Distribution and Extent of Cotesia Flavipes Cameron (Hymenoptera: Braconidae) Parasitism in Northeastern Ethiopia

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Source: International Journal of Insect Science, 5(1)

Published By: SAGE Publishing

URL: https://doi.org/10.1177/IJIS.S11009

International Journal of Insect Science

ORIGINAL RESEARCH

Distribution and Extent of *Cotesia Flavipes* Cameron (Hymenoptera: Braconidae) Parasitism in Northeastern Ethiopia

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Abstract: The distribution and extent of parasitism of *Cotesia flavipes* Cameron (Hymenoptera: Braconidae) on stem borer species attacking maize and sorghum were assessed in three zones of northeastern Ethiopia. *Cotesia flavipes* was found to be the key larval parasitoid of cereal stem borer species in all areas surveyed. This parasitoid has been introduced into several African countries for the control of *Chilo partellus* in maize and sorghum, but it has never been released in Ethiopia. The survey results indicated that the distribution and extent of parasitism of *Cot. flavipes* followed the distribution and severity of its suitable host, *C. partellus*. A *Cotesia flavipes* parasitism rate of between 33% and 82% was recorded in sub-moist warm (lowland) AEZs of all zones. In contrast, a parasitism rate of less than 6% was recorded in moist, cool highland areas where *Busseola fusca* was the predominant species. *Cotesia flavipes* caused lower rate of parasitism on stem borers in maize (up to 72%) than that of sorghum (up to 82%) in the three zones. In summary, high rates of parasitism of *Cot. flavipes* were recorded in lowland areas where *C. partellus* was the dominant borer species and low rates of parasitism were recorded in highland areas where *B. fusca* was the predominant species. *Cotesia flavipes* caused the highest parasitism (82%) on *C. partellus*. This result verified that *Cot. flavipes* contributed to the reduction of *C. partellus* population in lowlands, regardless of the zone, and its rate of parasitism varied between crop stages, crop types, elevations, host, and host stages. Findings of this study have particularly relevant information on the contribution of *Cot. flavipes* to the population reduction of stem borers, time or stage of its occurrence in relation to host stages and crop stages, and its distribution in relation to the availability of a suitable host across each zone. In conclusion, this larval parasitoid plays an important role in reducing stem borer populations and can be used as one component of integrated stem borer management in northeastern Ethiopia.

Keywords: maize, sorghum, parasitoid, *Chilo partellus*, *Busseola fusca*, stemborer, stem borer

International Journal of Insect Science 2013:5 9–19

doi: 10.4137/IJIS.S11009

Introduction

Lepidopteran stem borers, *Busseola fusca* Fuller (Lepidoptera: Noctuidae) and the exotic *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae) are the most damaging field insect pests of maize and sorghum in East Africa.[1–3] C*otesia flavipes* Cameron (Hymenoptera: Braconidae), a gregarious koinobiont endoparasitoid of *C. partellus* larvae in Asia, was introduced into Kenya for a classical biological control program from Pakistan and later from India in 1991.[4] It was first released in the coastal areas of Kenya in 1993 and readily established during the same season.[5] Following the release of *Cot. flavipes*, the populations of *C. partellus*, *C. orichalcociliellus,* and *S. calamistis* declined by about 30%, with *C. partellus* particularly affected (more than 50%). Maize yield, on the other hand, increased by 10%.[3,6] Parasitism in western Kenya, where it was not released purposely, was low when compared to the coast and eastern provinces, which was likely due to the presence of two unsuitable hosts, *B. fusca* and *E. saccharina*, both of which were considered as a sink for population growth.[6] Following the success in Kenya, *Cot. flavipes* was released in east and southern Africa. *Cotesia flavipes* from the same laboratory colony in Kenya was released in Mozambique in 1996, followed by a release in Uganda and Somalia in 1997.[4] In Uganda, *Cot. flavipes* was recovered with parasitism of 31% on *C. partellus* and 12% on *B. fusca*.[7] The success of the introduced *Cot. flavipes* was demonstrated by its establishment and spread from the release points, increasing parasitism, and decrease in stem borer density by 70%.[8] Another indication of success was the positive economic impact associated with the introduction.[9,10]

In Ethiopia*, Cot. flavipes* was recorded for the first time in 1999 by Emana et al, without being released.[2] The source of *Cot. flavipes* population in Ethiopia is unknown but is most likely the source released by ICIPE in Somalia, Kenya, Tanzania and Uganda.[2,11] Based on the molecular analysis results of Emana[12] and Yossef et al,[13] the *Cot. flavipes* population established in Ethiopia was closely related to the populations released against *C. partellus* in maize in other parts of Africa, which were themselves derived from the original population imported from Pakistan; its dispersal rate was estimated to be 200 km per year. Yossef[14] showed that *Cot. flavipes* was recovered from *Sesamia calamistis* in the central sugarcane-producing region of Ethiopia. It caused up to 50% parasitism on *C. partellus* in sugarcane in the northeastern parts of the country.[14] The relative importance of *Cot. flavipes* in the different AEZs will provide a basis for identifying future release sites and help aid population enhancing conservation measures. The objectives of this study therefore were to assess the distribution and extent of *Cot. flavipes* of stem borers on maize and sorghum in different agroecological zones (AEZ) of northeastern Ethiopia, under natural conditions.

Materials and Methods

Survey sites description

Field surveys were conducted in three zones of Amhara Regional State, northeastern Ethiopia (Fig. 1A). A total of six districts, two from each zone, were assessed. The six districts included in the study were Tehulederi (39°40'E and 11°19'N; 1680–2338 m) and Kalu (39°43'E and 11°6'N, 1492–2084 m) from South Wollo; Habru (39°39'E and 11°40'N; 1508–1889 m) and Gubalafto (39°31'E and 11°52'N; 1758–2044 m) from North Wollo and Dawa chefa (39°48'E and 10°51'N; 1419–1669 m) and Bati (39°59'E and 11°11'N; 1412–1657 m) from Oromia zones. Based on the agro-ecological zones (AEZs) classification, almost all zones experienced sub-moist warm (Kola < 1,500 m), dry—warm to moist cool (Woinadega 1,500–2,500 m) and moist cool (Dega 2,500–3,500 m).[15]

The annual rainfall, temperature (maximum and minimum), and relative humidity of each locality are presented in Table 1. All districts produce sorghum under rain-fed and maize under irrigation. The study areas experience bimodal rainfall, wherein the short rain period is from April to May and the long rain period from June to September. Most farmers prefer to plant late maturing sorghum cultivars using short rain as the cultivars are high yielding (>50 qt/ha). The early maturing cultivars are planted in the main rain period when the short rain fails to come on time. During this study, all fields were covered by late maturing local cultivar, namely *Degalit.* Therefore, all the samples were taken from this cultivar (in all districts).

Sampling procedures

Sampling procedures were followed the work of Emana et al[2] and Georges et al.[16] Three to four peasant

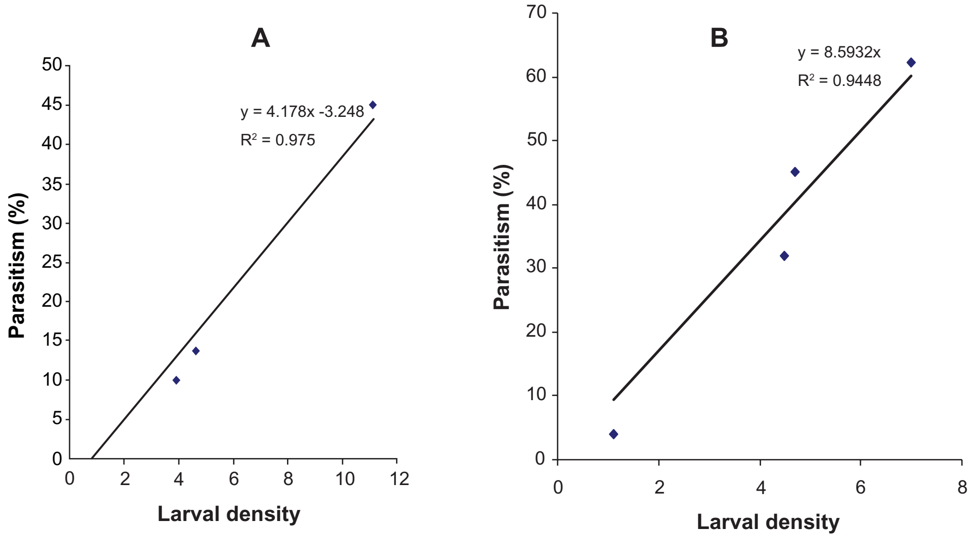

Figure 1. The relationship between mean percentage of larval parasitism and larval density per plant (N = 16) at booting (**A**) and at harvest (**B**) stages of sorghum in Tehulederi district.
Note: The 4 points in the graph showed the mean of 4 replications.

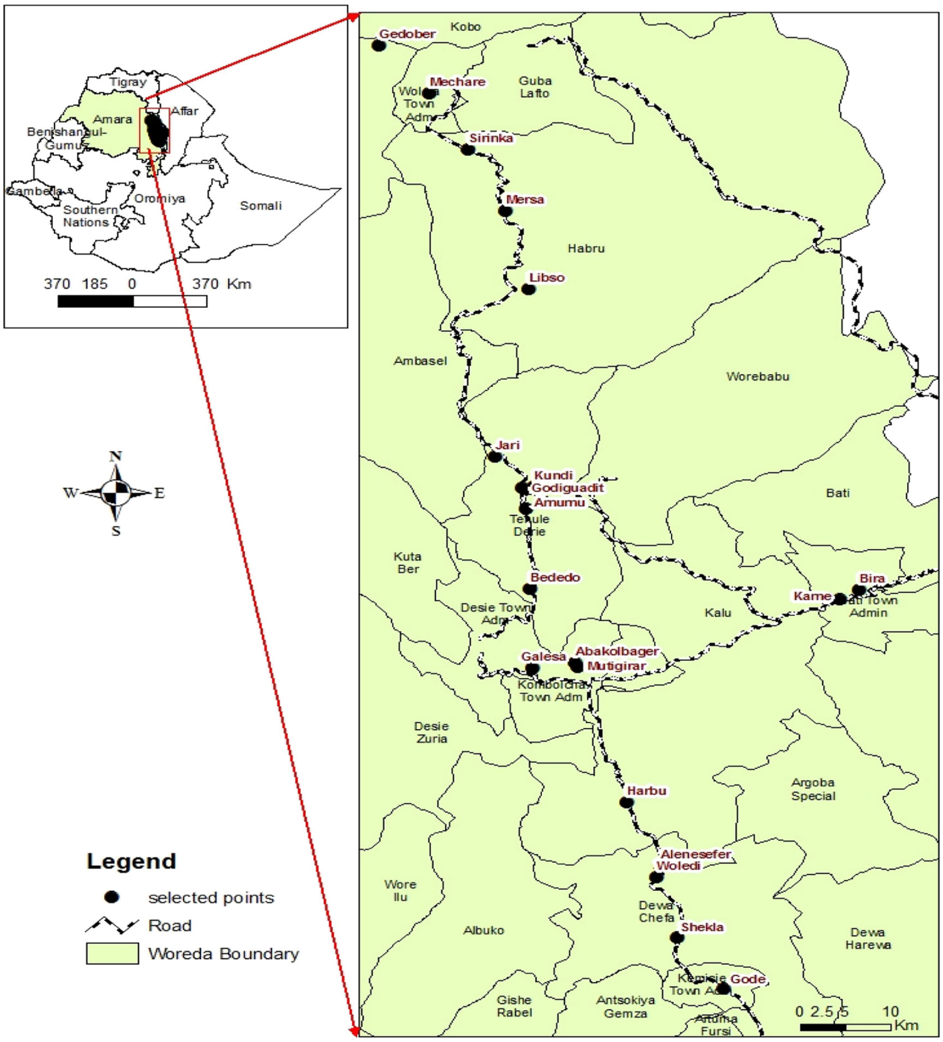

Figure 1A. Map of northeastern Ethiopia showing districts and localities surveyed in three zones.

associations (PAs) were selected in each district. PAs in transition agro ecological zones (one agro ecology to other) were included. In each selected PA, three to four well managed (weed free, well ploughed, thinned, fertilized, etc) zones were selected. The selected fields were not sprayed with any synthetic chemicals. The minimum size of each field was one hectare. Moreover, all fields were at seedling stages while selected. In each farm, five plots with a size of 3 m × 3 m were sampled in 'Z' fashion. Sorghum was sampled at two stages, booting, and harvesting. In addition samples were gathered from irrigated maize (local cultivar) only at harvesting stage. The samples for the different stages were taken from the same sorghum fields.

Larval parasitoid was identified using reports of different authors in the earlier molecular techniques and specimens.[12,14] The same authors did molecular investigation to confirm whether the parasitoid recorded in Ethiopia is *Cot. flavipes* or not by running Polymerase Chain Reaction (PCR) of DNA fragments of *Cot. flavipes* collected from Ethiopia and other African and Asian countries.

The number of total larvae, parasitized larvae, and dead larvae were recorded from six randomly selected plants. Parasitized larvae were taken to laboratory for the emergence of adult wasps and parasitism rate determination. Geographical coordinates and elevations of each field were recorded using GPS (Garmin eTrex Venture HC GPS Receiver).

Data Analysis

Percent parasitism was calculated as:

$$\text{Parasitsm (\%)} = \frac{\text{Number of parasitized larvae}}{\text{Number of healthy larvae} + \text{Number of parasitized larvae}} \times 100$$

The data were arranged in nested design and analyzed using SPSS Version 12 software. The significantly different means (<0.05) were separated using Student-Newman-Keuls (SNK) multiple range test.[17,18] To normalize the data, arcsine and square root transformations were used for percentage and count data, respectively. Correlations of different data were analyzed.

Results

Extent of *Cot. flavipes* parasitism in South Wollo zone

Tehulederi district

The proportions of *B. fusca* and *C. partellus* were 0%–16% and 84%–100% at 1680–1750 meters, 69%–92% and 8%–31% at 1960–1970 meters, and 65%–80% and 9%–35% in 1887–1911 meters, respectively (Table 1). Significantly high *Cot. flavipes* rates of parasitism were recorded in areas where *C. partellus* accounted for 8%–100% of the total stem borer population. *Cot. flavipes* was the most important larval parasitoids in lowland areas where *C. partellus* was predominant with a parasitism rate of 35%–62% compared to *B. fusca* in the predominated highland areas. The highest parasitism (62%) was recorded in elevations of 1680–1750 meters and >27 °C while the lowest (5%) was in the 2291–2338 meter range and 21.6 °C (Table 2). Levels of parasitism were higher at the harvesting than booting stage of sorghum and ranged between 5%–62% and 0%–45%, respectively. Because the third and the fourth instars came out at the booting and harvesting stages of the crops respectively, the later larval stages of the host, which is suitable to the parasitoid, were available at later stages of the crop. Higher rates of parasitism were recorded on sorghum (5%–62%) than maize (10%–35%) (Table 2). Percentage of parasitism and borer density had significantly positive relationships at the booting ($R^2 = 0.98$, $P = 0.045$) and harvesting stages of sorghum ($R^2 = 0.95$, $P = 0.045$).

Kalu district

There were significant differences between elevations in rates of *Cot. flavipes* parasitism (Table 2). Significantly high parasitism (76%) was recorded at elevations of 1492–1527 meters, where *C. partellus* was the only borer species attacking sorghum and maize. Extents of *Cot. flavipes* parasitism reduced with the increase in elevation and thus parasitism

Table 1. Elevation (m), temperature (°C), relative humidity (%) and rainfall of each locality of the three zones of north-east Ethiopia in 2010.

Zones/PAs	Annual rainfall (mm)	Mean temperature (°C)		Mean relative humidity (%)
		Max.	Min.	
South Wollo zone				
Tehulederi district				
Bededo	1899.2	21.6	9.6	na
Godiguadit	1899.2	25.6	10.6	na
Jari	1479.5	27.2	11.4	na
Amumu	1835.3	26.3	10.6	na
Kalu district				
Abakolbager	1313.5	26.3	13.2	na
Mutigirar	1313.5	26.2	13.2	65.2
Galesa	1426.4	24.6	11.3	71.0
Harbu	1220.8	31.8	12.8	55.8
North Wollo				
Gubalafto district				
Gedober	1285.3	26.2	13.2	na
Mechare	1396.2	25.2	11.5	na
Jarsa	1396.2	27.7	11.5	na
Habru district				
Libso	997.2	29.1	14.0	na
Mersa	1244.3	28.8	13.7	na
Sirinka	1199.8	26.5	13.1	62.6
Oromia				
Dawachefa district				
Woledi	1027.3	29.9	12.7	64.0
Shekla	1027.3	29.9	12.7	60.3
Gode	1375.2	30.7	14.6	55.7
Alenesefe	1027.3	29.9	12.7	64.0
Bati district				
Kame	1183.0	28.3	13.6	67.2
Bira	1183.0	28.3	13.6	67.2
Fura	1183.0	28.3	13.6	67.2

Abbreviation: na, data not available.

rates of 19%–55%, 12%–37% and 3%–24% were recorded at elevation ranges of 1841–1857 meters, (25.6 °C), 1834–1842 meters (26.2 °C), and 1923–2084 meters (24.6 °C) respectively. In all elevations, a higher percentage of larval parasitism was recorded on sorghum at the harvesting (24%–76%) than at the booting stage (10%–48%). Higher rates of parasitism were recorded on sorghum (24%–76%) than maize (3%–42%) (Table 2).

A strong positive relationship between the borer density and *Cot. flavipes* parasitism was obtained both at the booting ($R^2 = 0.85$, $P = 0.048$) and harvesting ($R^2 = 0.92$, $P = 0.023$) stages of sorghum (Fig. 2).

Extent of *Cot. flavipes* parasitism in North Wollo zone

Habru district

C. partellus was the only stem borer species recorded at an elevation between 1508–1670 meters but *B. fusca* and *C. partellus* shared 51%–73% and 27%–49% at 1850–1889 meters, respectively (Table 2).

High rates of parasitism (34%–68%) were recorded in the lowland (1508–1670 meters, >28.8 °C) areas where *C. partellus* was the only borer species on both maize and sorghum (Tables 1). In contrast, low rates of parasitism (4%–39%) were recorded at 1850–1889 meters, with mean temperature of 26.5 °C where *B. fusca* was the dominant and accounting for 51%–72%. High rates of parasitism were recorded on stem borer larvae on both maize at harvesting and sorghum at different stages. Rates of parasitism were higher at harvesting (39%–68%) than at the booting (4%–49%) stage of sorghum. On the other hand, rates of parasitism were higher on sorghum (4%–68%) than on maize (21%–39%) in different elevations (Table 1). Generally, this study's results showed that the efficiency of *Cot. flavipes* was highly determined by distribution of its suitable host, host stages, elevations, and crop stages (Table 1).

Rate of *Cot. flavipes* parasitism and borers' density had significantly positive relationships at booting ($R^2 = 0.99$, $P < 0.0342$) and harvesting ($R^2 = 0.97$, $P < 0.0041$) stage of sorghum, respectively (Fig. 3).

Gubalafto district

Busseola fusca was the dominant stem borer, sharing 69%–88% as compared to *C. partellus* which shared 12%–31% at elevations of 1856–2044 meters (Table 2). Rates of parasitism of *Cot. flavipes* on stem borer larvae were low in maize (5%–13%) and sorghum (2%–8%). Rates of parasitism were slightly higher at harvesting (4%–8%) than at booting (2%–4%) stage of sorghum. Rates of parasitism were higher on maize (5%–13%) than sorghum (2%–8%) (Table 1). Because of low population of *C. partellus*, rate of parasitism was low on both maize and sorghum in the district and the result depicted that the parasitism rate of *Cot. flavipes* was highly influenced by the distribution of its suitable hosts, host

Table 2. Elevation (m), stem borers species composition (%) and natural parasitism rates of *Cot. flavipes* on maize and sorghum in South and North Wollo zones in 2010/11.

Districts	Elevations (m)	Species composition (%)		Parasitism (%)		
		Bf	*Cp*	Maize	Sorghum at	
					Booting	Harvesting
Tehulederi (SW)	2291–2338	100	0	0	0^c	4.8 ± 1.2^c
	1887–1911	64.6–80.2	8.9–35.4	10.2 ± 1.3^c	13.8 ± 9.7^b	25.1 ± 5.8^b
	1680–1750	0–16.4	83.6–100	23.0 ± 0.6^{bc}	10.0 ± 0.0^b	22.6 ± 2.4^b
	1960–1970	68.8–91.8	8.2–31.2	34.8 ± 1.9^a	45.1 ± 4.8^a	62.2 ± 8.1^a
			F	52.0	13.0	23.2
			P	0.000	0.001	0.000
			df	15	15	15
Kalu (SW)	1841–1857	58.2–90.3	9.7–41.8	19.4 ± 8.3^b	31.7 ± 5.3^a	$54.6 \pm 6.0^{a,b}$
	1834–1842	67.0–80.4	19.6–33.0	11.7 ± 1.0^b	25.2 ± 9.1^a	37.0 ± 3.2^b
	1923–2084	57.5–92.9	7.1–42.5	3.1 ± 0.4^b	10.0 ± 0.0^b	23.6 ± 2.9^b
	1492–1527	0	100	42.9 ± 3.4^a	48.3 ± 4.8^a	76.2 ± 4.8^a
			F	11.0	12.0	14.1
			P	0.003	0.002	0.000
			df	15	15	15
Gubalafto (NW)	1885–1980	69.1–82.8	17.2–30.9	12.9 ± 3.2^a	4.1 ± 1.1^a	8.0 ± 1.2^a
	1870–2044	82.8–88.0	17.2–12.0	4.7 ± 1.6^b	2.2 ± 0.3^a	3.8 ± 0.9^a
	1856–1980	72.2–80.3	19.7–22.8	7.7 ± 2.8^b	3.5 ± 1.3^a	6.2 ± 3.1^a
			F	1.9	2.1	1.61
			P	0.03	0.07	0.12
			df	12	12	12
Habru (NW)	1508–1670	0	100	34.2 ± 6.3^a	45.3 ± 10.6^a	68.4 ± 4.9^a
	1595–1670	0	100	38.5 ± 5.3^a	48.5 ± 6.8^a	59.6 ± 3.1^a
	1850–1889	50.9–72.6	27.4–49.1	20.5 ± 3.5^a	3.7 ± 2.2^b	38.6 ± 4.8^b
			F	1.9	9.1	3.04
			P	0.13	0.001	0.001
			df	12	12	12

Notes: Mean (±SE) within columns, along each district, followed by the same letters do not differ significantly at the 5% (multiple range test).
Abbreviations: *Bf, Busseola fusca; Cp, Chilo partellus.*

stages, elevation, and crop stages (Table 1). *Cotesia flavipes* and borers' density had weak and negative relationships ($R^2 = 0.03$, $P = 0.412$ and $R^2 = 0.003$, $P = 0.541$) at booting and harvesting stage of sorghum, respectively (Fig. 4).

Extent of *Cot. flavipes* parasitism in Oromia zone

Dawachefa district

Chilo partellus is the predominant species, accounting for 100% of the total borer in all districts of the Oromia administrative zone with elevations less than 1670 meters and temperature greater than 29 °C (Table 3).

Stem borers larval parasitism ranged between 32%–63% on maize and 33%–75% on sorghum in the Dawachefa district. Parasitism rates increased through time and were higher at harvesting (60%–75%) compared to booting (33%–46%) stage of sorghum. Regarding crop types, rates of parasitism were higher on sorghum (33%–75%) than maize (32%–63%) (Table 3).

Parasitism rates and borer density had positive relationships at booting ($R^2 = 0.84$, $P = 0.058$) and harvesting ($R^2 = 0.75$, $P = 0.1518$) stages of sorghum (Fig. 5).

Bati district

C. partellus is the predominant species accounting for 100% in all localities of Bati district having an elevation less than 1670 meters and temperature greater than 28 °C (24).

In Bati district, larvae parasitism ranged from 55%–73% on maize and 45%–82% on sorghum.

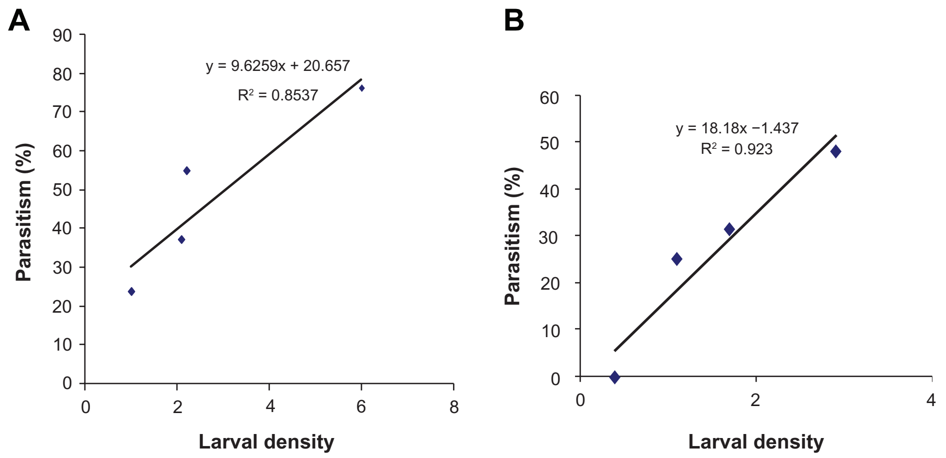

Figure 2. The relationship between mean percentage of larval parasitism and larval density per plant (N = 16) at booting (**A**) and at harvest (**B**) stages of sorghum in Kalu district.
Note: The 4 points in the graph showed the mean of 4 replications.

Rates of parasitism were higher at harvesting than at booting stage of sorghum, with a range of 45%–53% and 61%–82% at the respective stages. Regarding crop types, rates of parasitism were relatively higher on sorghum (45%–82%) than on maize (54%–73%) (Table 3). Of all the zones in which the study was carried out, the highest rate of parasitism (82%) was recorded in this district.

The percentage of parasitism and borer density had a significantly positive relationship at booting ($R^2 = 0.69$, $P = 0.04$) and harvesting ($R^2 = 0.96$, $P = 0.02$) stages of sorghum (Fig. 6).

Discussion

This research showed that the distribution and extent of parasitism of this parasitoid varied with agroecological zones and subsequently affected its major host, *C. partellus*. Moreover, *C. partellus* was a dominant species in lowlands (<1750 meters) with high temperatures (28 °C–32 °C). Rates of parasitism were higher in lower elevated areas where *C. partellus* was the dominant species. In contrast, the rate of parasitism was lower in highlands (>1850 meters) where *B. fusca* was dominant. Other workers also reported that geographic distribution of these two species depends on elevation, with *C. partellus* being lowland and *B. fusca* a mid-altitude to highland species.[1,19,20] Cugala et al[21] described that rate of *Cot. flavipes* parasitism varied with agro ecology. Kfir et al[22] also reported that *Cot. flavipes* dramatically reduced populations of stem borers in East Africa, although its impact and rate of parasitism varied from one agro-ecological zone to another because of availability of the suitable host, *C. partellus*. Tillman et al[23] and Mendel et al[24] reported that parasitization was affected by elevation—which is related

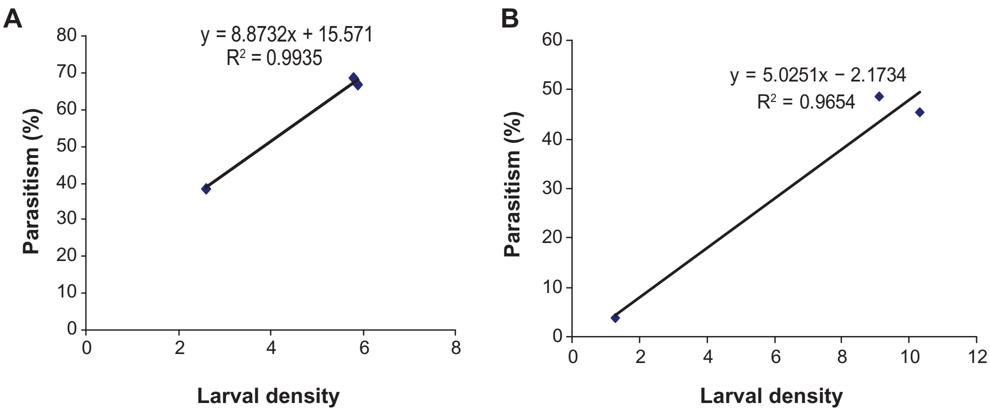

Figure 3. The relationship between mean percentage of larval parasitism and larval density per plant (N = 12) at booting (**A**) and at harvest (**B**) stages of sorghum in Habru district.
Note: The 3 points in the graph showed the mean of 4 replications.

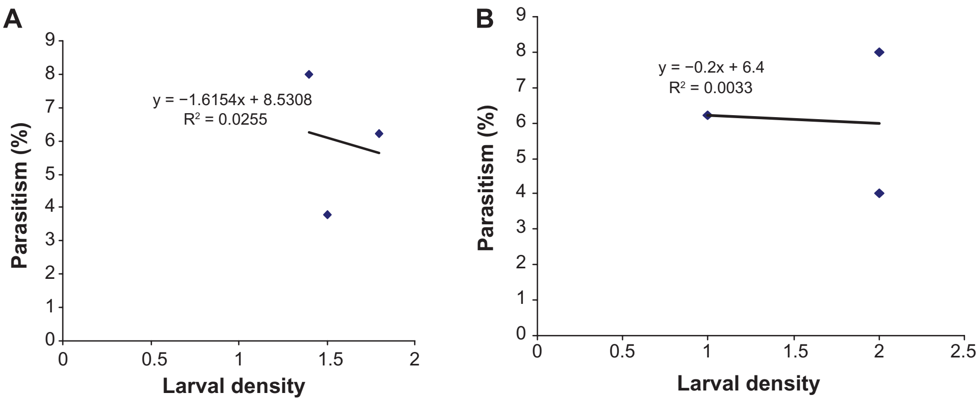

Figure 4. The relationship between mean percentage of larval parasitism and larval density per plant (mean N = 12) at booting (**A**) and at harvest (**B**) stages of sorghum in Gubalafto district.
Note: The 3 points in the graph showed the mean of 4 replications.

to temperature and relative humidity—and host factors such as host stage and host quality. Additionally, low temperature (highland areas) could negatively affect the establishment of *Cot. flavipes*. Zhou et al[25] showed that *Cot. flavipes* caused a 50% reduction in stem borer population in the warmer coastal region of Kenya (lowlands), but that the impact of the parasitoid was reduced in cooler climates (highlands). Low temperature (<25 °C) affected the host development and age structure of *C. partellus*—in all likelihood younger and smaller host instars are available for a longer period in cooler climates than at higher temperatures (>27 °C).[25] Growth and development, as well as host searching of *Cot. flavipes*, were highly influenced by altitude, which subsequently affected the temperature, relative humidity, and the host.[5,8,26]

In our study, higher parasitism rates (82%) were recorded than the earlier reports in Ethiopia (11%–73%),[11,14,27,28] in Uganda (12%–31%),[7] in India (30%),[29] and in Kenya (76.4%).[30] In Ethiopia, the parasitism rate of *Cot. flavipes* on larvae of *C. partellus* increased through time since its first record from 7.5% in 1999, 11%–20% in 2002, 58.8% in 2005, and 73% in 2007.[11,28]

This research results showed that a low rate of *Cot. flavipes* parasitism was recorded on *B. fusca*.

Table 3. Elevation (m), stem borers species composition (%) and natural parasitism rates of *Cot. flavipes* on maize and sorghum in Oromia zone in 2010/11.

Districts	Elevations (m)	Parasitism (%)			
		Maize	Sorghum at		
		Cp	Maize	Booting	Harvesting
Dawa Chefa	1640–1669	100	$54.6 \pm 7.2^{a,b}$	35.8 ± 8.9^{a}	64.8 ± 1.9^{a}
	1432–1669	100	42.4 ± 5.5^{b}	45.6 ± 10.0^{a}	73.9 ± 1.6^{a}
	1419–1431	100	62.5 ± 10.3^{a}	41.5 ± 14.8^{a}	75.2 ± 5.0^{a}
	1471–1490	100	32.2 ± 5.2^{b}	33.1 ± 4.5^{a}	60.1 ± 3.3^{a}
		F	13.3	0.18	3.0
		P	0.000	0.14	0.06
		df	15	15	15
Bati	1555–1576	100	72.7 ± 6.3^{a}	48.6 ± 10.4^{a}	82.2 ± 7.3^{a}
	1640–1657	100	65.3 ± 6.3^{a}	52.5 ± 3.4^{a}	$79.2 \pm 4.7^{a,b}$
	1412–1515	100	54.8 ± 4.7^{a}	45.0 ± 10.1^{a}	60.8 ± 3.2^{b}
		F	0.02	1.9	12.3
		P	0.35	0.45	0.000
		df	11	11	11

Notes: Mean (±SE) within columns, along each district, followed by the same letters do not differ significantly at the 5% (multiple range test).
Abbreviations: *Bf, Busseola fusca; Cp, Chilo partellus.*

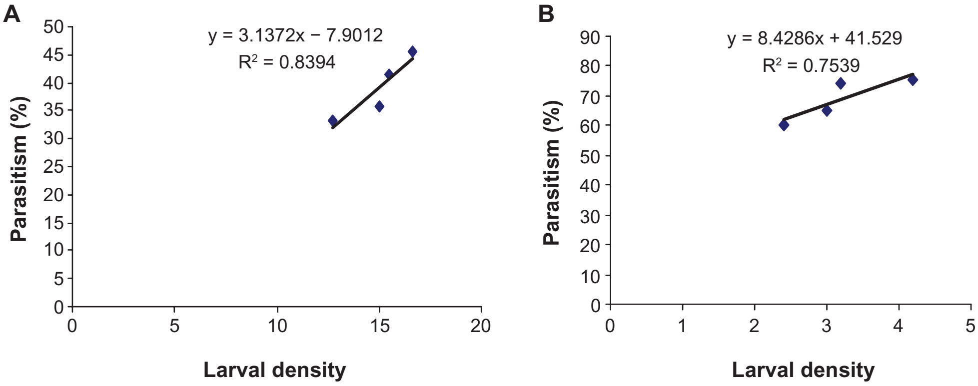

Figure 5. The relationship between mean percentage of larval parasitism and larval density per plant (N = 16) at booting (**A**) and at harvest (**B**) stages of sorghum in Dawachefa district.
Note: The 4 points in the graph showed the mean of 4 replications.

Similarly, Ngi-Song et al[29] reported that *Cot. flavipes* parasitized 76.4% on *C. partellus*, 63.2% on *Chilo orichalcociliellus*, 42.2% on *Sesamia calamistis*, and nil on *B. fusca*. The same author indicated that if *Cot. flavipes* was to be released in areas where suitable and unsuitable hosts occurred sympatrically, the parasitoid population would suffer mortality in the unsuitable host, *B. fusca.* Similarly, a high rate of *Cot. flavipes* parasitism was recorded on *C. partellus* (31%) compared to *B. fusca* (0%–12%) in Uganda.[7,31] Variation in elevation affected the efficiency of *Cot. flavipes* parasitization, mainly through the availability of its suitable host, *C. partellus*. *B. fusca* was acceptable for oviposition but no parasitoid progeny developed to maturity.[5] Overholt[4] suggested that *B. fusca* is not suitable for the development *Cot. flavipes,* but the presence of acceptable but unsuitable hosts would create a sink for *Cot. flavipes* eggs and depress population growth. Ngi-Song et al[32,34] also reported that *Cot. flavipes* successfully developed only on *C. partellus*. Cugala et al[21] showed that *B. fusca* was partially suitable for the development of *Cot. flavipes*, with 6.7% of the larvae stung producing cocoons compared with 29.4% in *C. partellus*. Emana[28] and Emana et al[33] reported that *C. partellus* and *S. calamistis* were the most suitable host for *Cot. flavipes* and it developed in only two populations of *B. fusca*.

Most female adult wasps were found to deposit their eggs on late instars host larvae during physiological maturity of sorghum (before harvesting). These results corroborate findings by Jiang et al[34] that high parasitism rates of *Cot. flavipes* at later host instars in Kenya. Ngi-Song et al[35] and Setamou et al[36] reported that the proportion of successfully parasitized *C. partellus* larvae by *Cot. flavipes* was higher in larger (ie, 4th and 5th instars) than smaller larvae (ie, 3rd instar).

A laboratory investigation on parasitization of different host ages of *C. partellus* larvae by *Cot. flavipes* at 27 °C ± 2 °C and 75% ± 5% relative humidity

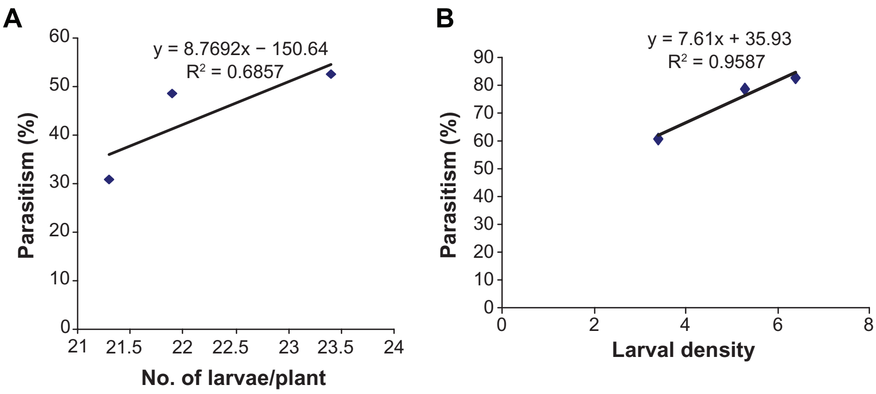

Figure 6. The relationship between mean percentage of larval parasitism and larval density per plant (mean N = 12) at booting (**A**) and at harvest (**B**) stages of sorghum in Bati district.
Note: The 3 points in the graph showed the mean of 4 replications.

showed that higher parasitization and cocoon formation was recorded on the 17 and 20 day old larvae of *C. partellus,* with 82.6% and 82.46% parasitization and 43.09 and 42.70 cocoon formation, respectively. No parasitization and cocoon was recorded in 5 day old larvae.[37,38]

However, various differences between maize and sorghum are expected. *Cot. flavipes* rates of parasitism were lower on maize than sorghum, 3%–43% on maize and 5%–54% on sorghum in South Wollo, 5%–38% on maize and 2%–68% on sorghum in North Wollo, and 32%–72% on maize and 33%–82% on sorghum in Oromia Zone. This result corroborated Setamou et al (2005) and their laboratory work's findings that host plant species significantly affects the rate of successfully parasitized larvae by *Cot. flavipes*. Because hosts continue to feed after parasitization, the amount and quality of host diet can affect the performance of koinobiont parasitoids. The same author showed that the differential survivorships of parasitized *C. partellus* suggest that host plant species significantly affects the rate of successfully parasitized larvae by *Cot. flavipes*. Thus, the quality of host larvae is of paramount importance in the performance of *Cot. flavipes*.[36]

In the present study, parasitism rate of *Cot. flavipes* and borers density had a significantly positive relationship, which was in agreement with the work of Matama et al,[7] who showed percentage parasitism by *Cot. flavipes* was positively associated with *C. partellus* densities in Uganda.

Information on the distribution and extent of *Cot. flavipes* parasitism that is reflected in its ecological requirement, host suitability, and host stages are the prerequisite in priority setting for stem borer control. The findings from this study are particular relevant as information on the contribution of *Cot. flavipes* in the population reduction of stem borers, time or stage of its occurrence in relation with host stages and crop stages, and its distribution in relation to the availability of suitable hosts across each zone or district of northeastern Ethiopia. It revealed that *Cot. flavipes* distribution and rate of parasitism varied with elevation that could affect the availability of suitable host, *C. partellus*. Its efficiency is affected by host stages—higher at later than early instars—that are active at later instars of the host and the crops.

Author Contributions

Conceived and designed the experiments: AD. Analysed the data: AD. Wrote the first draft of the manuscript: AD. Contributed to the writing of the manuscript: AD. Agree with manuscript results and conclusions: AD, EG, FA, AA. Jointly developed the structure and arguments for the paper: AD, EG, FA, AA. Made critical revisions and approved final version AD, EG, FA, AA. All authors reviewed and approved of the final manuscript.

Funding

Author(s) disclose no funding sources.

Competing Interests

Author(s) disclose no potential conflicts of interest.

Disclosures and Ethics

As a requirement of publication author(s) have provided to the publisher signed confirmation of compliance with legal and ethical obligations including but not limited to the following: authorship and contributorship, conflicts of interest, privacy and confidentiality and (where applicable) protection of human and animal research subjects. The authors have read and confirmed their agreement with the ICMJE authorship and conflict of interest criteria. The authors have also confirmed that this article is unique and not under consideration or published in any other publication, and that they have permission from rights holders to reproduce any copyrighted material. Any disclosures are made in this section. The external blind peer reviewers report no conflicts of interest.

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