diversity ($H' = 0.944$) and evenness ($J' = 0.587$). The high-altitude zone had extremely low diversity ($H' = 0.029$) and evenness ($J' = 0.041$). Shannon diversity declined significantly with altitude (Spearman's $\rho = -0.41$, $p < 0.001$).

Altitude vs. season effects on stemborer communities

Results revealed altitude as the primary driver of community structure, explaining 16.5% of the observed variation ($R^2 = 0.1649$, $F = 35.73$, $p < 0.001$). Season also has a smaller but significant effect, accounting for 2.8% of community variation ($R^2 = 0.0282$, $F = 2.61$, $p = 0.002$). The analysis of altitude-season combined effect exhibited 21.2% of the community variation ($R^2 = 0.1876$, $F = 13.78$, $p < 0.001$) while the remaining 78.8% were attributed to

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Table 3. Distribution and abundance of Stemborers by host plant across different altitudinal gradients and seasonal variations (C: Cultivated crop; F: Fodder; W: Wild; 0: Absence)

		Plant		Low altitude			Medium altitude			High altitude		
No	Family	Scientific name	Common name	Dry season	Short rainy season	Long rainy season	Dry season	Short rainy season	Long rainy season	Dry season	Short rainy season	Long rainy season
1	Poaceae	*Zea mays L.* (C)	Maize	0	149	286	0	169	394	0	52	167
2	Poaceae	*Pennisetum purpureum* (W, F)	Napier grass	379	50	23	181	14	3	460	46	0
3	Poaceae	*Tripsacum mandersonii* (W, F)	Guatemala grass	29	0	2	41	0	0	3	0	0
4	Poaceae	*Chrysopogon zizanioides* (W, F)	vetiver	39	5	21	0	0	0	0	0	0
5	Typhaceae	*Typha spp.*(W)	cattail	13	0	0	21	2	0	3	0	0
6	Cyperaceae	*Cyperus spp.* (W)	Cyperus	26	0	0	17	0	0	0	0	0
7	Poaceae	*Echinochloa pyramidalis* (W)	Grass	9	0	0	0	20	0	0	0	0
8	Poaceae	*Panicum spp.* (W)	Grass	3	2	0	31	0	0	0	0	0
9	Poaceae	*Sorghum halepense* (W)	Johnson grass	11	0	0	20	0	0	0	0	0

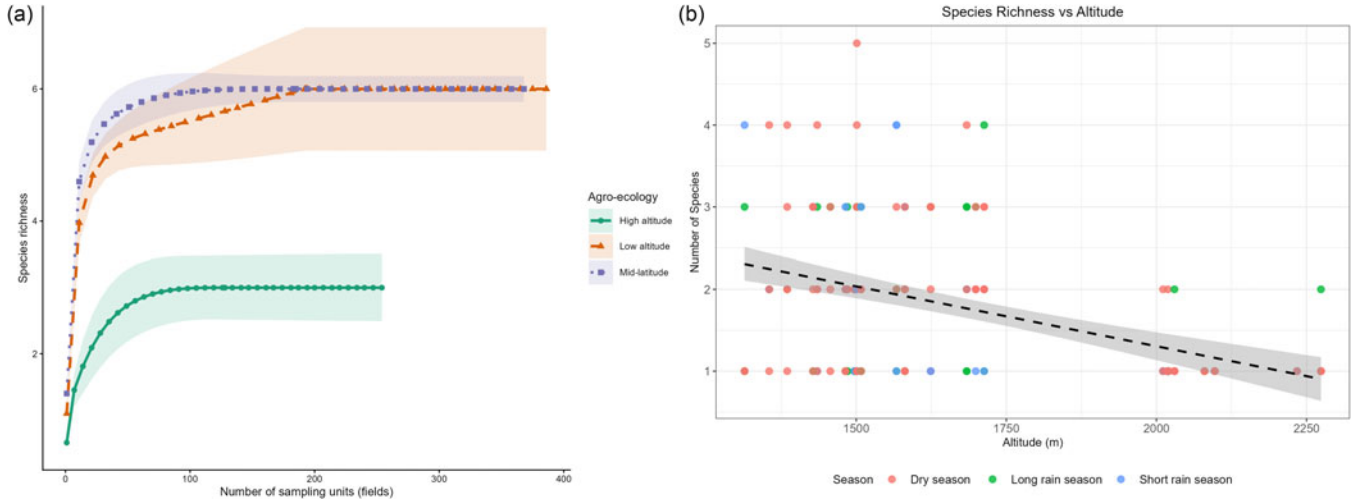

Figure 4. Rarefaction and species richness. (a) Sample-based rarefaction curve with extrapolation (dotted line segments) at 95% confidence intervals (shaded areas); (b) Altitudinal species richness in response to seasonal variations.

unmeasured factors. Further, there was negligible shared variance between altitude and season (negligible shared variance: −0.2%).

Stemborers community structure and seasonal variation

The NMDS test indicated reliable representation of community dissimilarity patterns (Stress: 0.065, $R^2 = 0.212$, $F = 9.53$, $p < 0.001$). Environmental vector fitting assessment identified altitude as the strongest ecological driver shaping stemborers community patterns, explaining 51% of ordination variance ($p < 0.001$) (Figure 5a). In addition, the permutational multivariate analysis of dispersion (PERMDISP) revealed marginally significant differences in stemborer groups dispersion among seasons ($F = 2.83$, $p = 0.055$), with short rainy season, showing significantly lower dispersion (mean distance to centroid = 0.522) compared to dry season (0.577) and long rainy season (0.584) (Figure 5b). Furthermore, the assessment of host plant use has indicated seasonal host-switching. The dry season communities use seven alternative host plant species with the highest diversty (Shannon = 1.30). The rainy season, however, was characterized

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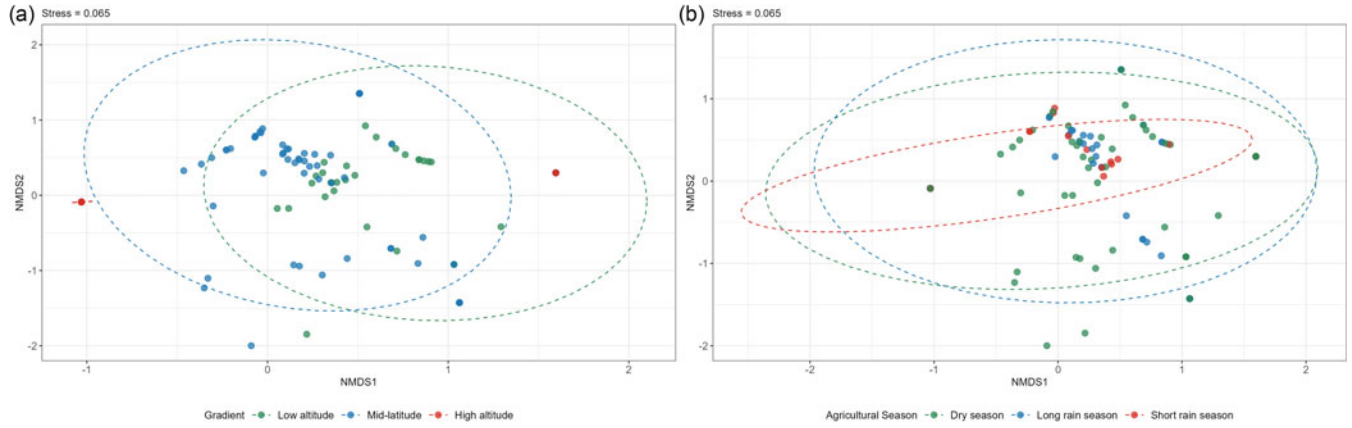

Figure 5. Altitudinal and seasonal structures of stemborer communities. (a) Altitudinal structures of stemborer communities ($R^2 = 0.21$, $p < 0.001$), (b) seasonal structures of stemborer communities ($F = 2.83$, $p = 0.055$, $\alpha = 0.10$).

by high maize abundance (49–59% of samples), associated with reduced alternative host plant diversity (Shannon = 0.97–1.20).

Results have also indicated that host plant composition differed significantly among seasons ($\chi^2 = 246.74$, df = 16, $p < 0.001$), with *Pennisetum purpureum* (Napier grass) serving as the primary dry season refugium sustaining 1020 stemborers across 105 samples (61% of dry season samples). Within seasons, the Bray-Curtis showed higher similarity during short rainy (0.271) compared to the long rainy (0.191). *Busseola fusca* was higher in dry season's alternative hosts (49.4%) while *Chilo partellus* showed higher abundance during short rainy season maize plantation (47.5%).

Discussion

This study represents the first investigation of lepidopteran stemborers community in Rwanda, providing insights into species composition, distribution patterns, host associations, and seasonal switching across different agroecological zones of Rwanda. Five key stemborer species were identified, namely *Busseola fusca*, *Sesamia calamistis*, *Sesamia nonagrioides* (Noctuidae), *Chilo partellus* (Crambidae), and *Eldana saccharina* (Pyralidae). All these species are known for their wide distribution range and ecological adaptability in East and Southern Africa (Assefa *et al.* 2010; Goftishu *et al.* 2018; Mutamiswa *et al.* 2022; Overholt *et al.* 2001). Our results showed that the larval stage was the most abundant across sites and seasons, indicating its particularly strong negative impact on cereal plants, as this is the stage that causes the greatest damage to crops (Assefa 2006; Goftishu *et al.* 2017; Overholt *et al.* 2001; Sokame *et al.* 2019). Findings also demonstrated that wild vegetation plays a substantial role in sustaining stemborer populations during maize off-seasons, suggesting that non-crop habitats act as reservoirs that support the pests' inter-seasonal persistence.

In our study, *Busseola fusca* was the most abundant species in the high-altitude zones but was also found in mid- and low-altitude areas, suggesting a potential expansion of its ecological niche. *Sesamia* spp. were concentrated in mid-altitudes, with limited presence in lowland zones, while *Chilo partellus* was found across both low and mid-altitudes. These patterns reflect the recent observations from Ethiopia, Kenya, Mozambique, South Africa, and the Democratic Republic of Congo, where shifts in stemborer distribution have been associated with climate change, habitats fragmentation, and resource competition (Goftishu *et al.* 2018; Kankonda *et al.* 2017; Le Rü *et al.* 2006a; Melaku *et al.* 2006; Wale *et al.* 2007). The strong altitudinal structuring of stemborer communities underscores the role of altitude-dependent environmental gradients in shaping stemborers pest assemblages, consistent with broader patterns as observed in tropical herbivorous insects (Tamiru *et al.* 2007; Zhao *et al.* 2023).

While altitude emerged as a significant driver of stemborer community structure (Mwalusepo *et al.* 2018; Tamiru *et al.* 2007; Zhao *et al.* 2023), the relatively narrow altitudinal gradient among the studied zones may have constrained the observed patterns. This limitation suggests that future research should incorporate broader elevation ranges and additional environmental variables comprising temperature, rainfall, and vegetation heterogeneity to better disentangle the effects of altitude from other ecological factors influencing stemborer distribution.

Contrary to earlier studies reporting higher stemborer abundance in cultivated cereals and limited presence in wild vegetation (Moolman *et al.* 2014; Ong'amo 2005; Otieno *et al.* 2008), our data show a greater proportion in wild vegetation. This finding challenges the conventional assumption that wild grasses serve only as minor refugia during maize off-seasons (Haile and Hofsvang 2002; Moolman *et al.* 2014; Ntirenganya *et al.* 2025). Instead, our results align with emerging evidence from Ethiopia, where wild grasses have been reported to support substantial stemborer populations (Goftishu *et al.* 2018), especially during dry periods when maize is absent (Gounou *et al.* 2009). While this trend may partly reflect our purposive sampling of host-relevant plant families, as noted in the methodology, acknowledging this bias is essential to enhance transparency and strengthens the validity of ecological interpretation by distinguishing design-driven patterns from genuine biological processes (Pili *et al.* 2025; Zvereva and Kozlov 2019).

Seasonal host-switching patterns were also evident. During the rainy cropping season, maize plantations supported a significantly higher abundance of stemborers, while the dry season was characterized by the absence of cultivated maize, the season showed a notable shift in stemborer populations toward wild vegetation, particularly Pennisetum purpureum (Elephant/Napier grass), which harboured approximately 61% of the stemborer population *P. purpureum* emerged as the primary dry season refugium, harbouring approximately 61% of the stemborer population. This seasonal host-switching behaviour underscores the ecological importance of wild grasses in sustaining stemborer populations during maize off-seasons (Assefa *et al.* 2010; Goftishu *et al.* 2018; Gounou *et al.* 2009; Ong'amo 2005), suggesting that integrated pest

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management (IPM) strategies must consider both cultivated and wild vegetation to achieve sustainable stemborers management.

The observed dominance of stemborers, particularly *Busseola fusca* in *Pennisetum purpureum* (Napier grass) compared to maize across seasons is notable and may be explained by regional differences in Napier grass application and management. In the highland of northern province of Rwanda, Napier grass is commonly maintained to full maturity and harvested after two years for non-agronomic uses such as supporting climbing beans, constructing domestic infrastructure, and producing handcraft materials (Ayuko *et al.* 2024; Chen *et al.* 2024). In the lowland of eastern province, Napier grass is frequently harvested for livestock feed and mulching (Ayuko *et al.* 2024; Chen *et al.* 2024; Tulu *et al.* 2023), keeping the yearly young generations in the area. These contrasting practices influence the phenological stage of the host availability to stemborers. Previous studies have shown that *B. fusca* exhibits a strong preference of younger Napier grass for oviposition (Assefa *et al.* 2015; Calatayud *et al.* 2008; Khan *et al.* 2007). Therefore, the predominance of *B. fusca* in low altitude of eastern Rwanda may be linked to the continuous availability of younger Napier grass due to regular harvesting, creating favourable conditions for oviposition and population buildup.

Our results do not ignore other eco-socio-economic benefits of Napier grass (ICIPE 2005; Niassy *et al.* 2022). The role of *Pennisetum purpureum* as a trap crop has been well-established within the framework of push-pull technology (ICIPE 2005; Khan *et al.* 2011, 2007; Niassy *et al.* 2020). When strategically planted around maize fields, it attracts ovipositing female moths, whose larvae suffer high mortality due to the grass's physical and chemical defences, including a sticky exudate that impedes development (Abedi *et al.* 2019; Calatayud *et al.* 2008; Glas *et al.* 2007; Haile and Hofsvang 2002; Khan *et al.* 2007). This mechanism effectively reduces pest pressure on maize and contributes to environmentally sustainable and economically viable integrated pest management (IPM) strategies (Niassy *et al.* 2020, 2022). However, in East African and regional agroecosystems, fodder grasses such as Pennisetum spp., Tripsacum spp., Vetiveria spp., and Setaria spp. have historically been domesticated for livestock feed and erosion control (Ayuko *et al.* 2024; Chen *et al.* 2024; Tulu *et al.* 2023), often without standardized spacing or integration into pest management frameworks.

However, in East African and regional agroecosystems, fodder grasses such as *Pennisetum spp.*, *Tripsacum spp.*, *Vetiveria spp.*, and *Setaria spp.* have historically been domesticated for livestock feed and erosion control (Ayuko *et al.* 2024; Chen *et al.* 2024; Tulu *et al.* 2023), often without standardized spacing or integration into pest management frameworks. We propose that future research should adopt a multifunctional approach to evaluate the dual role of these grasses in IPM and soil conservation, alongside improving farmers' awareness on standard distancing/spacing between fodders and cultivated crops. Such studies are essential for redesigning sustainable push-pull or intercropping pest management strategies tailored to mountainous and terraced landscapes like Rwanda, where landslides or erosions control and pest suppression must be co-optimized.

Conclusion

This study provides the first comprehensive data on stemborer species composition and distribution across Rwanda's agroecological zones. The findings confirm that *Busseola fusca*, *Sesamia calamistis*, *Sesamia nonagrioides* (Lepidoptera: Noctuidae), *Chilo partellus* (Lepidoptera: Crambidae), and *Eldana saccharina* (Lepidoptera: Pyralidae) are the most abundant stemborer species in wild plants. Even though altitudinal gradient and seasonal variation can independently influence stemborers community structure, our findings demonstrated that their combined effects exert a stronger and more ecologically meaningful influence on stemborer community structures. *Pennisetum purpureum* (Napier grass) emerged as a key alternative host, whose widespread and varied harvesting practices may contribute to stemborer persistence across different agro-ecological zones. Evidence of potential habitat shifts by *B. fusca* and *C. partellus*, further suggests potential niche expansion that warrants long-term monitoring under changing climatic and agricultural conditions. We recommend future research to determine the optimal spatial arrangement between crops and fodder grasses and to assess the multifunctional benefits of these grasses such as their roles in soil stabilization, erosion and landslide mitigation, and pest suppression particularly within mountainous and terraced agroecosystems common in Rwanda. Such insights will be critical for redesigning sustainable push-pull and intercropping strategies that enhance both crop productivity and ecological resilience pest management.

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Competing interests. The authors declare none.

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