Insecticides for the Management of Tef Epilachna (*Chnootriba similis* Thunberg, Coleoptera: Coccinellidae) in Barley in Wolaita Zone, Southern Ethiopia

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Abstract

Tef epilachna, *Chnootriba similis*, is an important pest of cereal crops in Ethiopia. It causes significant yield loss on barley under heavy infestation. The efficacy and application time of five foliar insecticides were evaluated to control *C. similis* on barley in two districts of Wolaita, southern Ethiopia during the short "Belg" and the main "Meher" rainy seasons of 2020. The trial was factorial in a randomized complete block design with three replications. The treatments were combinations of five insecticides (carbaryl, diazinon, imidacloprid, λ-cyhalothrin, malathion) and two application times (early and late). Early applications (tillering stage) of insecticides were either better or on par with the late applications (booting stage) in the two seasons and locations in terms of mortality of larvae, leaf damage and grain yield. Higher larval mortalities were recorded for the insecticides λ-cyhalothin (87 - 100%), carbaryl (84 – 100%), diazinon (78 – 99%), malathion (86 – 100%), and imidacloprid (71 – 97%). Barley protected with insecticides against *C. similis* had lower leaf damage and resulted in significantly higher yield. The insecticides carbaryl, λ-cyhalothrin, malathion, diazinon, and imidacloprid, applied at the early tillering stage of barley can effectively control *C. similis* on barley. The insecticide λ-cyhalothrin that consistently provided higher protection and gave the highest return is the best choice for the control of *C. similis*.

Keywords: Cereal pests, economic benefit, efficacy of insecticides, leaf damage, mortality, time of application, yield gain.

Introduction

Tef epilachna, *Chnootriba similis* Thunberg (Synonym *Epilachna similis*) (Coleoptera: Coccinellidae) was first reported as a pest of rice in 1970 in Africa from the Accra plains of Ghana (Scheibelreiter and Inyang, 1974). In Ethiopia, it was reported as a minor pest of cereal crops in 1977 (Crowe and Shitaye, 1977) From then on, it was reported as one of the serious insect pests of cereal crops, especially barley, wheat, rice, maize, and sorghum in many parts of the continent as well as in Ethiopia (Schmutterer, 1971; Brenière, 1983; Haile and Ali, 1986; Moharram *et al.*, 1996; Beyene *et al.*, 2006, Beyene, 2007; Wioletta and Karol, 2016).

Tef epilachna is a widely distributed sporadic insect pest of cereal-growing regions of Ethiopia (Beyene, *et al.*, 2006). However, it has not been reported in the eastern highlands of the country (Wale, 1998; Beyene *et al.*, 2006; Mulatu *et al.*, 2008). In areas where it infests barley, yield losses of 45 to 57% were reported on early planted barley in southern Ethiopia (Beyene *et al.*, 2007); 3 to 18 % in northern Ethiopia (Mulatu *et al.*, 2008) and sometimes complete crop failures were encountered (Beyene *et al.*, 2006). The insect has been indicated as an important pest of maize in Uganda with mean percent plant damages in three fields ranging from 34% to 41% (Chidege *et al.*, 2016).

Chnootriba similis is a bivoltine insect that passes the dry off-season of the year in dormancy as an adult along riversides and migrates to crop fields following the breaking of the dormancy due to the onset of rainfall (Beyene, *et al.*, 2009). Natural enemies have a major impact on the insect population dynamics of *C. similis* (Beyene, *et al.*, 2007). Both, larvae and adults of *C. similis* feed on leaves of the vegetative stage of the host plant by

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scraping the soft tissue of the leaves (Beyene, 2007; Wioletta and Karol, 2016). Late instar larvae are the most damaging stage of the insect (Scheibelreiter and Inyang, 1974).

Despite the prevalence and nationwide distribution of the insect in Ethiopia; few studies have been conducted on its management options. Beyene (2007) evaluated the host preference of *C. similis* and the impact of sowing date on the level of damage caused by the pest. They suggested that the most preferred crop barley and perhaps wheat could be considered to be used as trap cops in the production of the least preferred crops, maize, tef, sorghum and finger millet in Ethiopia. It has been also indicated that barley planted later in the season suffers less than the planting made early and intermediate of the season. However, robust integrated management recommendations for tef epilachna are lacking. Cultural management techniques might not be always effective because *C. similis* occasionally occurs at high population levels (Beyene, 2007; Tuey and Port, 2008). There are reports of sporadic occurrence of the insect in high populations not only on small cereals but also on maize and sorghum. For example, around Mizan, Ethiopia, very high infestations and defoliation of sorghum were reported in 2018 (Eyasu Asfaw, Mizan Teferi Plant Health Clinic, personal communication). Therefore, in such situations, the use of management methods like insecticides which act fast could be required. Hence, this study was designed to determine the effectiveness of conventional insecticides and the appropriate spray time for the management of *C. similis* on barley in southern Ethiopia. The insecticides evaluated have been in use for many pests and some of them (diazinon, malathion) are formulated in the country.

Materials and Methods

The field experiments were conducted in 2020 at two locations, Shasha gale area, Damot Gale district (37^{0}49’56.5’ E and 6^{0}55’36.2” N, alt. 2136 m a.s.l.) and Kokate area, Sodo Zuria district (37^{0}47’9.3” E and 6^{0}52’73.7” N, alt. 2192 m a.s.l.) in Wolaita Zone, southern Ethiopia. At both locations, the experiment was conducted in two seasons: the short rainy season (April-June) “Belg" and the main rainy season (July-September) "Meher”. The short rainy season plantings were made in the third week of March and the main rainy season plantings were in the first week of August. The treatments were combinations of five insecticides and a no-insecticide control with two application times (early or late). The insecticides were carbaryl (Carbimog 85 WP) @ 2 kg/ha, diazinon (Ethiozinon 60 EC) @ 1.2 L/ha, imidacloprid (Fighter 350 SC) @ 1.1 L/ha, malathion (Malamar 50 EC) @ 2 L/ha and λ-Cyhalothrin (Karate 5 EC) @ 0.32 L/ha.).

The experiment was factorial in a randomized complete block design with three replications at each study site. Each plot was 2 m x 3 m (6 m^2) with a distance of 1 m between plots and 1.5 m between replications. The seeds of the farmers’ barley variety (Nechgebs) were sown following the planting calendar of local farmers in the first week of April in the short rainy season and in the first week of August in the main season at both Shasha Gale and Kokate. These areas were selected based on earlier reports of high infestations of tef epilachna (Beyene *et al*., 2006) and in consultation with the Wolaita Zone Bureau of Agriculture.

The seeds were sown at the rate of 125 kg per hectare with a row-to-row spacing of 20 cm. The plots were kept weed-free by hoeing using a hand hoe until the crop matured. Data were collected on the number of larvae, level of leaf injury/damage, and grain yield. The data on the number of larvae were recorded before spray and three days after spraying for all treatments on 1 m x 1m quadrat in the central rows of each plot.

In all experimental fields, the early insecticide treatments were applied when the crop was between tillering and stem elongation stages (28-33 days after plantings), whereas the late treatments were applied between booting and ear emergence stages (20 days after the early applications). The application rate of each insecticide was according to the respective manufacturer's recommendation. The insecticides were applied only once using a 15-liter capacity manual knapsack sprayer at the rate of 300 liters/ ha. The control plots in all replications were not sprayed.

The efficacy of the insecticides was calculated using Abbott's formula (Abbott, 1925)

$$\text{Corrected Mortality \%} = \left(1 - \frac{\text{n in T after treatment}}{\text{n in Co after treatment}}\right) * 100$$

Where : n = Insect population , T = treated , Co = control

Leaf damage was estimated visually by inspecting 20 plants from each plot (Wilson et al., 1969) one week after the treatment, and the levels of damage were ranked using a scale of 0 to 8 as described by Buntin *et al.*(2004) in which, 0 = no defoliation, 1 = 1-5% defoliation on flag leaves, 2 = 5-10% defoliation, 3 = 10-20% defoliation, 4 = 20-40% defoliation, 5 = 40-60% defoliation, 6 = 60- 80% defoliation, 7 = 80-95% defoliation, and 8 = 95-100% defoliation. To permit direct comparisons of defoliation levels in all trials, the 0-8 scale values were converted to the estimated actual percentage of defoliation using the midpoint defoliation level of each category (Buntin *et al*, 2004). The grain yield data were from whole plots of each treatment. The grain yield was adjusted to 12.5 % moisture content and converted to a hectare basis.

Statistical analysis

The collected data were subjected to analysis of variance (ANOVA) for a completely randomized (2 x 6) factorial treatment design; using the R function experimental design package in the R software (R CoreTeam, 2022) and differences among means were compared by the Tukey's Honest Significant differences test, tests at a 5% level of significance. Before analysis, the insect counts data were logarithmically transformed as $tx = \log_{10}(x+1)$; where tx = transformed number of insects and x = original number of insects (Little and Hills, 1991). The untransformed values are presented in the tables of the results.

Partial budget analysis

The partial cost and benefit of each treatment were analyzed, and the marginal rate of return was computed by considering the variable costs used for the respective treatment (CIMMYT, 1988). The grain yield and the selling price, and the costs of the insecticides were determined. The grain yield obtained from each treatment was adjusted downward by 10%. The total gross benefit of the field (GB) was computed by multiplying the barley grain yield with the local market price (Birr 35 per kg). Total variable cost (TVC) was the sum of all variable costs associated with the insecticide labor for application and knapsack sprayer rental. The cost of other inputs and production practices were assumed to remain the same among the treatments. The price per liter of the insecticides was 550 ETB for diazinon, 800 ETB for λ-cyhalothin, 850 ETB for imidacloprid, 300 ETB for malathion, and 400 ETB per kg for carbaryl. The labor cost per man-day was 200 ETB and the cost of Knapsack sprayer rental per day was 50 ETB. The net benefit (NB) was calculated by subtracting all variable costs from the gross benefit (NB=GB-TVC). The marginal rate of return (MRR) that provides the value of the benefit obtained per the amount of additional cost incurred was calculated as MRR%= (NB/TC)*100.

Results

The insecticide treatments reduced the *C. similis* population (Tables 1 and 2), leaf damage (Table 3) and significantly improved grain yield compared to the untreated control plots regardless of the application time and type of insecticides used (Tables 5 and 6).

Effect on the population of *C. similis*

The number of larvae per meter square was significantly ($p < 0.05$) reduced three days after insecticide application in the two seasons and locations, while application time and insecticide by application time interaction did not affect the insect population (Tables 1 and 2). In both seasons and locations, the control plots had significantly higher *C. similis* populations, than the insecticide-sprayed plots. Although values show statistical differences, none of the insecticide treatments had more than 3.6 *C. similis* larvae / m^2 in any of the seasons and locations. In contrast, the lowest populations of *C. similis* in the unsprayed control plots were 7.9 larvae / m^2 during the short rainy season and the highest 34.3 larvae/ m^2 during the main rainy season in Damot Gale District (Table 1). There was no significant difference between early and late applied insecticides in the number of larvae surviving the treatment.

The mortality caused by the insecticides and application time of insecticides were significantly ($P < 0.05$) different in both locations and seasons (Tables 1 and 2). The highest and most consistent mortalities were caused by λ-cyhalotrhrin with 100% mortality when applied early in the growth stage of barley in both seasons and locations and 86.6% to 98.6% in the late applications (Tables 1 and 2). The other insecticides also caused higher mortalities; carbaryl (84 – 100%), diazinon (78 – 100%), imidacloprid (70 – 97%), and malathion (86 – 100%) depending on the sites and seasons (Tables 1 and 2). On the other hand, efficacies were significantly lower for late applications except for the early treatment during the short rainy season in Damot Gale district (Table 1).

Effect on leaf damage by *C. similis*

The type of insecticide and time of insecticide application, and their interactions significantly ($P \leq 0.05$) affected the extent of plant leaf damage in both locations and seasons (Table 3). In the short rainy season at Damot Galle and Sodo Zuria districts, lower and at par mean percent plant leaf damage was recorded in barley treated at the early stage of growth with the insecticides carbaryl, λ-cyhalothrin, and malathion (Table 3). All early-applied insecticides had significantly lower plant leaf damage compared to the same insecticides applied at a later stage in both seasons and locations (Table 3). On the other hand, all the insecticides applied at the early stage in the main rainy season at both Damot Galle and Sodo Zuria districts resulted in significantly lower leaf damage than the control without significant differences between themselves. Leaf damage on the control plots ranged from 65% to 85%.

Effect on yield

The type of insecticide and insecticide application times significantly ($P < 0.05$) affected the grain yield of barley in both seasons and locations (Tables 4 and 5). The early treated plots produced significantly higher barley grain yield than the late treated in the two seasons and locations (Tables 4 and 5). Barley sprayed with insecticides at the early stage resulted in 1004 to 1163 kg/ha in the short rainy season, 2117 to 2390 kg/ha main rainy season in Damot Gale, and 435 to 486 kg/ha in the short and 1496 to 1696 kg/ha in the main rainy season in Sodo Zuria Districts. On the other hand, the grain yields of unprotected barley were about 510 to 519 kg/ha in the short rainy season and 1498 to 1506 kg/ha in the main rainy season of Damot Gale, 234 to 239 kg/ha in the short and 814 to 972 kg/ha in the main rainy seasons of Sodo Zuria.

Higher barley grain yield was obtained from early treated plots with λ-cyhalothrin, which was at par with carbaryl, diazinon and malathion, and the lowest yield was from the control plots in both seasons and locations (Table 4 and5). There were no differences in barley grain yield among late-applied insecticides in the short and main rainy seasons of Damot Galle district (Table 4) and the main rainy season of Sodo Zuria district (Table 5). In both locations and seasons, the early application had higher yield gain than the late application for all the insecticides. Yield gain was higher for early treatments on barley sown during the short rainy season ranging from 99% to 128% in Damot Gale district, and 86% to 108% in Sodo Zuria district. Among the insecticide treatments, yield gain was consistently higher for λ–cyhalothrin, carbaryl, diazinon, and malathion.

Table 1. Effect of insecticides on the population density (Mean number of larvae per meter square) and mortality of *Chnootriba similis* at Shasha Gale in Damot Gale district during two growing seasons in Wolaita zone, southern Ethiopia, 2020.

	Short rainy season						Main rainy season					
	Early Application			Late Application			Early Application			Late Application		
Insecticides	BS	3DAS	Mortality (%)	BS	3DAS	Mortality (%)	BS	3DAS	Mortality (%)	BS	3DAS	Mortality (%)
Carbaryl	8	0.3^{B}	96.3^{AB}	7.3	1.0^{B}	86.2^{BC}	29	0.0^{B}	100^{A}	26.9	0.3^{B}	98.8^{A}
Diazinon	8.3	0.3^{B}	96.4^{AB}	7.6	1.7^{B}	77.8^{C}	31.4	0.3^{B}	99.5^{A}	29.8	0.3^{B}	98.9^{A}
Imidacloprid	9	1.6^{B}	82.2^{C}	7	1.3^{B}	81.4^{C}	30	2.3^{B}	92.3^{B}	23.7	0.6^{B}	97.4^{A}
Malathion	9.8	0.0^{B}	100^{A}	9	0.6^{B}	86.2^{BC}	28.6	0.3^{B}	98.9^{A}	28.1	0.3^{B}	98.9^{A}
λ-cyhalothin	8.3	0.0^{B}	100^{A}	7.5	1.0^{B}	86.6^{BC}	24.4	0.0^{B}	100^{A}	22.2	0.3^{B}	98.6^{A}
Control	8	8.7^{A}		7.9	8.0^{A}		28	34.3^{A}		26	30.7^{A}	
Application time		1.9^{a}	94.1^{a}		2.3^{a}	83.6^{b}		6.2^{a}	98.2^{Aa}		5.4^{a}	88.6^{b}

Means followed by the same capital letter in columns for insecticides and time of application for each season; and small letter in a row for application time are not significantly different at $P \leq 0.05$. BS: Before insecticide spray; 3DAS: three days after insecticide spray.

Table 2. Effect of insecticides on the population density (Mean number of larvae per meter square) and mortality of *Chnootriba similis* at Kokate in Sodo Zuria district during two growing seasons in Wolaita zone, southern Ethiopia, 2020.

	Short rainy season						Main rainy season					
	Early Application			Late Application			Early Application			Late Application		
Insecticides	BS	3DAS	Mortality (%)	BS	3DAS	Mortality	BS	3DAS	Mortality (%)	BS	3DAT	Mortality (%)
Carbaryl	9.3	1.0^{BC}	89.3^{AB}	8.3	1.3^{BC}	84.3^{BC}	28.6	0.0^{B}	100^{A}	27.9	2.3^{B}	91.8^{B}
Diazinon	8	1.0^{BC}	87.5^{AB}	7.3	1.0^{BC}	86.3^{AB}	31.4	0.3^{B}	99.1^{A}	30	0.6^{B}	98.2^{A}
Imidacloprid	7.9	2.3^{B}	70.8^{C}	8.6	1.3^{BC}	84.9^{BC}	24.4	2.3^{B}	90.0^{AB}	21.8	3.6^{B}	71.7^{C}
Malathion	7.6	0.3^{C}	95.7^{AB}	9.3	1.0^{BC}	89.3^{AB}	30	0.3^{B}	99.9^{A}	24.3	1.7^{B}	93.7^{AB}
λ-cyhalothin	8.5	0.0^{C}	100^{A}	9.6	1.0^{BC}	89.6^{AB}	25.7	0.0^{B}	100^{A}	29	0.7^{B}	87.6^{B}
Control	9	8.0^{A}		9	8.0^{A}		29	34.3^{A}		27.3	30^{A}	
Application time		2.1^{a}	88.6^{a}		2.3^{a}	86.8^{a}		6.2^{a}	97.8^{a}		6.4^{a}	88.6^{b}

Means followed by the same capital letter in columns for insecticides and time of application for each season; and small letter in a row for application time are not significantly different at $P \leq 0.05$. BS: Before insecticide spray; 3DAS: three days after insecticide spray.

Partial budget analysis

All the insecticide applications provided greater net benefits than the untreated plots (Table 6). In both locations and seasons, early application of the insecticides gave a higher net benefit than late applications. The partial budget analysis revealed that early treatment with λ–cyhalothrin (14859-74835 ETB), carbaryl (14365-74750 ETB), diazinon (14131-72343 ETB), and malathion (13451-71789-ETB) resulted in higher and comparable net benefits across all experimental locations. The net benefit from imidacloprid was lower than the other insecticides and ranged from 12518 to 65501 ETB when applied early. Treatment with λ–cyhalothrin gave the highest marginal return rates ranging from 23% to 45% in the short and 40% to 61% in main rainy seasons at Damot Gale; and 10 % to 17% in the short and 38% to 50% in the main rainy seasons of Sodo Zuria district. All the other insecticides did not achieve a 35% marginal rate of return in any of the locations, seasons and application times.

Table 3. The level leaf damage (%) by *C. similis* on barley treated with insecticides at early and late growth stages during two cropping seasons at Wolaita, southern Ethiopia, 2020.

Insecticides	Damot Gale District				Sodo Zuria District			
	Short rainy season		Main rainy season		Short rainy season		Main rainy season	
	Early	Late	Early	Late	Early	Late	Early	Late
Carbaryl	14.0^{GH}	48.9^{C}	9.12^{E}	40.9^{CD}	16.6^{FG}	54.7^{C}	11.3^{EF}	40.4^{CD}
Diazinon	22.6^{FG}	34.3^{DE}	12.0^{E}	62.4^{B}	21.7^{EF}	53.7^{C}	18.4^{E}	46.9^{BC}
Imidacloprid	29.4^{EF}	72.9^{B}	16.3^{E}	57.0^{B}	33.2^{D}	77.2^{A}	17.5^{E}	64.0^{AB}
Malathion	17.4^{GH}	32.8^{DE}	8.8^{E}	32.4^{D}	14.2^{FG}	63.4^{B}	7.4^{F}	52.5^{B}
λ–cyhalothrin	11.4^{H}	39.4^{D}	12.2^{E}	46.8^{C}	9.0^{G}	28.6^{DE}	13.9^{EF}	37.3^{D}
Control	78.5^{AB}	85.8^{A}	74.0^{A}	75.6^{A}	83.9^{A}	79.9^{A}	64.6^{A}	70.1^{A}
Application time	28.8^{b}	52.35^{a}	22.21^{b}	52.4^{a}	29.7^{b}	60.0^{a}	22.2^{b}	52.1^{a}

Means followed by the same capital letter in the columns for the seasons in each district; and small letter in a row for application time are not significantly different at P≤ 0.05.

Table 4. Barley grain yield (Mean) and yield gain treated with insecticides during two different growth stages at Shasha Gale, Damot Galle district in Wolaita zone, southern Ethiopia, 2020.

Insecticides	Short rainy season				Main rainy season			
	Early application		Late application		Early application		Late application	
	Yield (kg/ha)	Yield gain (%)	Yield (kg/ha)	Yield gain (%)	Yield (kg/ha)	Yield gain (%)	Yield (kg/ha)	Yield gain (%)
Carbaryl	1149^{AB}	125.3	837^{E}	61.3	2400^{A}	60.2	2140^{BC}	42.1
Diazinon	1071^{ABC}	110	914DE	76.1	2322^{AB}	55	2158^{BC}	43.3
Imidacloprid	1004^{CD}	96.9	856^{E}	64.9	2117^{BC}	41.3	1971^{C}	30.9
Malathion	1016^{BDC}	99.2	916DE	76.5	2306^{AB}	53.9	2022^{C}	34.3
λ–cyhalothrin	1163^{A}	128	860^{E}	65.7	2390^{A}	59.5	2081^{C}	38.2
Control	510^{F}		519^{F}		1498^{D}		1506^{D}	
Application time	985.5^{a}		817^{b}		2158.17^{a}		1979.66^{b}	

Means followed by the same capital letter in the columns for the seasons; and small letter in a row for application time are not significantly different at P≤ 0.05.

Table 5. Barley grain yield (Mean) and yield gain treated with insecticides during two different growth stages at Kokate, Sodo Zuria district in Wolaita zone, southern Ethiopia, 2020.

	Short rainy season				Main rainy season			
	Early application		Late application		Early application		Late application	
Insecticides	Yield (kg/ha)	Yield gain (%)	Yield (kg/ha)	Yield gain (%)	Yield (kg/ha)	Yield gain (%)	Yield (kg/ha)	Yield gain (%)
Carbaryl	483[A]	106.4	333[CD]	39.3	1696[A]	74.5	1364[C]	67.6
Diazinon	474[A]	102.6	335[CD]	40.2	1601[A]	64.7	1399[C]	71.9
Imidacloprid	435[AB]	85.9	279[DE]	16.7	1424[BC]	46.5	1285[C]	57.9
Malathion	454[AB]	94	262[E]	9.6	1574[AB]	61.9	1365[C]	67.7
λ–cyhalothrin	486[A]	107.7	386[BC]	61.5	1692[A]	74.1	1374[C]	68.8
Control	234[E]		239[E]		972[D]		814[D]	67.6
Application time	427.7[a]		305.7[b]		1493.2[a]		1266.9[b]	

Means followed by the same letter in the columns for the seasons; and small letter in a row for application time are not significantly different at P≤ 0.05.

Table 6. Partial budget analysis, for insecticide type and their time Application on grain yield of barley at Shasha Gale in Damot Gale district and Kokate in Sodo Zuria district during two cropping seasons

	Damot Gale District								Sodo Zuria District							
	Short rainy season				Main rainy season				Short rainy season				Main rainy season			
	Early		Late		Early		Late		Early		Late		Early		Late	
Treatments	NB	MRR (%)	NB	MRR (%)	NB	MRR (%)	NB	MRR (%)	NB	MRR (%)	NB	MRR (%)	NB	MRR (%)	NB	MRR (%)
Control	16065		16349		47187		47439		7371		7529		3062		25641	
λ-cyhalothin	36185	44.7	26640	22.9	74835	61.4	65102	39.5	14859	16.6	11709	9.5	52848	49.8	42831	38
Carbaryl	35344	22.7	25516	10.8	74750	32.4	66560	22.5	14365	8.2	9640	2.5	52574	25.5	42116	19.4
Diazinon	32937	21.1	27991	14.5	72343	31.4	67177	24.6	14131	8.5	9753	3	49632	23.7	43269	22.3
Malathion	31154	17.8	28004	13.7	71789	28.9	62843	18.1	13451	7.2	7403	-0.1	48731	21.1	42148	19.4
Imidacloprid	30441	12.1	25874	7.9	65501	15.4	60902	11.4	12518	4.3	7604	0.7	43671	10.9	39293	12

NB. = net benefit in Ethiopian Birr; MRR= Marginal Rate of Return.

Discussion

All the insecticides λ-cyhalothrin, carbaryl, diazinon, imidacloptid and malathion effectively reduced the population of *C. similis* population, reduced leaf damage, and increased barley grain yield in their respective orders at both locations during both the short and main rainy seasons. Similar to Beyene (2007), the yields recorded on the control plots of the current study were significantly lower compared to any of the insecticide treatments. Although imidacloprid was statistically at par with the other insecticides, it showed lower tendencies in reduction of the population of the larvae and grain yield gains in both locations and application times.

There is a dearth of data on the use of insecticides for the management of phytophagous Coccinellidae in general and *C. similis* in particular, in direct comparison with the present research findings. However, studies conducted in North America and European countries showed that λ-cyhalothrin, carbaryl, and malathion were effective in controlling the cereal leaf beetles (Coleoptera: Chrysomelidae), which closely resemble to *C. similis* in their damage. Higher biological efficacy of insecticides under the pyrethroids chemical family was reported in field evaluation of cereal leaf beetles (*Oulema melanopus* L.) in Eastern Europe (Sapko *et al.*, 1990; Tanasković *et al.*, 2012; Kaniuczak, 2013) and North America (Buntin, *et al.*, 2004) and these reports agree with our findings on the efficacy of λ-cyhalothrin on *C. similis*. Likewise, Jensen *et al.* (1993) reported that carbaryl and malathion effectively controlled the cereal leaf beetle in Montana, U.S.A. Similarly, Buntin *et al.* (2004) reported high efficacy of carbamate (methomyl and carbaryl) and organophosphate (malathion) on cereal leaf beetles in northern America, when treatment was applied after most eggs had hatched. Tanasković *et al.* (2012) also reported similar results from Romania (Eastern Europe). These reports are generally comparable and in agreement with our findings.

Imidacloprid is among the insecticides used for the management of cereal beetles in many countries. It has lower hydrophobicity, which makes it poor in cuticular penetration and has lower insecticidal activity on foliar application than injection or seed treatment (Perry *et al.*, 2013). Wenda-Piesik *et al.* (2018) from Poland reported that seed treatment with imidacloprid in wheat was effective against cereal leaf beetles. However, Tharp *et al.* (2000) from Montana, USA, reported 40% mortality with imidacloprid seed treatment on barley crops, while foliar spray caused about 90% mortality in cereal leaf beetles. In our findings, imidacloprid significantly reduced *C. similis* compared to the control and was comparable to the other insecticides. Environmental conditions where the research was carried out are the main factors that influence the efficacy of insecticides under field conditions and differences in findings probably could be due to these variations (Cress, 2006).

Larvae of *C. similis* begin to cause damage on leaves within two weeks of germination and the late instar larvae (3rd and 4th) cause the main leaf scarification (Beyene *et al.*, 2007). Similarly, Scheibelreiter and Inyang (1974) reported that the fourth instar larvae inflicted major damages on leaves of maize. The field research findings of Buntin *et al.* (2004) showed that significant grain yield-related differences by cereal leaf beetle in North America were associated with early treatments of the plots. Beyene *et al.* (2007) also recommend early treatment of *C. similis* to reduce yield loss and to target the early larval stage (1st and 2nd instar larvae) right after hatching, which will help achieve early control before leaf damage occurs. The insect has only one peak egg-laying period per season (Beyene *et al.*, 2009) and a single application of insecticides against early instar larvae might be enough to reduce leaf damage and grain yield loss. The current study also showed that applications of insecticides at earlier growth stages of barley reduces the infestation and damage by barley and enables to secure higher yield.

Conclusion and Recommendation

In areas like Damot Gale and Sodo Zuria of Woliata, Ethiopia, *C. similis* has become a regular pest and control with insecticides can significantly increase the yield of barley planted in both the short (Belg) and main (Meher) rainy seasons. The current study has shown that protecting barley from the damage of *C. similis* with the use of insecticides gives higher grain yield. The insecticides carbaryl, λ-cyhalothrin, malathion, diazinon, and imidacloprid, applied at the early tillering stage of barley can effectively control *C. similis* on barley. All the insecticides tested in this study can be used for the management of tef epilcahna. However, the insecticide, λ-cyhalothrin which had better performance, and gave the highest net benefit and marginal rate of return is the best choice. Besides additional studies on the evaluation of the efficacy of insecticides with different chemistries and modes of action, future investigations need to evaluate the relationship between population levels, damage, and yield loss, and establish treatment threshold levels.

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