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Distribution and relative importance of cereal stem borers and their natural enemies in the semi-arid and cool-wet ecozones of the Amhara State of Ethiopia

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Abstract. The distribution and relative importance of lepidopteran and coleopteran stem borers and their natural enemies on maize and sorghum were studied in cereal growing zones of the Amhara State of Ethiopia from 2003 to 2004. Sorghum is the major crop in semi-arid eastern and maize in the cool-wet western zones of the Amhara state. Four administrative zones, 10 districts and 88 localities in the semi-arid ecozone (SAE) and four zones, 19 districts and 71 localities in the cool-wet ecozone (CWE) were chosen for the study. In SAE, the species composition was 91% *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae), 8% *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and 1% *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae). In the CWE, maize and sorghum are grown in different ecozones and thus *B. fusca* was the dominant species on sorghum, whereas 61% *B. fusca* and 39% *S. calamistis* were recorded on maize. Borer density generally increased with crop growth stage. *C. partellus* parasitism by *C. flavipes* Cameron (Hymenoptera: Braconidae), which occurred only in SAE, varied among districts ranging from 5% to 39%. In the CWE, unidentified nematodes parasitized medium-sized *B. fusca* larvae during the wet months. Population of native parasitoids was very low. The coleopteran borer, *Rhynchaenus niger* (Horn) (Coleoptera: Rhynchophoridae), attacked sorghum plants in both regions. Sorghum yields were negatively related to plant damage variables and positively to larval parasitism and plant growth variables. On maize, plant damage was too low to affect yields. Taylor's power law indicated aggregated distribution for *C. partellus* and *B. fusca* larvae and pupae combined.

Résumé. Distribution et importance relative des foreurs de graminées et de leurs ennemis naturels dans les zones semi-arides et plus humides et froides de l'état d'Amhara en Ethiopie. La distribution et l'importance relative des lépidoptères et coléoptères foreurs ainsi que de leurs ennemis naturels ont été étudiées de 2003 à 2004 dans les zones de culture du maïs et du sorgho de l'état d'Amhara en Ethiopie. Le sorgho est principalement cultivé dans les zones semi-arides de l'Est de l'état, alors que le maïs est plutôt cultivé dans des zones froides et humides à l'Ouest. Quatre zones administratives ont été choisies pour cette étude dans les zones semi-arides comprenant 10 districts et 88 localités; et quatre autres zones administratives comprenant 19 districts et 71 localités dans les zones froides et humides. Dans les zones semi-arides, parmi les espèces de lépidoptères collectés, 91% a été représenté par *Chilo partellus* (Swinhoe) (Lepidoptera : Crambidae), 8% par *Busseola fusca* (Fuller) (Lepidoptera : Noctuidae) et 1% par *Sesamia calamistis* Hampson (Lepidoptera : Noctuidae). Dans les zones froides et humides, le maïs et le sorgho ne sont pas cultivés ensemble, mais dans différentes zones écologiques. De ce fait, *B. fusca* était l'espèce de lépidoptère foreur dominante sur sorgho, alors qu'elle ne représentait que 61% sur maïs où *S. calamistis* était aussi présent pour 39%. La densité de lépidoptères foreurs a augmenté généralement avec le stade de développement des plantes. Le taux de parasitisme de *C. partellus* par *Cotesia flavipes* Cameron (Hymenoptera : Braconidae), qui est présent seulement dans les zones semi-arides, variait selon les districts de 5% à 39%. Dans les zones froides et humides, une espèce de nématode non identifiée attaquait les larves de *B. fusca* de taille moyenne pendant les mois les plus humides. La population des parasitoïdes autochtones de cette zone était très faible. Le coléoptère foreur, *Rhynchaenus niger* (Horn) (Coleoptera : Rhynchophoridae), infestait le sorgho dans les deux types de régions. Le rendement en sorgho était négativement corrélé aux paramètres liés aux dommages de la plante et positivement au parasitisme larvaire et aux variables liées à la croissance de la plante. Sur maïs, les dommages de la plante étaient trop faibles pour en affecter son rendement. La loi de Taylor a indiqué une distribution d'agrégation pour les larves et les chrysalides de *C. partellus* et *B. fusca*.

Keywords: Stem borer, parasitoids, importance, distribution, Ethiopia.

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In Africa, maize and sorghum are major staples with ca 42 and 20 million tons produced, respectively, in 2002 (FAO 2003). In Ethiopia, these crops are grown on 2.4 million hectares contributing about 41% of the country's annual grain production (CSA 2000; CACC 2003). Maize is one of the major staple food crops, 90% of which is used mainly for human consumption (Ferdu *et al.* 2001). It thrives well in cool and wet intermediate altitudes (1500-2000 m above sea level [m asl]), while sorghum is the dominant crop in the lowlands (< 1500 m asl). The major pests of field-grown maize are the crambid *Chilo partellus* (Swinhoe 1885), the noctuids *Busseola fusca* (Fuller 1901) and *Sesamia calamistis* Hampson 1910 (Assefa 1985), and various species of termites (*Macrotermes* and *Microtermes* species). In addition to those species, *Sesamia nonagrioides botanephaga* (Lefèbvre 1827), *Rhynchaenus niger* (Horn 1873) (Coleoptera: Curculionidae), *Pissodes dubius* (Strom 1783) (Coleoptera: Curculionidae) have been recorded from sorghum (Emana 2002). Recently, the exotic braconid parasitoid *Cotesia flavipes* Cameron 1891 was found parasitizing *C. partellus* larvae in some parts of Ethiopia (Emana 2002; Emana *et al.* 2003). This parasitoid was introduced into Kenya in 1993 by the International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya, as part of a classical biological control program now encompassing eleven countries in East and Southern Africa (Overholt *et al.* 1994a). In coastal Kenya, it has reduced *C. partellus* densities by 60% and increased yields by 10-15% (Overholt *et al.* 1997; Zhou *et al.* 2001). It is believed that it has invaded Ethiopia probably from Somalia where it was introduced in 1997 (C. Omwega, ICIPE, Kenya, pers. comm.). Molecular analysis of the Ethiopian and Kenyan *C. flavipes* populations has revealed 100% similarity (Yoseph Assefa, KwaZulu-Natal University, South Africa, *pers. comm.*).

Reported crop losses in Ethiopia by *C. partellus* and *B. fusca* range from 15 to 100% (Assefa 1989; Tadesse 1989; Gashawbeza & Melaku 1996; Emana 1998). Although the Amhara State is contributing one-third of both the area and production of the country's maize and sorghum grain (BOA 1999; CACC 2003), information about the species composition and pest status of stem borers and their natural enemies in the region is scanty (Shegaw *et al.* 1999). Borers are believed to have aggravated recurrent famines especially in semi-arid eastern Amhara (BOA 1999; Emana 2002). Information about the relative importance of a key pest is a prerequisite for priority setting in pest management (Ndemah *et al.* 2001a). Thus, the objective of the present study was to assess the distribution and importance of stem borer species and to establish a catalogue of natural enemies in the Amhara State.

Materials and methods

Study area

The study was conducted in 2003 and 2004 in the Amhara National Regional State (ANRS), which is located in north-western, north-eastern and central parts of Ethiopia. In this study, the Amhara State is divided into two ecologically distinct parts, i.e., semi-arid eastern and cool-wet western Amhara. The State is situated between 8° 45' N to 13° 45' N latitude and 35° 46' E to 40° 25' E longitude and has an area of 170,000 km^2 (PEDB 1999). Rainfall gradually increases from 700 mm in the semi-arid to over 2000 mm in the cool-wet western Amhara. In the cool-wet ecozone, there is one effective rainy season that lasts for three to six months (June to November), its intensity and duration increasing westward. However, there is a short rainy period, lasting about a month, around April, which is not sufficient to grow crops, but it is used for land preparation and to plant long maturing sorghum varieties in some highlands of East Gojam.

The semi-arid eastern part, however, is sufficiently bimodal as it also receives some rains from March to May (short rains) due to easterly winds, in addition to the main rainy season of mid-June to September. The study areas in the semi-arid region of the Amhara state, which are planted mainly to sorghum, lay between 1200 to 1985 m asl and the cool-wet western region, mostly planted to maize, lay between 1300 and 2600 m asl.

Sampling procedures

In the cool-wet ecozone, four administrative zones, i.e., East Gojam, West Gojam (maize belt of the State), South Gondar and North Gondar, and in the semi-arid ecozone four sorghum producing zones, i.e., North Shoa, Oromiya, South Wolo and North Wolo of the Amhara State were studied. A total of 159 localities (fields) were surveyed (fig. 1). In the semi-arid eastern ecozone, 88 localities within 10 districts and 4 zones, and in the cool-wet ecozone, 71 localities within 19 districts and 4 zones were sampled. The number of localities and the distance between them varied between zones depending on the scale of cereal production. In areas of continuous production, fields were selected at 10-km intervals. At each locality, more accessible fields close to the road were sampled. The latitude, longitude, and elevation of each study site were determined with a Global Positioning System (GPS).

In both regions, fields were sampled at various growth stages of the crops. These include the seedling, knee height, flag leaf, tasseling, grain filling and harvest stages. The study was mostly conducted during the main growing season. Length of time between stages varied with crop variety and ecozone. In the semi-arid region, both late, which need two consecutive seasons, i.e. about 9-months, and early, 4 to 5-month, maturing sorghum varieties were planted; maize is always early maturing in this region. The cool-wet ecozone received rains one month earlier than the semi-arid ecozone but crops in the latter region grew faster due to higher temperature and matured almost at the same time as in the cool-wet region. Number of localities surveyed at each growth stage varied from 31 to 57 in the semi-arid, and 29 to 45 in the cool-wet region. Much of the semi-arid eastern Amhara is planted with sorghum, whereby late maturing varieties, which grow as tall as 4m, are planted during the short rains in April and are harvested in December. Different sorghum varieties were identified based on the duration to maturity. Long maturing refers to 8-9 month, medium refers to 6-7 month and early for 4-5 month varieties. Maize is also grown in semi-arid eastern Amhara, especially during the short rains, i.e., from around February to May, and harvested before the main rainy season, i.e., June to September. In the semi-arid region, the field size varied from less than a quarter of a hectare in hilly terraces to tens of hectares grown in extensive vertic plains. In this same region, some 60% of farmers intercrop sorghum with beans or sesame. In the cool-wet ecozone, on the other hand, field sizes varied from less than a hectare to about two hectares and most farmers traditionally intercrop maize with mustard and faba bean on a wide variety of soil types.

Destructive sampling procedure was used. Each field was divided into 4 sections, from which 3×3 m^2 quadrants were sampled. On each quadrant, total plant density, number of

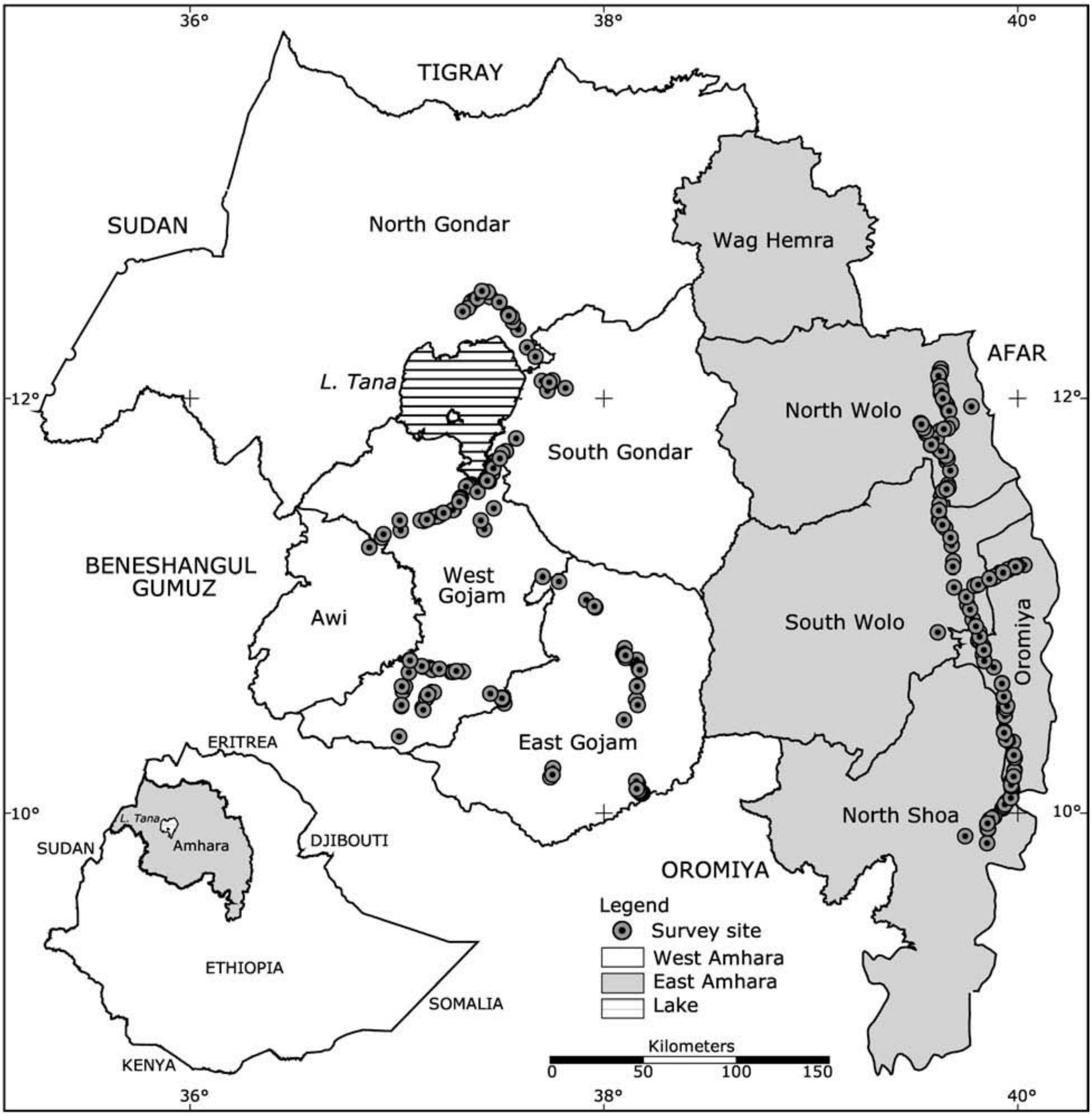

Figure 1
Survey localities in the Amhara state, 2003 and 2004 (dotted circles indicate survey localities, West Amhara is the cool-wet and East Amhara the semi-arid ecozones, and L Tana indicates Lake Tana).

plants infested (dead-heart and leaf damage) and un-infested were recorded. Five plants were then randomly selected per quadrant and dissected to determine the number of larvae and pupae as well as of natural enemies. Plant growth stage, plant height, basal stem diameter, number of internodes (damaged and undamaged), length of stem tunnelling, number of holes, number of borers, *Cotesia* spp. cocoon masses and other parasitoids and earwigs were recorded. At harvest peduncle for sorghum and cob for maize damage per plant, and grain yield from a 16 m^2 area per field were estimated. Peduncle damage was assessed by observing the peduncle. It could be either damaged or undamaged. This damage symptom is common observation in the area, even when other parts of the plant are not attacked. Cob damage was estimated by counting the number of grain bearing rows in a cob. If one row of 10 in a cob was fully infested, we took that as 10% infested, etc. A sample of the grain was taken and its moisture content determined using a moisture tester and the yield was then adjusted at 14% moisture content for both crops.

Borer larvae were kept in 3 × 1 inch vials and reared on pieces of sorghum or maize stem until adult moth or parasitoid emergence. The parasitoids were identified at the International Center of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya.

Statistical analysis

Analyses of variance (ANOVA) were conducted using the mixed model procedure (SAS 1999-2000) to determine variation in borer density, natural enemies (% larval parasitism and of earwig density), plant damage variables and yield between years, regions, zones, and crop growth stages. Locality, district, year x zone x district x locality constituted random effects, while year, zone, crop growth stage and variety constituted fixed factors. Localities were nested within districts, districts within zones, zones within years. The percentage variance estimates for the random effects were calculated, and when the mean estimates of fixed factors were significant, they were separated using Tukey-Kramer test.

Correlation analyses were conducted to assess interactions between plant growth, plant damage, borer density, percent parasitism, altitude, and plant growth stage using mean data for each locality.

Stepwise multiple regressions were computed to evaluate the effects of plant growth parameters, borer damage and parasitism to sorghum and maize yields (SAS 1999-2000).

Taylor's (1961) power law was used to describe the dispersion of borer larvae and pupae at different growth stages of the crop. The law postulates a consistent relationship for a particular species between variance S^2 and the mean X:

$$S^2 = aX^b \quad (1)$$

where b is a measure of dispersion of the species, with $b>1$ indicating an aggregated distribution, $b = 1$ randomness, and $b < 1$ regular distribution, while a is considered a mere scalar factor without biological meaning. These coefficients were computed by regressing the natural logarithm of the between plant variance ($\ln S^2$) against the natural logarithm of mean density ($\ln X$), for each crop species, crop growth stage, region, or sampling occasion. Slope values across crop growth stages of a particular borer species were compared by using the PROC GLM and also with 1 using the PROC REG procedures of SAS.

When necessary, percentage data were arcsine and counts log (x+1) transformed to stabilize the variance. The significance level was set at $P = 0.05$.

Results

Seasonal and regional variation in abundance of stem borers and their natural enemies

Stem borers

Across sampling periods, 12,500 borers were collected in the two agroecozones investigated. Borer density and species composition varied with region (semi-arid eastern and the cool-wet western Amhara), administrative zone, year, crop phenology, crop type and variety (tab. 1). Of the total borers collected, 75.4% were found in the semi-arid eastern (SAE) and 24.6% in the cool-wet ecozone (CWE) regions. Furthermore, 62.2% were *C. partellus*, 33.7% *B. fusca* and 4.1% *S. calamistis*. Again, 60.2% of borers were *C. partellus* borers found on sorghum and 2% on maize; 23.2% were *B. fusca* borers on sorghum and 8% on maize; and, some 1% *S. calamistis* borers on sorghum and 3.2% on maize. In addition, 154 *R. niger* stemboring grubs and adults were collected from inside the dissected stems. In the cool-wet region, where maize was the major crop, *B. fusca* and *S. calamistis* were of similar importance, especially in areas near Lake Tana, while on sorghum, *B. fusca* was dominant and *S. calamistis* was rare. In the semi-arid region, where sorghum was the major crop, the predominant species was *C. partellus* followed by *B. fusca* and *S. calamistis* (tab. 1).

The species composition was similar during both years. In 2004, in semi-arid region, on sorghum, the composition was 91% *C. partellus*, 8% *B. fusca* and 1% *S. calamistis*.

For total borer density on sorghum, random effects (Locality x District x Zone x Year, hereafter referred to as L x D x Z x Y) contributed 34% of the variation. On both plant species most of the variation in borer densities was due to residual, i.e., between plant variation followed by L x D x Z x Y and Z x Y (tab.1).

In the cool-wet region, on sorghum, it was solidly *B. fusca*, whereas on maize 61% *B. fusca* and 39% *S. calamistis* were recorded; at tasseling stage, however, 91% of the borers were *S. calamistis*.

R. niger was found on sorghum in both regions. Densities were generally low but they were higher in semi-arid eastern Amhara. Total borer densities on sorghum tended to be higher in eastern (semi-arid ecozone) than the cool-wet western Amhara and they were higher in the 2003 than the 2004 season (tab. 1). On both sorghum and maize, borer densities increased from the seedling to the grain filling stage and then decreased at harvest. As it can be seen on sorghum in table 1, overall densities of *C. partellus* in the Amhara state were 2–4 times higher than those of *B. fusca*. In most study areas, *S. calamistis* was minor on sorghum, but surprisingly it was the only species on maize in West Gojam and South Gondar zones bordering Lake Tana (tab. 1; fig. 1). This area specifically covers the plains in the southeastern parts of the lake, which crosses the two neighboring zones. Its importance declines as we move away from the lake area. In the semi-arid region, total borer density and *Ch. partellus* steadily decreased northwards from North Shoa to North Wolo zones (tab.1; fig. 1). Unlike *R. niger*, lepidopterous borer density was significantly higher on the traditional long maturing sorghum varieties than medium and early maturing ones (tab.1).

Natural enemies

Across all sampling periods, 1879 cocoon masses were collected from inside the dissected stems. *C.*

Table 1. Effects of year, location and crop growth stage on abundance of borers per plant on sorghum and maize in the semi-arid and cool-wet ecozones of Amhara state, Ethiopia, in 2003 and 2004.

	Sorghum	Maize	Sorghum	Sorghum			Maize	
	Total lepidopterous borers/ plant		*R. niger*/ plant	*C. partellus*	*B. fusca*	*S. calamistis*	*B. fusca*	*S. calamistis*
Random effects				**% Variation explained**				
Locality (D x Z x Y)*	34.0	12.9	21.1	32.6	23.5	24.7	10.4	6.1
Zone (year)	11.3	14.0	43.0	17.0	1.3	0.5	9.1	4.5
District	0.0	2.8	0.9	0.0	16.2	0.1	7.1	0.0
Residual	54.7	70.3	35.0	50.4	59.0	74.7	73.4	89.4
Fixed effects				**Least square means (±SE)**				
Year								
2003	2.4±0.46a	0.56±0.30a	0.091±0.01a	1.86±0.34a	0.50±0.11a	0.03±0.01a	0.37±0.31a	0.09±0.06a
2004	1.1±0.43b	0.01±0.33b	0.001±0.01b	0.83±0.31b	0.28±0.10b	0.01±0.01b	0.01±0.33b	0.07±0.05a
F value	15.90	13.29	89.98	12.10	6.54	9.82	16.62	0.09
P value	<.0001	0.0007	<.0001	0.0006	0.0114	0.0020	0.0002	0.7666
Administrative zone **(No. localities)** **								
East Gojam (20)	1.2±0.8b	0.67±0.3a	0.001±0.01c	DE	0.93±0.16a	0.0030±0.01b	0.52±0.32	0.09±0.05
West Gojam (22)	0.0±2.3c	0.28±0.3a	0.020±0.02bc	DE	0.00±0.55b	0.0003±0.06ab	0.05±0.24	0.13±0.04
South Gondar (16)	1.4±1.4b	0.01±0.6a	0.001±0.02c	DE	0.43±0.31a	0.0100±0.02ab	0.10±0.32	0.11±0.08
North Gondar (20)	1.8±0.8b	0.00±0.9a	0.001±0.01c	DE	0.93±0.18a	0.0100±0.01ab	0.15±0.12	0.00±0.16
North Shoa (15)	3.2±1.1a	-	0.080±0.02b	2.94±0.49a	0.23±0.21a	0.0050±0.01b	-	-
Oromiya (24)	2.9±0.7a	-	0.070±0.01b	2.64±0.35a	0.05±0.15b	0.0060±0.01b	-	-
South Wolo (22)	2.0±0.7b	-	0.131±0.01a	1.78±0.37b	0.25±0.15a	0.0500±0.01a	-	-
North Wolo (23)	1.2±0.6b	-	0.172±0.01a	1.23±0.35b	0.34±0.14a	0.0400±0.01a	-	-
F value	2.20	1.06	29.07	4.10	3.85	5.22	0.47	0.42
P value	0.0371	0.4000	<.0001	0.0292	0.0457	<.0001	0.6345	0.7415
Growth stage								
Seedling	0.6±0.5c	0.0±0.1c	0.001±0.01c	0.31±0.32d	0.25±0.11c	0.014±0.01b	0.0±0.0b	-
Knee height	2.6±0.4b	0.6±0.3ab	0.001±0.02c	2.25±0.33b	0.45±0.11b	0.010±0.01b	0.0±0.0b	0.10±0.05a
Tasseling/ Flag leaf†	2.4±0.6b	0.9±0.3a	0.131±0.04a	1.78±0.51ac	0.56±0.18ac	0.023±0.02ab	0.51±0.31a	0.19±0.05a
Grain filling	3.3±0.4a	0.9±0.5a	0.082±0.01a	2.71±0.31a	0.61±0.10a	0.039±0.01a	0.01±0.53b	0.08±0.10ab
Harvest	0.9±0.4c	0.4±0.3b	0.081±0.01a	0.47±0.31cd	0.51±0.10ab	0.007±0.008b	0.44±0.28a	0.01±0.03b
F value	112.10	9.49	5.68	111.56	28.245	8.32	7.77	19.15
P value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Variety* **								
Long maturing	4.4±0.2a	-	0.23±0.06b	4.2±0.19a	0.17±0.01a	0.05±0.004a	-	-
Medium maturing	1.5±0.3b	-	1.26±0.18a	1.43±0.38b	0.04±0.02b	0.02±0.005b	-	-
Early maturing	1.9±0.2b	-	1.30±0.12a	1.79±0.31b	0.09±0.02b	0.03±0.007b	-	-
F avlue	15.74	-	28.57	34.02	15.74	15.24	-	-
P value	<.0001	-	<.0001	<.0001	<.0.0001	<.0001	-	-

† Flag leaf for sorghum and tasseling for maize; - indicates no data or minor crop status; DE stands for the pest does not occur; ** 1st four administrative zones are in the cool-wet western Amhara (cool and wet climate), 2nd four in semi-arid eastern Amhara (semi-arid climate); *** long maturing stands for 8-9 month, medium for 6-7 month and early for 4-5-month varieties of sorghum only; Y stands for Year, Z for zone and D for district. Means followed by the same letter(s) within a column of a fixed effect are not significantly different according to Tukey-Kramer (P < 0.05).

flavipes was the predominant parasitoid species and it was only found in the *C. partellus*-dominated semi-arid eastern Amhara (North Shoa, Oromiya, South Wolo and North Wolo zones) (tab.2). Number of cocoon masses per plant and percent parasitism was highest in North Shoa and lowest in North Wolo zone. Larval parasitism was similar during both years though cocoon mass numbers were higher in 2003 than 2004. Larval parasitism increased with crop stage up to grain filling and then decreased at harvest. Long maturing sorghum varieties had significantly higher parasitism by *C. flavipes* and cocoon mass density than medium maturing ones (tab.2). In addition to *C. flavipes*, ten species of parasitoids and one hyperparasitoid, *Aphanogmus fijiensis* (Ferriere)

Table 2. Effects of year, location and crop growth stage on abundance of cocoon masses and earwigs per plant, on level of larval parasitism by C. flavipes and nematodes in the Amhara state, in 2003 and 2004.

	Sorghum				Maize	
	Cocoon masses/ plant	% Larval parasitism	Number of earwigs/ plant	Nematodes / plant	Nematodes / larva	Nematodes / plant
Random effects			**% Variation explained**			
Locality (district x zone x year)	21.2	16.5	14.1	7.9	2.2	3.1
Zone (year)	4.9	4.6	0.6	1.8	0.2	0.0
District	2.6	1.6	0.0	0.0	0.0	0.3
Residual	71.3	77.3	85.2	90.4	97.6	96.6
Fixed effects			**Least square means (±SE)**			
Year						
2003	0.7±0.06a	8.9±2.5	0.08±0.02a	0.01±0.005	0.005±0.003	0.004±0.04
2004	0.4±0.04b	11.3±2.0	0.02±0.00b	0.01±0.005	0.002±0.004	0.001±0.05
F value	9.48	0.58	64.57	0.22	0.62	0.12
P value	<.0001	0.4480	<.0001	0.6376	0.4313	0.7271
Administrative zone						
North Shoa	0.9±0.07a	23.4±5.5a	0.03±0.01a	0.003±0.010	0.001±0.004	-
Oromiya	0.5±0.05b	18.6±4.1ab	0.03±0.01a	0.010±0.004	0.002±0.003	-
South Wolo	0.5±0.06b	16.4±3.9bc	0.07±0.01a	0.010±0.004	0.003±0.003	-
North Wolo	0.3±0.06c	16.0±3.6c	0.03±0.01a	0.003±0.004	0.001±0.003	-
East Gojam	-	-	0.00±0.02b	0.010±0.010	0.010±0.004	0.01±0.11b
West Gojam	-	-	0.00±0.01b	0.010±0.030	0.010±0.025	0.05±0.07a
South Gondar	-	-	0.00±0.03b	0.010±0.010	0.010±0.010	0.02±0.14b
North Gondar	-	-	0.00±0.02b	0.010±0.010	0.0001±0.004	0.01±0.10b
F value	19.68	6.28	8.81	0.41	0.60	5.40
P value	<.0001	0.0003	<.0001	0.8926	0.7519	0.0341
Growth stage						
Seedling	0.2±1.1b	0.0±2.7c	0.00±0.01c	0.001±0.01b	0.0004±0.004b	-
Knee height	0.2±0.2c	1.3±2.1c	0.00±0.01c	0.001±0.01b	0.0005±0.005b	0.06±0.04
Tasseling/ Flag leaf †	0.5±0.3b	24.0±1.4a	0.01±0.01b	0.040±0.012a	0.0240±0.009a	0.00±0.04
Grain filling	1.3±0.13a	28.5±1.2a	0.01±0.01b	0.002±0.005b	0.0014±0.004b	0.00±0.09
Harvest	0.4±0.13b	14.8±1.4b	0.05±0.01a	0.000±0.010b	0.0000±0.004b	0.00±0.03
F value	25.24	66.74	9.14	17.38	9.82	2.17
P value	<.0001	<.0001	<.0001	<.0001	<.0001	0.0926
Variety*						
Long maturing	0.8±0.07a	16.8±1.4a	0.03±0.02b	-	-	-
Medium maturing	0.1±0.14b	1.1±2.7b	0.01±0.04b	-	-	-
Early maturing	0.6±0.11a	15.5±2.2a	0.27±0.03a	-	-	-
F value	10.97	13.37	24.59	-	-	-
P value	<.0001	<.0001	<.0001	-	-	-

† Flag leaf for sorghum and tasseling for maize; - indicates no data or minor crop status; means followed by the same letter(s) within a column of a fixed effect are not significantly different according to Tukey-Kramer (P<0.05).

Table 3. Hymenopteran parasitoids of stem borers on cereal crops in different areas of the Amhara State, Ethiopia, in 2003 and 2004.

Family	Species	# Parasitoid	% Parasitism*	Host borer reared from	Behavior	Zone	Region
Braconidae	*Cotesia flavipes* Cameron	Thousands	29.00	*C. partellus larvae*	Gregarious	All zones	EA
Braconidae:	*Cotesia sesamiae*	2	0.7	*B. fusca* larvae	Gregarious	East Gojam	WA
Braconidae	*Euvipio rufa* Szepligeti	1	0.7	*B. fusca*	Solitary	North Gondar	WA
Braconidae	*Dolichogenidea*	1	0.2	*B. fusca* larvae	Gregarious**	South Gondar	WA
Braconidae	*Cotesia sesamiae*	1	0.7	*B. fusca* larvae	Gregarious	East Gojam	WA
Braconidae	*Dolichogenidea fuscivora* Walker	1	2.2	B. fusca	Gregarious	North Gondar	WA
Braconidae	*Dolichogenidea fuscivora* Walker	1	2.2	*B. fusca***	-	North Gondar	WA
Braconidae	*Dolichogenidea fuscivora* Walker	1	0.2	*B. fusca*	Gregarious**	South Gondar	WA
Ceraphronidae:	*Aphanogmus fijiensis* Ferriere	1	0.7	*C. partellus*	Gregarious	North Wolo	EA
Eulophidae	*Pediobius furvus* Gahan	1	2.3	*C. partellus* pupa	Gregarious	Oromiya	EA
Eulophidae	*Pediobius furvus* Gahan	1	1.0	*C. partellus* pupa	Gregarious	South Wolo	EA
Eulophidae	*Pediobius furvus* Gahan	1	0.4	*B. fusca* pupa	Gregarious	North Wolo	EA
Ichneumonidae		1		Unidentified pupa	Solitary	West Gojam	WA
Ichneumonidae		1		*B. fusca* pupa	Solitary	West Gojam	WA
Ichneumonidae		1		*B. fusca*	Solitary	West Gojam	WA
Ichneumonidae	*Dentichasmias busseolae* Heinrich	1	1.0	*C. partellus* pupa	Solitary	South Wolo	EA
Ichneumonidae	*Procerochasmias nigromaculatus* Cameron	2	1.3	*B. fusca*	Solitary	West Gojam, North Gondar	WA
Ichneumonidae	*Dentichasmias busseolae* Heinrich	1	0.2	*C. partellus* pupa	Solitary	Oromiya	EA

* percentage parasitism was calculated for individual survey sites, where the parasitoids were found, except for *Co. flavipes* which occurred widely;
** empty cocoon masses from which adult parasitoids have emerged were discovered; EA semi-arid eastern Amhara, WA the cool-wet western Amhara.

Table 4. Taylor's power law coefficients of borers at various growth stages of sorghum in the two regions of the Amhara state.

	Crop growth stage	Intercept (log a)	Slope (b)	r^2	P >F
Eastern Amhara	**Sorghum**				
	Ch. partellus				
	Seedling (belg)	0.78	1.22*a	0.93	<.0001
	Knee height	0.47	1.27*a	0.84	<.0001
	Grain filling	0.49	1.10a	0.66	<.0001
	Harvest	0.22	0.91a	0.76	<.0001
	B. fusca				
	Knee height	0.65	1.27*a	0.92	<.0001
	Grain filling	–0.06	0.97a	0.48	0.0182
	Harvest	–0.09	0.53*b	0.99	<.0001
	Pooled	0.28	1.64*a	0.79	<.0001
	S. calamistis				
	Seedling	0.40	1.06b	0.88	0.0060
	Knee height	0.35	1.10b	1.00	<.0001
	Grain filling	0.63	1.27*a	0.93	<.0001
	***C. flavipes* cocoon masses**				
	Knee height	0.69	1.27*a	0.87	<.0001
	Grain filling	0.33	1.17*a	0.91	<.0001
	Harvest	0.63	1.15b	0.65	0.0027
Western Amhara	**Maize**				
	B. fusca				
	Pooled	0.34	1.10	0.66	<.0001

* Slope different from 1, F-test, P<0.001; for each species separately slopes followed with the same letter(s) are not significantly different (P=0.05).

(Ceraphronidae) - belonging to five hymenopteran families were recorded (tab. 3). However, compared to *C. flavipes*, the rates of parasitism were exceedingly low (< 3%).

Number of earwigs varied significantly with administrative zone; it was higher during 2003 than 2004 and it increased with crop growth stage until harvest. Residual or between plant variance contributed more than 70% of the overall variation followed by L x D x Z x Y (tab. 2).

In much of the cool-wet western Amhara, unidentified nematode species parasitized medium *B. fusca* larvae during the wet months between August and September in both years, which was lower in 2004

Table 5. Effect of year, location and crop growth stage on damage variables on sorghum and maize in the Amhara state, in 2003 and 2004.

	Sorghum			Maize			
	% Stem tunneling	% Internode damage	# Holes/ plant	% Stem tunneling	% Internode damage	# Holes/ plant	% Cob damage
Random effects				**% variation explained**			
Locality (year x zone x district)	32.9	45.5	37.0	16.5	23.0	25.5	11.5
Zone (year)	17.7	9.3	13.9	10.9	0.0	11.3	0.0
District	0.4	1.1	1.4	2.0	24.2	15.5	5.9
Residual	49.0	44.1	47.7	70.6	52.8	47.7	82.6
Fixed effects				**Least square means (±SE)**			
Year							
2003	13.2±2.4a	24.4±3.9a	6.5±1.2a	7.6±1.8a	24.5±5.1a	4.2±1.5	0.3±1.8a
2004	7.9±2.1b	17.9±3.2b	3.2±1.2b	5.1±1.9a	17.1±4.3b	2.4±1.6	1.4±1.5a
F value	7.20	4.93	10.89	3.73	30.66	2.65	0.35
P value	0.0081	0.0280	0.0012	0.0621	<.0001	0.1129	0.5596
Administrative zone							
East Gojam	8.3±0.5d	8.5±0.9b	0.5±0.2bc	5.4±2.0	20.7±5.5	5.3±1.7	0.3±2.2
West Gojam	0.0±0.0e	0.0±0.0c	0.0±0.0c	6.3±1.5	20.4±4.2	5.2±1.2	1.8±1.5
South Gondar	12.7±1.3cd	9.5±1.3b	0.1±0.2bc	9.3±3.8	21.4±9.2	5.5±3.2	0.6±3.1
North Gondar	21.5±0.7ab	22.8±0.8a	2.3±0.2bc	-	-	-	-
North Shoa	26.2±1.2a	40.2±1.3a	11.6±0.6a	-	-	-	-
Oromiya	18.7±0.7ac	36.0±0.9a	10.6±0.4a	-	-	-	-
South Wolo	16.9±0.7ad	31.1±0.9a	9.0±0.4a	-	-	-	-
North Wolo	10.0±0.5cd	31.2±0.8a	7.4±0.2b	-	-	-	-
F value	74.59	109.82	121.09	2.03	0.01	0.76	0.19
P value	<.0001	<.0001	<.0001	0.1297	0.9940	0.5602	0.8332
Growth stage							
Seedling	0.0±0.0d	0.0±0.0c	0.0±0.0d	-	-	-	
Knee height	3.4±0.4c	17.4±1.2b	2.4±0.3c	7.3±0.8a	-	1.5±0.3b	-
Flag leaf/ Tasseling	17.8±0.9b	37.0±4.2a	7.7±0.2b	6.2±0.6ab	32.2±4.7a	4.2±0.4a	-
Grain filling	22.3±0.7a	32.1±1.0a	10.3±0.4a	5.8±1.9b	26.1±4.1a	4.4±1.9a	-
Harvest	19.6±0.5b	24.7±0.5b	7.3±0.2b	0.2±0.3c	9.4±4.1b	0.0±0.2c	-
F value	244.69	531.70	193.26	35.65	107.44	38.78	-
P value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	-
Variety*							
Long maturing	38.6±1.2a	50.6±1.1a	20.6±0.7a	-	-	-	-
Medium maturing	21.5±2.3b	30.4±2.2b	12.1±1.4b	-	-	-	-
Early maturing	18.4±1.8b	33.1±1.8b	9.7±1.14b	-	-	-	-
F value	54.0	55.42	38.33	-	-	-	-
P value	<.0001	<.0001	<.0001	-	-	-	-

† Flag leaf for sorghum and tasseling for maize; - no data available or minor crop status in the area; maize is uncommon in North Gondar and sampling was not enough to present data; * differences in varietal duration to maturity were more substantial in sorghum than maize means within a column of a fixed effect followed by the same letter(s) are not significantly different from each other according to Tukey-Kramer (P < 0.05).

than 2003. Nematodes were also discovered from a few borers in semi-arid eastern Amhara in 2004. Sampling error contributed more than 90% of the variation in nematode population (tab. 2).

Between plant distribution of borers and their natural enemies in maize and sorghum

In semi-arid eastern Amhara, for *C. partellus* on sorghum, the regressions between log (mean) and log (variance) yielded significantly higher coefficients of determination (r^2) at seedling, knee height, grain filling and harvest stages. The slopes (*b*) were greater than 1 at seedling, knee height, grain filling stages, indicating an aggregated distribution of *C. partellus*, while at harvest, a random distribution was observed (tab.4). All slopes were not significantly different from each other. When pooled across crop growth stages, an aggregated distribution ($b = 1.32$, $r^2 = 0.87$, $P = 0.001$) was obtained. Similarly, an aggregated distribution was found for *S. calamistis* at the seedling knee height and grain filling stages. *C. flavipes* cocoon masses showed an aggregated distribution across all growth stages. *B. fusca* had variable distribution from random to regular to aggregated at different crop stages while the pooled data gave highly aggregated distribution. In the cool-wet region, on maize, the pooled data of *B. fusca* had aggregated distribution (tab.4).

Plant damage variables

In general, plant damage variables followed the same trend as borer numbers. On sorghum, percentage stem tunneling, internode damaged and number of holes per plant were higher during 2003 than 2004, higher in eastern than the cool-wet western Amhara, and tended to increase with crop growth stage (tab.5). There was a general trend of decrease in damage levels from North Shoa northwards to North Wolo. Long maturing varieties had significantly higher damage levels. On sorghum, the sums of the contribution of the random effects of Locality x D x Z x Y and Z x Y was more than the contribution of variation by the residual in borer damage (tab.5). On maize, the residual contributed 48–83% of the variation in borer damage symptoms.

On maize, percent internodes damaged varied significantly with year, while the number of holes/plant

Table 6. Effect of year and location on sorghum and maize yield and yield components in the Amhara state, in 2003 and 2004.

	Sorghum		Maize	
	Head weight (g/ plant)	Grain yield (kg/ ha)	Cob weight (g/ plant)	Grain weight (kg/ ha)
Random effects	**% Variation explained**			
Locality (district x zone x year)	28.3	100.0	51.7	41.0
District	12.1	0.0	0.0	0
Residual	59.6	0.0	48.3	59.0
Fixed effects	**Least square means (±SE)**			
Year				
2003	63.8±1.4a	1833.1±181.1a	206.3±10.1a	3837.1±865.9a
2004	57.9±2.0b	1891.4±228.2a	167.7±9.1b	3724.6±834.3a
F value	152.10	0.04	9.57	0.01
P value	<.0001	0.8472	0.0021	0.9926
Administrative zones				
East Gojam	70.2±2.9b	1932.9±340.9ab	155.9±11.8b	3438.5±234.4
West Gojam	-	1271.4±191.5b	232.0±7.6a	5913.2±367.1
South Gondar	11.0±3.9c	1321.0±334.0b	173.1±17.1b	2140.8±402.2
North Gondar	17.7±1.7c	1261.4±404.2b	*	*
North Shoa	68.2±3.9b	1721.6±475.5ab	*	*
Oromiya	67.7±2.7b	2281.1±294.6ab	*	*
South Wolo	70.8±3.0b	1668.8±336.9b	*	*
North Wolo	120.2±3.8a	2867.3±377.1a	*	*
F value	6.61	2.54	16.05	4.99
P value	<.0001	0.0298	<.0001	0.0561

* crop not grown or minor status means within a column of a fixed effect followed by the same letter(s) are not significantly different from each other according to Tukey-Kramer ($P < 0.05$).

varied significantly with crop growth stages (tab.5) In most cases, significantly higher damage levels were recorded at around tasseling and grain filling than other growth stages (tab.5). Cob damage was generally low and non-significant; residual or between-plant variance contributed most to the overall variability followed by district (tab.5).

Yield and yield components

Head weight of sorghum and cob weight of maize were significantly higher in 2003 than 2004 (tab. 6). Moreover, sorghum grain yields varied significantly with administrative zone. More than twofold sorghum yield was obtained in North Wolo than in North or South Gondar (tab. 6). The highest mean maize grain yield was obtained in West Gojam zone. On sorghum, random effects and residual contributed about 40% and 60% to the variation in head weight, respectively (tab. 6). On maize, both the random effects and the residual contributed equally in both cob and grain weight.

Relationships between borers, parasitism, borer damage, plant growth variables, altitude and yield

Abundance of *B. fusca* was significantly and positively correlated with altitude (r = 0.27, $P < 0.05$) while *C. partellus,* borer damage levels, and larval parasitism by *C. flavipes* were significantly and negatively related to altitude (r = –0.18 to –0.46, $P < 0.05$). All plant growth parameters, borer numbers, and parasitism were significantly and positively correlated with crop growth stage (r = 0.14 to 0.70, $P < 0.05$). Furthermore, plant growth variables, damage and borers were all significantly correlated with each other. Yield per plant was significantly negatively correlated with percent tunneling and *B. fusca* population (r = -0.05, $P < 0.05$).

A stepwise regression analysis indicated that sorghum head weight was positively related to plant height, stem diameter and parasitism, and negatively to percent peduncle damage, number of holes per plant, and % stem tunneling (tab.7). On maize, cob weight was positively related to plant height and stem diameter only, while plant damage and insect variables had no effect.

Table 7. Effect of borer damage variables and plant growth parameters on head weight of maize and sorghum in the Amhara state, Ethiopia, in 2003 and 2004.

	b	F value	P value
	Sorghum		
Y head weight (g/ plant)			
X_1 plant height (m)	28.19	73.13	<.0001
X_2 stem diameter (cm)	50.86	190.72	<.0001
X_3 internodes/ plant	–3.96	29.38	<.0001
X_4 % peduncle damage	–0.40	19.54	0.0089
X_5 % tunneling	–0.20	0.51	0.0451
X_6 # holes/ plant	–0.44	6.86	0.0358
X_7 % larval parasitism	0.13	4.42	0.0358
Intercept = -5.11, r^2 = 0.29, N = 6680			
	Maize		
Y cob weight (g/ plant)			
X_1 plant height (m)	173.0	107.19	<.0001
X_2 stem diameter (cm)	150.53	88.21	<.0001
Intercept = –421.2, r^2 = 0.69, N = 207			

* Stepwise multiple regressions; *b* values are partial regression coefficients.

Discussion

In the present study, three lepidopteran, i.e., *Chilo partellus, Busseola fusca and Sesamia calamistis*, and one coleopteran, *Rhynchaenus niger*, borer species were found in the Amhara state of Ethiopia. In addition to these borer species, Emana *et al.* (2001) reported others including the lepidopteran *Sesamia nonagriodes botanephaga,* and the coleopteran *Pissodius dubius* in Ethiopia. The coleopteran borers are recent records (Emana 2002) and they were observed attacking sorghum. Their economic importance is virtually unknown. They are known as flee weevils and feed by boring wild trees (Anonymous 2000). The recent and present findings suggested that these beetles are shifting to cultivated crops. *B. fusca* dominated the cool-wet western and *Ch. partellus* the warm semi-arid eastern Amhara, indicating differences in their environmental requirements (Tessema 1982; Assefa 1985). *S. calamistis* was commonly observed at the vegetative stages of maize and when moisture was abundant suggesting its sporadic status (Assefa 1991). In Cameroon, *S. calamistis* was reported attacking mostly pre-tasseling stages (Ndemah & Schulthess 2002) and maize ears in Uganda (Kalule *et al.* 1997). In the humid zones of West Africa, it is the key noctuid pest of maize (Schulthess *et al.* 1997).

Correlation analyses showed that the abundance of *B. fusca* increased with altitude. In East Gojam (i.e., cool-wet ecozone), *B. fusca* populations were found as high as 2600 m corroborating earlier studies in southern, central, eastern and western Ethiopia (Assefa 1985; Emana *et al.* 2001). *C. partellus*, on the other hand, was found to be negatively correlated with altitude. In semi-arid eastern Amhara, *C. partellus* was found up to 1900 m elevation, corroborating findings by Emana *et al.* (2001) on the distribution of stem borers in Ethiopia. Studies elsewhere in East and southern Africa also indicate that *C. partellus* and *B. fusca* are low to medium and high elevation borer species, respectively (Ingram 1958; Seshu Reddy 1983; Assefa 1985; Overholt *et al.* 1997; Haile & Hofsvang 2001). Based on the geographic information systems, in the Amhara state, *C. partellus* is predicted to occur east of Ethiopia's eastern escarpment (western bank of the Rift Valley), i.e., areas below 1800 m elevation, and in the western districts of the Amhara state bordering Sudan, i.e., < 800 m (Emana *et al.* 2002; Muchugu, ICIPE, Nairobi, *pers. comm.*). Emana *et al.* (2002) showed that rainfall and temperature play significant role in *C. partellus* distribution. In eastern Amhara, the dry winds from the east must have modifying effect in favour of *C. partellus* on altitudes as high as 2000 m (Muchugu, ICIPE, Nairobi, Kenya, *pers. comm.*). In South Africa, *Ch. partellus* was increasingly invading the cooler areas, displacing *B. fusca* (Kfir 1997). Similar displacement might have happened in eastern Amhara. *C. partellus* has been in eastern Amhara since at least the 1970s and has never climbed up the nearby plateau, although it managed to invade the nearby high altitudes as high as 1900 m. So far, *C. partellus* was not found in the mid and high altitudes of western Amhara.

The extensive cold plateau, i.e., the high elevations west of the Rift Valley, traditionally known as Western Highlands, stretch from northeast to southwest of the state and create a long, wide buffer zone between semi-arid eastern and cool-wet western Amhara, probably preventing *C. partellus* from invading west. Geographical barriers (mountain ranges and forests) play significant role in limiting the distribution and economic importance of borers and their enemies among African regions and ecozones (Schulthess *et al.* 1997). Similarly, the major pest in Cameroon is *B. fusca* (Ndemah *et al.* 2001a) while in the rest of West Africa, which is separated from Cameroon by mountain ranges and swamps, the key pests are *Eldana saccharina* (Walker) and *S. calamistis* (Schulthess *et al.* 1997). Also, because of dense humid forests and lack of east-west thorough roads, *C. partellus* has not yet spread to most of Central and West Africa.

In West Gojam zone, *S. calamistis* replaced *B. fusca* in maize fields near Lake Tana, especially during the flag leaf stage. The Lake Tana area of West Gojam zone is warmer than other nearby zones, where *B. fusca* dominates. Shanower *et al.* (1993) reported that maize is the best host for *S. calamistis* development and survival.

Levels of infestation varied significantly with year, location, growth stage, crop type and variety. Infestation was higher in 2003 than 2004. The first effective rainfall and the total rainfall in the planting month of June in some representative locations in the cool-wet western Amhara was 26-33% higher in 2003 than at the same time in 2004. This higher rainfall could have caused an early and increased emergence of larvae from diapausing larvae in 2003 than 2004. Borer populations are strongly influenced by amount and distribution of rainfall (Cardwell *et al.* 1997; Ndemah *et al.* 2000; Ndemah & Schulthess 2002). On one hand, young larvae feeding in the whorl might drown, on the other hand, sufficient soil water might increase the vigour of the plant and thereby survival of young larvae (Sétamou *et al.* 1995).

Crop residues are stacked for animal feed and construction purposes guaranteeing the steady maintenance of stem borers in the two regions. They harbor diapausing larvae during the off-season and, thus, are major source of infestation (Van den Berg *et al.* 1998; Harris & Nwanze 1992; Assefa 1988a; 1988b; Adesiyun & Ajayi 1980). Stem borers were minor in South Gondar, East and West Gojam zones. Farmers in these areas plough their fields immediately after harvest. Furthermore, nematodes and the high rainfall may also contribute to reducing borer infestations.

Long maturing varieties had higher infestations due to long time of exposure to borers allowing for more than one generation on the same plant. This corroborates results by Van den Berg *et al.* (1990) and Tanzubil *et al.* (2002).

C. flavipes was the most abundant parasitoid species in semi-arid eastern Amhara with an average larval parasitism of up to 30%. Emana *et al.* (2001) reported maximum rates of around 7.5% between 1999 and 2000, which indicates that parasitism is on the increase. Back in 1998, when Mulugeta (2001) surveyed several cereal growing areas of Ethiopia, *C. flavipes* was not yet present. Consequently, *C. flavipes* must have invaded Ethiopia in 1999, probably from Somalia, where it was released in 1997 (Emana *et al.* 2001; Emana *et al.* 2003). Its advance westwards to the cool-wet western Amhara has been hindered by the physical barrier, the Western Highlands (plateau), that also prevented *C. partellus* from moving west. Though *C. flavipes* is very abundant in semi-arid eastern Amhara, borer populations and their effects are still high. Zhou *et al.* (2001) reported that in Coastal Kenya it took five years before *C. flavipes* had a significant effect on *C. partellus* infestations. Thereafter, densities decreased by around 70%. Larval parasitism tended to be higher on long maturing varieties. Several indigenous larval and pupal parasitoids were also observed but parasitism was below 2%. Earlier reports showed that parasitism of *C. partellus* and *B. fusca* by *C. sesamiae* outside of the Amhara State varied considerably, i.e., 0 to 1.2% (Emana *et al.* 2001); 25% (Assefa 1985) and >25%

(Mulugeta 2001). By contrast, Kfir (1995) reported 90% parasitism of *B. fusca* by *Co. sesamiae* and up to 100% parasitism of pupae by *Dentichasmias busseolae* and *Pediobius furvus* of up to 100% in South Africa.

Nematodes were observed during the wet months in the cool-wet western Amhara. Wet habitats are essential for nematode survival (Kaya & Gaugler 1993; Poinar Jr & Polaszek 1998). Nematodes might have contributed to low *B. fusca* infestations in the cool-wet western Amhara. Similarly, Emana *et al.* (2001) reported higher nematode densities (i.e., *Steinernema intermedia*) on *B. fusca*. In Africa, 16 species of nematodes are recorded to attack cereal stem borers (Poinar Jr & Polaszek 1998). Both crop damage levels and grain yields were higher in eastern than the cool-wet western Amhara; the two regions vary greatly in, among others, crops and varieties, soil fertility and drainage, climate and borer species. Sorghum yields were negatively affected by tunneling, holes bored and peduncle damage across region. Stem tunnelling (Bosque-Perez & Mareck 1991; Van den Berg *et al.* 1991; Kalule *et al.* 1994; Setamou *et al.* 1995; Kalule *et al.* 1997; Songa *et al.* 2001; Ndemah & Schulthess 2002; Chabi-Olaye *et al.* 2005a) and bored internodes (Macfarlane 1990) were considered as good indicators of the degree of plant damage and, thus, yield loss. Yields were also negatively related to *B. fusca* larval density corroborating previous reports (Ndemah & Schulthess 2002; Chabi-Olaye *et al.* 2005a). In contrast, Ndemah *et al.* (2001a) reported no relation between cob yield and borers because borers migrate, reach adulthood, or get killed by natural enemies.

When pooled across plant growth stages and, thus, age of borers, *C. partellus*, *B. fusca* and *S. calamistis* larvae and pupae had an aggregated distribution. Similar findings were reported from *C. partellus* (Overholt *et al.* 1994b), on *B. fusca* (Chabi-Olaye *et al.* 2005b) and on *S. calamistis* (Schulthess *et al.* 1991). The distributions become progressively less aggregated as insects aged (Overholt *et al.* 1994b; Ndemah *et al.* 2001b). Stem borer eggs are laid in batches, thus eggs and young larvae are pseudo-aggregated. The decrease in aggregation with age of larvae indicates dispersal of larvae. In fact, second instar larvae migrate from the oviposition site inside the leaf sheaths to the whorl where they feed on the leaves or balloon off to other plants (Berger 1989, 1993; Päts & Ekbom 1992). Older larvae migrate if plant vigour is affected by stem tunneling.

Conclusion

The objective of this study was to determine the distribution and importance of stem borers and their natural enemies in the Amhara State of Ethiopia. The results show that *C. partellus* and *B. fusca* were the major borers, while *Co. flavipes* and nematodes were the major natural enemies in the semi-arid eastern and cool-wet western ecozones of the Amhara State, respectively. Knowledge of the composition and status of borers and natural enemies provides the foundation for any pest management. This gives a great opportunity to tackle the two major pests by *Co. flavipes* and nematodes in the two regions (ecozones) of the State. To that end, impact assessment of *Co. flavipes* and its supplementary release in isolated areas like the cool-wet western Amhara, and population dynamics of both major borers and their natural enemies in representative locations of two regions are suggested.

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