SINET: Ethiop. J. Sci., 44(1): 27–37, 2021 ISSN: 0379–2897 (PRINT)

eISSN: 2520–7997

DOI: https://dx.doi.org/10.4314/sinet.v44i1.3

Efficacy of plant derived and synthetic insecticides against cabbage aphid, *Brevicoryne brassicae* (L.) (Homoptera: Aphididae) and their effect on coccinellid predators

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ABSTRACT: Cabbage aphid, *Brevicoryne brassicae* (L.) is one of the major insect pests of brassica crops worldwide. Mainly insecticides are being used for its management which poses hazardous effects on the environment and the applicator. Low efficacy and non-target effect of the available insecticide are the main challenge in the management of the pest in Ethiopia. The use of bio-rational and neonicotinoid pesticides is a promising alternative as they are less vulnerable to resistance development and relatively safe to the environment and the applicator. This study was carried out in 2018/19 cropping season to evaluate the efficacy of plant derived and synthetic insecticides for the management of cabbage aphid and their effect on coccinellid predators on Ethiopian kale. Ten treatments including six synthetic and two botanical insecticides were tested in comparison with the standard check dimethoate 40% EC and the untreated control in Randomized Complete Block Design with three replications. Significant ($P<0.05$) differences were observed among the treatments in terms of cabbage aphid population reduction and their effect on coccinellid beetles. The botanical mix (Garlic+onion+pepper) and imidacloprid were at par with each other and found to be the best treatment with 93.79% and 91.04% efficacy, respectively. The maximum leaf yield was obtained from imidacloprid (14.18 t/ha) followed by botanical mix (13.45 t/ha) and lufenuron (12.42 t/ha). The highest yield increment over control was obtained from imidacloprid (3.1 t/ha), followed by botanical mix (2.37 t/ha). The botanical mix, imidacloprid and neem seed extract were highly effective in aphid control as well as less hazardous to ladybird beetle (*Coccinella septempunctata* L.). The highest cost benefit ratio was recorded with profenofos (1:1.14) followed by lufenuron (1:0.2), spinosad and nimbecidine (1:0.18). Results of the current study demonstrated that imidacloprid and plant-based insecticides can reduce aphid populations equally to conventional insecticides and could be used as an alternative component for the integrated pest management (IPM) of cabbage aphid, *Brevicoryne brassicae* (L.) on kale crop under field condition of smallholder farming system.

Key words/phrases: Botanicals, Cabbage aphid, Efficacy, Ethiopian Kale, Ladybird beetle

INTRODUCTION

Ethiopian kale (*Brassica carinata* Braun) is a native crop to the central highlands of Ethiopia and the neighboring east African countries. It is an important smallholder subsistence crop in Ethiopia, Kenya, Zimbabwe and Mozambique as a key component of the local diet and nutritionally very important for people who cannot afford expensive vegetables (Lo'hr and Kfir, 2004). The leaves are rich in vitamin A, thiamine and ascorbic acid. It has high levels of glucosinates, which is a compound with anti-oxidant and has anti-cancer activities (Mnzava and Schippers, 2007). The average leaf and shoot yield are 35 t/ha on farmers' field and 50–55 t/ha on research field depending on season and cultivar type (Mnzava and Schippers, 2007; Tesfaye Teklehaymanot *et al.*, 2019). Insect pests are one of the major yield limiting factors of brassica crops and has the potential of reducing the marketable yield severely or completely destroying the crop if not managed (Dent, 2000; Mpumi *et al.*, 2020). Among the insect pests infesting brassica crops, cabbage aphid, *Brevicoryne brassicae* (L.) is a primary pest causing economic damage worldwide (Kessing and Mau, 1991; Tsedeke Abate and Gashawbeza Ayalew, 1994). Both nymph and adult stages of this insect cause economic damage by sucking the cell sap from all the plant parts. Prolonged feeding by a large population of aphids results in stunted plant growth, yellowing, curling, and consequent drying of leaves, reduced number of leaf, low seed and oil yield (Blackman and Eastop, 2000; Ahmad and Aslam, 2005; Mpumi *et al.*, 2020). Based on overseas study reports, if the cabbage aphid is not managed, it can cause up to 80% yield loss and

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also decrease the quality of the produce (Chowfla and Baruah, 1990; Ahmad and Aslam, 2005; Ahmad and Akhtar, 2013).

Currently, the major pest management strategy followed by vegetable producers in Ethiopia is the frequent application of synthetic insecticides (Belay Mengistie *et al*., 2017). Thus, the efficacy of available conventional insecticides was reduced and farmers are forced to use high doses with repeated applications, which affect the beneficial insect fauna and hasten insecticide resistance development (Belay Mengistie *et al*., 2017; Birhanu Sisay *et al*., 2019). This has necessitated the search for alternative, eco-friendly, newer group of botanical and synthetic insecticides to sustainably manage the pest and delay the development of resistance against conventional insecticides (Ahmad and Aslam, 2005; Pavela, 2009). Therefore, the objective of the current study was to evaluate the efficacy of some newer synthetic and plant derived insecticides against cabbage aphid under field conditions and asses their impact on ladybird beetle.

MATERIALS AND METHODS

Description of the study site

The study was carried out from August 2018 to January 2019 in the experimental field of Debrezeit Agricultural Research Center (DZARC), found 47 km to south east of Addis Ababa and it is located at 08° 44′ N, 38° 58′ E. The elevation of the site was 1900 m above sea level. The mean annual maximum and minimum temperatures and relative humidity of the area were 28.3°C and 8.9°C and 72%, respectively. It has a bimodal type of rainfall, where the short rain is received in February to April and the long rain from June to early September. The annual total rainfall was 851 mm. The center has mainly two soil types, which are black soil (vertisols/ nitosols) and light soils (Alfisols/Mollisols) (http://www.eiar.gov.et/dzarc).

Experimental design and field management

The treatments were synthetic insecticides *viz*., spinosad 45 SC @ 60ml/ha, Malathion 50EC @1000 ml/ ha, imidacloprid 17.8 SL @60g/ha, lufenuron 050 EC @700 ml/ ha, dimethoate 40% EC @1500 ml/ha, and profenofose 720 EC @1500 ml/ha and plant derived insecticides neem seed extract @ 5%W/V, nimbecidine (Neem oil) 0.03% EC @ 3000 ml/ha and botanical mix @ 5% W/V. The experiment was laid out in a randomized complete block design in three replications. The plot size was 3m x 2m and the spacing between plants, rows, and plots were 30 cm, 60 cm, and 2 m, respectively. The Ethiopian Kale variety locally named as *'Yabesh Gomen'* was used for the experiment. Seeds obtained from the highland areas of 'Ziqual Abo monastery' were planted on nursery bed on 5th of July 2018 with the standard seed bed management practices. Seedlings were transplanted at the age 35 days (10th August /2018). All agronomic practices recommended for conventional cabbage production were applied (Asfaw Zeleke and Eshetu Derso, 2015).

Botanical mixture preparation

A single bulb of garlic and onion (~10g each) obtained from vegetable crops research program of DZARC were pealed and grinded with pestle and mortar, mixed with 10g of dried pepper powder obtained from the supermarket ('Selam Baltina') and stored until use. The mixture was soaked in one liter of water for 24 h and hand-squeezed to extract the juice. The juice was rinsed into a vessel using a double layer of muscling cloth (Mhazo, 2011; Sohail *et al.,* 2012). Before spray, three drops of liquid soap were added to the mixture of spray solution as an emulsifier to enhance its delivery and stickiness onto the leaf surface. The mixture/solution was placed in 1000 ml volume measuring cylinder and filled to the level of 1000ml final volume to make a 3% concentration. It was sprayed to the experimental plot using a manually operated CP-15L knapsack sprayer.

Neem seed aqueous extract (NSE) preparation

Fresh ripen neem seeds were collected from Worer Agricultural Research Center. It was cleaned and washed with sterile water to avoid dust and any microorganisms present on the surface. Then, it was dried under shade conditions with good ventilation and at the room temperature of 18°C–25°C and kept for ten days. The dry kernel was grounded to powder with pestle and mortar. The powder was sieved with 0.25 mm mesh size and uniform fine powder was obtained packed in air tight dry container for further use. About 100 g of the fine neem seed powder was taken and soaked in 1000 ml of water for 24 hrs and the solution was agitated well and filtered repeatedly with double layers of muslin cloth. The resulting solution was refilled with additional water up to 1000 ml total volume, and was adjusted to 10% concentration level (w/v). Before spray, three drops of liquid soap were added to the extract as an emulsifier to enhance its delivery and stickiness onto the leaf surface.

Treatment application

Three foliar applications of the treatments were made biweekly intervals based on the aphids' population. An untreated control plots were sprayed with tap water with the same volume of water used for mixing insecticides. There was a one-week gap between each treatment application to allow aphid population build up to attain the economic threshold level. The first application was done on 15th of September 2018 (i.e. 35 days after transplanting); the 2nd application was done on September 30, 2018, and the 3rd application was done on 16th of October, 2018. The spray was made as foliar applications using a manually operated CP-15L knapsack sprayer. Separate sprayer tanks were used for botanical and synthetic insecticides and after spraying of each treatment, the sprayers were thoroughly washed with clean water and soap. Care was taken to prevent the drift effects of treatments, by putting polythene sheet screen between each plot at the time of spraying.

Data collection

Aphid and the lady bird beetle counts were made at weekly interval on five randomly selected and marked plants from each plot, by searching the whole plant. The same sample plants were considered for the whole trial period. The numbers of aphids and the lady bird beetle on the plants were recorded starting from one week after transplanting of the seedlings (17th August 2018) and continued until harvesting. Pre and post treatment aphid populations were recorded one day before treatment application and two, five, and seven days after treatment application. Fresh leaf yield was harvested from each plot. Healthy and damaged leaves were separately weighted and recorded at each harvest and finally pooled, and converted to tones per hectare. Similarly, the population of lady bird beetle was recorded on five selected plants before and after every spray in all plots. Data on plant morphological parameters such as leaf canopy spread at maturity (cm), plant height at maturity (cm), number of damaged leaves/plot, number of healthy leaves/plot, weight of damaged leaves /plot, weight of healthy leaves/plot and fresh leaf yield (t/ha) were measured.

Data analysis

All the data recorded were subjected to analysis of variance (ANOVA) using SAS software (SAS Institute, 2009) and means were separated by Tukey's honest significance difference (HSD) test at 5% level of significance. Incremental Cost: Benefit Ratio (ICBR) was calculated based on yield increment over the control, market value of yield obtained, cost of the treatment, and profit due to the treatment. Percentage control (efficacy) was calculated using Abbott's (1925) formula modified by Henderson and Tilton (1955) as follows: -

$$\%\ Efficacy = \left[1 - \frac{(Ta\ x\ Cb)}{(Tb\ x\ Ca)}\right] x\ 100$$

***Where*: -**
Ta = Infestation in treatment plots after spray;
Cb = Infestation in control plots before spray
Tb = Infestation in treatment plots before spray;
Ca = Infestation in control plots after spray.

RESULTS

The efficacy of selected insecticides against cabbage aphid at 1st, 2nd, and 3rd sprays were presented in Tables 1, 2, and 3, respectively. After the first spray, the aphid populations recorded were significantly ($P<0.05$) different among the treatments. Two days after spray, imidacloprid and lufenuron were found highly effective and gave 82.84% and 76.57% efficacy, respectively. On the contrary, nimbecidine and dimethoate resulted in the lowest of 54.93% and 66.9%, respectively. The rest of the treatments resulted in moderate efficacy ranging from 71%–73.92%. Five days after spray, imidacloprid and botanical mixture were found to be superior to the other treatments and resulted in 91.73% and 92.46% efficacy, respectively. Similarly, seven days after spray imidacloprid and botanical mixture were the most effective and resulted in 94.23% and 95.7%, respectively (Table 1).

Table 1. Mean (±se) cabbage aphid populations before spray and percent efficacy on aphids after 2-7 days of the first application.

Common Name	1st Application							Mean % Efficacy
	(No. of aphids/plant) 1 DBS	(No. of aphids/plant) 2DAS	%Efficacy	(No. of aphids/plant) 5DAS	%Efficacy	(No. of aphids/plant) 7DAS	%Efficacy	
Control	6.93±0.3	15.13±0.8a*		26.17±2.3a		46.13±2.3a		
Spinosad45% SC	8.60±1.2	5.39±0.5bcde	71.28	5.34±0.5b	83.55	4.77±0.4bc	91.67	85.71
Malathion50 %EC	8.19±1.0	5.00±0.7e	72.04	4.00±0.7b	87.07	5.50±0.2c	89.91	85.97
Imidacloprid 17.8% SL	8.01±0.7	3.00±0.3de	82.84	2.50±0.4b	91.73	3.07±0.3bc	94.23	91.51
Lufenuron05 0%EC	8.81±0.7	4.51±0.5cde	76.57	4.45±0.6b	86.61	3.84±0.2bc	93.45	88.48
Dimethoate 40%EC	6.36±0.5	4.60±0.7cde	66.90	3.87±0.4b	83.87	2.87±0.2bc	93.21	85.86
Profenophos e72SC	8.39±0.5	5.35±0.7b	70.80	3.75±0.2b	88.16	8.41±0.5bc	84.94	83.46
NSE[a]	10.71±0.8	6.10±0.7bcd	73.92	4.87±0.1b	87.96	6.50±0.5bc	90.89	87.07
Neem Oil 0.3.%EC	8.17±0.8	8.04±0.7bc	54.93	6.17±0.6b	79.99	7.20±0.6b	86.77	79.23
Botanical Mix[b]	11.19±1.1	6.53±0.5bcd	73.28	3.19±0.2b	92.46	3.20±0.3c	95.70	90.85
Mean	8.54	6.17		6.44		8.73		
SE±	2.07	1.10		1.28		2.06		
CV%	24.22	17.91		19.89		23.63		
LSD	NS	3.23		3.75		6.04		

**Means followed by the same letter (s) within a column are not significantly different at 5% level, Tukey's honest significance difference (HSD) test; [a]NSE = Neem Seed Extract; [b]Botanical Mix= Garlic bulb + Onion bulb + dry pepper + liquid soap; DBS= Day Before spray; DAS= Days After Spray; se = standard error.*

Two days after the second spray, only lufenuron was effective among the treatments and resulted in 84.26% efficacy. Five days after spray, most of the treatments were found highly effective and resulted in efficacy ranging from 81.38% to 90.15%. Neem seed extract and profenofos were resulted in low percent efficacy of 63.3%, and 65.37%, respectively. Seven days after spray, maximum percent efficacy of 94.8%, 94.24%, 94.12%, and 93.6% were obtained from botanical mix, neem seed extract, lufenuron and imidacloprid, respectively. On the other hand, the lowest percentage efficacy of 57.17% was recorded on spinosad (Table 2).

In the third application, there were significant ($P<0.05$) variations among the treatments in the reduction of aphid population compared to the untreated control. Thus, two days after spray, the maximum percent efficacy of 87.2% was obtained from imidacloprid followed by botanical mix for which the percent efficacy was 70.94%. However, the rest of the treatments resulted in low efficacy percentage, ranging from 12%–60% (Table 3). Similarly, five and seven days after sprays, imidacloprid and botanical mix were found the most effective and resulted in 87.69%, 86.82%, and 88.1%, 82.44% efficacy, respectively (Table 3).

Table 2. Mean (±se) cabbage aphid populations before spray and percent efficacy on aphids after 2-7 days of the 2nd application.

Common Name	2nd Application							Mean % Efficacy
	(No. of aphids/plant) 1 DBS	(No. of aphids/plant) 2DAS	% Efficacy	5 No. of aphids/plant at DAS	% Efficacy	No. of aphids/plant at 7DAS	% Efficacy	
Control	301.3±0.9a*	315.67±1.7a		342.17±5.1a		384.6±4.2a		
Spinosad45% SC	179.5±4.2b	81.71±5.7b	56.54	33.9b±4.3c	83.37	98.11±1.9b	57.17	65.58
Malathion50%EC	22.28±0.9c	4.85±0.6c	79.22	4.04±0.3c	84.03	2.4±0.5c	91.56	85.35
Imidacloprid 17.8% SL	52.28±3.5c	13.31±0.4c	75.7	5.85±0.4c	90.15	4.27±0.4c	93.6	87.05
Lufenuron050%EC	66.52±4.2c	10.97±0.9c	84.26	9.0±1.6c	88.09	4.99±0.7c	94.12	89.15
Dimethoate 40%EC	48.67±4.1c	20.84±1.1c	59.13	10.29±0.5c	81.38	4.78±0.7c	92.31	78.67
Profenophose72SC	63.9±2.7c	40.67±1.6c	39.25	25.13±3c	65.37	12.57±0.8bc	84.59	64.55
NSE[a]	61.18±3.9c	37.07±1.0c	42.17	25.5±2c	63.3	12.67±1.0bc	83.78	64.45
Neem Oil 0.3.%EC	48.93±4.2c	11±0.7c	78.54	5.87±0.6c	89.44	3.6±0.5c	94.24	87.91
Botanical Mix[b]	195.83±1.1b	55.7±0.7c	72.85	28.33±1.2bc	87.26	13b±1.8c	94.8	85.68
Mean	104.04	59.18		49.01		54.1		
SE±	18.36	34.43		20.78		44.66		
CV%	17.64	58.18		42.41		82.56		
LSD	53.73	100.79		60.84		130.75		

Means followed by the same letter (s) within a column are not significantly different at 5% level, Tukey's honest significance difference (HSD) test; [a]NSE = Neem Seed Extract; [b]Botanical Mix= Garlic bulb + Onion bulb + dry pepper + liquid soap; DBS= Day Before spray; DAS= Days After Spray se = Standard error

Table 3. Mean (±se) cabbage aphid populations before spray and percent efficacy on aphids after 2-7 days of the 3rd application.

Common Name	3rd Application							Mean %Efficacy
	(No. of aphids/plant) 1 DBS	(No. of aphids/plant) 2DAS	%Efficacy	(No. of aphids/plant) 5DAS	%Efficacy	(No. of aphids/plant) 7DAS	%Efficacy	
Control	25.11±0.6a*	33.33±0.9a		38.35±2.2a		28.67±1.8a		
Spinosad45% SC	11.783±0.9ab	10.97±1.2b	29.86	4.2±0.4b	76.66	5.02±0.3b	62.69	57.12
Malathion50%EC	3.58±0.4b	2.22±0.4b	53.28	3.42±0.2b	37.45	0.98±0.0b	76.02	53.73
Imidacloprid 17.8% SL	7.713±0.5b	1.31±0.0b	87.20	1.45±0.1b	87.69	1.05±0.1b	88.08	87.64
Lufenuron050%EC	7.39±0.5b	3.88±0.4b	60.45	3.88±0.4b	65.62	2.85±0.5b	66.22	64.07
Dimethoate 40%EC	4.24±0.6b	2.38±0.3b	57.71	2.51±0.3b	61.24	1.63±0.2b	66.33	61.52
Profenophose72SC	9.59±0.8b	8.89±1.0b	30.16	7.91±0.3b	45.99	9.32±0.8b	14.88	31.85
NSE[a]	7.39±0.5b	8.09±1.1b	17.53	6.84±1.0b	39.40	7.11±0.8b	15.74	25.37
Neem Oil 0.3.%EC	6.56±0.7b	7.66±1.2b	12.03	6.06±0.7b	39.51	7.59±0.5b	-1.33	18.72
Botanical Mix[b]	13.12±0.8ab	5.06±0.3b	70.94	2.64±0.4b	86.82	2.63±0.4b	82.44	80.30
Mean	9.65	8.35		7.73		6.69		
SE±	5.12	4.3		3.29		3.74		
CV%	53.06	51.44		42.52		55.89		
LSD	14.99	12.58		9.62		10.94		

Means followed by the same letter (s) within a column are not significantly different at 5% level, Tukey's** honest significance difference (HSD) test; **[a]NSE = Neem Seed Extract; [b]Botanical Mix= Garlic bulb + Onion bulb + dry pepper + liquid soap; DBS= Day Before spray; DAS= Days After Spray, se = Standard Error

The pooled mean efficacy was summarized in Table 4. Two days after spray, the maximum efficacy of 76.28% was recorded in imidacloprid treatment, followed by botanical mix (72.02%) and lufenuron (71.94%). Similarly, in five days after spray imidacloprid, botanical mix, Spinosad and Lefenoron were significantly suppressed the aphid population and resulted in 88.2%, 87.3%, 82.8%, and 82.2% efficacy, respectively. The overall efficacy, seven days after spray clearly indicated that botanical mix and imidacloprid were found the best treatments with the efficacy of 93.79% and 91.04%, respectively. On the other hand, nimbecidine and neem seed extract showed low to moderate efficacy of 61.61% and 40.81%, 76.69% and 61.53%, 79.04% and 75.95% at two, five and seven days after spray, respectively (Table 4).

Table 4. Pooled mean (±se) of cabbage aphid populations and % Efficacy at different days before and after treatment application.

Treatments	Aphids/plant 1 DBS	Aphids/plant 2DAS	% efficacy	Aphids/ plant 5DAS	% efficacy	Aphids/ plant 7DAS	% efficacy
Control	111.11±0.5a*	121.38±0.7a	-	135.6±1.1a	-	153.13±2.0a	-
Spinosad45% SC	66.62±0.8ab	32.60±0.7ab	55.20	14.48±0.4b	82.18	35.97±1.0b	60.82
Malathion50% EC	11.35±0.4b	4.02±0.3b	67.55	3.82±0.4c	72.41	2.96±0.4c	81.08
Imidacloprid1 7.8% SL	22.67±0.7ab	5.87±0.3b	76.28	3.27±0.2c	88.19	2.80±0.5c	91.04
Lufenuron050 %EC	27.57±0.9ab	8.45±0.2b	71.94	5.78±0.4bc	82.83	3.89±0.5c	89.75
Dimethoate 40%EC	19.76±0.4ab	9.27±0.7b	57.04	5.56±0.5bc	76.94	3.09±0.3c	88.64
Profenophose7 2SC	27.29±0.8ab	18.30±0.5ab	38.61	12.26±0.5b	63.17	10.10±0.7bc	73.15
NSE[a]	26.43±0.9ab	17.09±0.6ab	40.81	12.40±0.8b	61.53	8.76±07bc	75.95
Neem Oil 0.3.%EC	21.22±0.6ab	8.90±0.5b	61.61	6.03±0.8bc	76.69	6.13±0.8bc	79.04
Botanical Mix[b]	73.38±4.4ab	22.43±0.6ab	72.02	11.39±0.9b	87.28	6.28±0.4bc	93.79
Mean	40.74	24.57		21.06		23.17	
SEm±	8.52	13.28		8.45		16.82	
CV%	31.64	42.51		34.94		54.03	
LSD= 0.05	34.36	38.87		24.74		49.24	

Means followed by the same letter (s) within a column are not significantly different at 5% level, Tukey's honest significance difference (HSD) test; [a]NSE = Neem Seed Extract; [b] Botanical Mix= Garlic bulb + Onion bulb + dry pepper + liquid soap; DBS= Day Before spray; DAS= Days After Spray
se = Standard Error

The non-target effect of the treatments on coccinellid beetles was presented in Table 5. Two days after spray the highest ladybird beetle population of 6.35 beetles/plant was observed in plots treated with the botanical mixture followed by imidacloprid with 5.35 beetles/plant and the untreated control with 5.35 beetles/plant. Five days after spray, imidacloprid treated plots showed the highest number of ladybird beetles of 5.5 beetles/plant followed by the botanical mix and the untreated control with 4.85 beetles/plant. Seven days after spray imidacloprid, botanical mix and the untreated control were not significantly different ($P<0.05$) as 3.85, 3.85, and 4.05 beetles/plant, respectively were recorded. On the contrary, Malathion, dimethoate, profenofos and nimbecidine treated plots showed the lowest number of beetles/plant, which were not significantly different ($P>0.05$) (Table 5).

Table 5. Mean (±SE) effect of different insecticidal treatments on coccinellid beetle.

Treatments	Mean coccinellid beetle /5 plants				Percent toxicity to coccinellid beetle			Over all % toxicity
	1 DBS	2DAS	5DAS	7DAS	2DAS	5DAS	7DAS	
Control	5.89±0.4	5.35±0.2b*	4.85±0.6b	4.05±0.4a	9.17	17.66	31.24	19.36
Spinosad45% SC	4.82±0.2	3.85±0.4f	2.85±0.2dc	1.85±0.2cd	20.12	40.87	61.62	40.87
Malathion50%EC	5.74±0.4	3.79±0.2g	1.67±0.3de	0.85±0.2de	33.97	70.91	85.19	63.36
Imidacloprid17.8% SL	6.70±0.6	5.35±0.5b	5.50±0.5a	3.85±0.4ab	20.15	17.91	42.54	26.87
Lufenuron050%EC	5.81±0.4	3.74±0.3h	3.11±0.1c	2.85±0.2bc	35.63	46.47	50.95	44.35
Dimethoate40%EC	4.68±0.2	1.85±0.4i	1.35±0.2e	0.34±0.2e	60.47	71.15	92.74	74.79
Profenophose72SC	6.84±0.4	4.07±0.3d	1.85±0.2de	0.34±0.2e	40.50	72.95	95.03	69.49
NSE[a]	4.88±0.2	4.85±0.2c	3.85±0.4bc	2.85±0.2bc	0.61	21.11	41.60	21.11
Neem Oil 0.3.%EC	6.84±0.4	3.93±0.3e	1.85±0.2de	0.85±0.2de	42.54	72.95	87.57	67.69
Botanical Mix[b]	5.86±0.4	6.35±0.4a	4.85±0.6ab	3.85±0.4ab	-8.36	17.24	34.30	14.39
SEm±	0.02	0.01	0.42	0.36				
CV%	0.35	0.38	13.34	16.48				
LSD= 0.05	Ns	0.048	1.24	1.05				

Means followed by the same letter (s) within a column are not significantly different at 5% level, Tukey's honest significance difference (HSD) test; [a]NSE = Neem Seed Extract; [b]Botanical Mix= Garlic bulb + Onion bulb + dry pepper + liquid soap; DBS= Day Before spray; DAS= Days after Spray
se = Standard Error

The effect of treatments on yield and yield components was presented in Table 6. The canopy spread, plant height, and total leaf yield (t/ha) were not significantly different (P>0.05) among the treatments. On the other hand, the mean number of healthy and damaged leaves were significantly different (P<0.05) among the treatments and highest number of damaged leaves of 18.8 leaves/plot was recorded from neem seed extract. The lowest number of damaged leaves of 4.44 and 4.53 leaves/plot were recorded on plots treated with imidacloprid and profenofos, respectively. The highest number of healthy leaves of 18.2 leaves/plot was recorded with profenofos followed by imidacloprid treated plots with 16.53 leaves/plot.

Regarding the marketable fresh leaf yield, the maximum fresh leaf yield of 14.17 t/ha was recorded from imidacloprid followed by botanical mix with 13.453 t/ha and Dimethoate with 12.72 t/ha. The lowest fresh leaf yield was recorded from nimbecidine and neem seed extract treatments with 4.64 t/ha and 4.82 t/ha, respectively which were not significantly different among each other (Table 6).

The incremental cost benefit ratio (ICBR) analysis was presented in Table 7. The incremental leaf yield over control was significantly different (P< 0.05) and the highest yield increment of 3.1t/ha was obtained from imidacloprid treated plot followed by botanical mix with 2.37 t/ha. On the contrary, the least yield incremental of 0.2 t/ha and 0.74 t/ha was obtained from profenofos and neem seed extract treatments, respectively. The highest cost of treatment, 94.3, 97, 80.9, and 97 USD /ha was incurred by spinosad, imidacloprid, lufenuron and nimbicidene, respectively. The maximum profit of 1155.1 USD/ha was obtained from imidacloprid followed by Botanical mix with 919.4 USD/ha. The lowest profit of 37.7 USD /ha was recorded with profenofos treatment. The highest cost: benefit ratio of 1:1.14 was recorded with profenofos followed by lufenuron with 1:0.2, Spinosad with 1:0.18 and nimbecidine with 1:0.18 (Table 7).

Table 6. Mean (±se) values of fresh leaf yield and yield components as affected by the treatments.

Treatments	Canopy spread at maturity (cm)	Plant height at maturity (cm)	Number of damaged leaves /plot	Number of healthy leaves/plot	Marketable leaf yield t/ha	Unmarketable leaf yield t/ha	Total leaf yield (q/ha)
Control	47.07±0.6	70.2±1.1	9.73±0.6ab*	10.13±0.5abc	11.08±0.6b	5.7±0.4abc	16.78
Spinosad45% SC	41.8±0.6	59.07±0.7	7.73±0.4ab	8.47±a0.2bc	12.59±0.8ab	4.0±0.2abc	16.59
Malathion50%EC	40.67±0.8	63.13±0.7	7.6±0.3ab	13.73±0.4abc	12.42±0.7ab	4.19±0.3abc	16.604
Imidacloprid17.8% SL	43.8±0.6	74.20±0.9	4.4±0.4b	16.53±0.4ab	14.18±0.4a	2.33±0.1c	16.501
Lufenuron050%EC	44.0±0.4	65.13±0.3	6.53±0.2ab	14.4±0.2abc	12.27±0.4ab	6.81±0.4abc	19.079
Dimethoate 40%EC	43.73±0.7	76.87±0.8	9.2 ±0.4ab	7.33±0.3abc	12.72±0.2ab	2.56±0.2bc	15.276
Profenophose72SC	43.67±0.6	69.33±0.6	4.53±0.3b	18.2±0.5a	11.28±0.5b	10.08±0.4a	21.34
NSE[a]	44.13±0.8	79.73±0.4	18.8±0.9 a	10.27±0.4abc	11.82±0.6b	10.58±0.5a	22.407
Neem Oil 0.3.%EC	40.80±0.7	60.93±0.7	12.671.0ab	5.47±0.3bc	12.64±1.0ab	10.14±0.4a	22.773
Botanical Mix[b]	39.07±0.5	62.67±0.9	15.07±0.6ab	4.27±0.2c	13.45±0.6a	6.84±0.4abc	20.291
Mean	42.87	68.13	9.63	10.88	12.44	6.32	18.77
SE	3.53	12.09	4.74	4.11	30.41	26.91	32.44
CV	8.23	17.74	49.25	37.76	30.87	46.66	20.06
LSD	NS	NS	13.881	12.027	89.03	77.97	NS

Means followed by the same letter (s) within a column are not significantly different at 5% level, Tukey's honest significance difference (HSD) test; [a]NSE = Neem Seed Extract; [b]Botanical Mix= Garlic bulb + Onion bulb + dry pepper + liquid soap; DBS= Day Before spray; DAS= Days After Spray
se = Standard error

Table 7: Incremental Cost: Benefit Ratio (ICBR) analysis of insecticidal treatments

Treatment	Average marketable yield (t/ha)	Incremental yield over control (t/ha)	Value of incremental yield ($USD/ha)	Cost of treatments ($USD/ha)	Profit due to treatments ($USD)	Incremental Cost: Benefit Ratio (ICBR)
Spinosad45% SC	12.587	1.51	609.7 [c]	94.3	515.4	1:0.18
Malathion50%EC	12.42	1.34	540.6	70.1	470.5	1:0.15
Imidacloprid17.8% SL	14.17	3.10	1252.2	97.0	1155.1	1:0.08
Lufenuron050%EC	12.27	1.19	480.3	80.9	399.5	1:0.20
Dimethoate 40%EC	12.72	1.64	661.9	48.5	613.3	1:0.08
Profenophose72SC	11.28	0.20	80.9	43.1	37.7	1:1.14
NSE[a]	11.82	0.74	300.8	36.4	264.4	1:0.14
Neem Oil 0.3.%EC	12.64	1.56	629.9	97.0	532.9	1:0.18
Botanical Mix[b]	13.45	2.37	959.8	40.4	919.4	1:0.04
Control	11.08					

[a]NSE = Neem Seed Extract; [b]Botanical Mix = Garlic bulb + Onion bulb + dry pepper + liquid soap;
[c]1$USD = 37.1 Birr with current exchange rate.

DISCUSSION

The treatments were variable in terms of cabbage aphid control and their effects on lady bird beetle which is the most important predator in cabbage field.

Results of the current study are in line with the findings of earlier workers. Faheem *et al.* (2010) reported that imidacloprid was the most effective treatment against cabbage aphid *Myzus persicae* (Sulzer) on round head cabbage. Likewise, Debbarma and Kumar (2020) reported that imidacloprid, thiamethoxam, spinosad, and acetamiprid were found to be effective against *B. brassicae,* while novaluron was less effective. Sahoo (2012) made a study in West Bengal and reported that imidacloprid and Thiamethoxam were found the most effective against mustard aphid under field condition. Moreover, Aslam and Munir (2002) reported that imidacloprid, endosulfan and trebon were resulted in better control of aphid on Chinese cabbage. Similarly, Faheem *et al.* (2010) reported that imidacloprid, endosulfan, and profenofos were found to be effective against cabbage aphid and resulted in 90.41, 77.01, and 69.84% efficacy, respectively. Thus, most of the above studies were in agreement with our findings and confirmed that Imidacloprid is the most effective treatment against cabbage aphid.

Regarding the botanical insecticides, Dougoud, *et al*. (2019) reviewed that the botanical extracts are suitable components of integrated pest management and have been used as an alternative to synthetic insecticides for long period of time. Thus, the findings of this study on botanicals are in line with earlier several work. Tadele Shibiru and Mulugeta Negeri (2016) reported that neem seed powder, fresh leaf extract of *Dodonae angustifolia* and leaves of *Cymbopogon citrates* resulted in 53.92%, 37.26%, and 62.72% efficacy, respectively against cabbage aphid. Abebe Megerssa (2016) reported that both 5 and 10% concentrations of garlic and 5% neem seed extracts have the potential to control pea aphid, equally to the commercial insecticide, Endosulfan 35% EC.

The findings of this study revealed that, imidacloprid, botanical mix, and neem seed extract were proved relatively safer to the lady bird beetles. Similarly, Dutta *et al.* (2016) reported that azadiractin 1% EC was less toxic product to coccinellid beetles and foraging honey bees. On the contrary, Ali and Zedan (2015) studied the non-target effect of five insecticides (viz. Thiamethoxam, Lambdacyhalothrin, Chlorpyriphos + Lambdacyhalothrin, Dimethoat and Chlorpyriphos) on the survival of coccinellid beetles and reported that these insecticides are hazardous to beetles. Similarly, Kibrom Gebremariam *et al.* (2012) showed that false neem (*Melia azedarach*) seed extracts were effective against cabbage aphids under field condition, but significantly reduced the predator population. In summary, the order of non-target effect of the insecticides tested against the lady bird beetles (from highly toxic to less toxic) was presented as follows: Dimethoate followed by profenofos, nimbecidine, Malathion, luefenuron, spinosad, imidacloprid, neem seed extract, and botanical mix.

With respect to yield, different studies have supported the positive contribution of insecticide treatments on leaf and seed yield of brassica crops. Accordingly, Patel *et al.* (2017) reported that the highest mustard seed yield of 1.24 t/ha was obtained from imidacloprid treatment, which remained on par with the thiamethoxam with 1.0 t/ha and quinalphos with 0.931 t/ha, while the lowest seed yield of 0.6 t/ha was obtained from the untreated plots. Khade *et al.* (2014) reported that imidacloprid gave maximum yield of cowpea with 45.27 q/ha which is 20.40 q/ha yield increment to the untreated control. Yadav and Singh (2016) reported maximum seed yield of 1.63 t/ha, 1.620 t/ha, and 1.615 t/ha from imidacloprid, thiamethoxam and Dimethoate, respectively, but the lowest seed yield of 1.37 t/ha was obtained from the untreated plots. Patil *et al* (2018) evaluated insecticides against cowpea aphid and reported that the highest cost: benefit ratio was recorded by acetamiprid with 1:1.59 followed by dimethoate with 1:1.48 and imidacloprid with 1:1.41 which are in agreement with the present findings.

CONCLUSION

From the present studies, it can be concluded that imidacloprid and botanical mix were the most effective among the nine tested insecticides against cabbage aphid. At the same time, imidacloprid and botanical mix treated plots showed less effect on the lady bird beetles and resulted in higher leaf yield comparable to synthetic insecticides. Moreover, the maximum profit due to treatment application was obtained from imidacloprid followed by botanical mix. Therefore, imidacloprid and botanical mix can be recommended for the management of cabbage aphid on brassica leafy vegetable crops produced in Ethiopia.

ACKNOWLEDGEMENTS

The authors are grateful to the Ethiopian Institute of Agricultural Research (EIAR) and Addis Ababa University for financing and providing institutional support for this study. We thank the Debrezeit Agricultural Research Center (DZARC), for providing assistance in the form of farm machinery, labor and land resources for conducting this research. Special thanks also go to the research and technical staffs of Horticultural Crops Research Program of DZARC for their unreserved technical supports in the field work and data collection.

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