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Assessment of *Moringa oleifera* Lam. Leaf Extract as Biopesticide for Hemipterans Damaging Okra, *Abelmoschus esculentus* L.

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Key words
***Amrasca biguttula, Bemisia tabaci, Oxycarenus hyalinipennis, Coccinella septempunctata*, Flubendiamide, Flonicamid, Biological compounds**

ABSTRACT

Shift toward sustainable alternatives to pesticides is attributed to their negative impacts on ecosystems, human health, and non-target organisms. This study hypothesized that *Moringa oleifera* leaf extract (MLE) can be an alternative to synthetic insecticides for managing okra pests. We compared MLE (2%) with insecticides with diverse modes of action in open cultivated fields for three consecutive seasons including spring and autumn 2022 and spring 2023. MLE-treated plots typically had lower populations of okra pests including *Amrasca biguttula* (Ishida), *Bemisia tabaci* (Gennadius), and *Oxycarenus hyalinipennis* (Costa) compared to untreated control plots and mostly provided similar pest control to synthetics. However, new chemicals like flonicamid and flubendiamide inconsistently provided the best pest populations reductions. Additionally, MLE sustained higher populations of predators including *Coccinella septempunctata* L., *Brumus suturalis* (F.) and arachnids compared to synthetic insecticides. In this context, we recommend MLE to be incorporated in okra pest production systems in rotation with synthetic chemicals, this will reduce the control costs and delay the development of resistance to arthropods while conserving predators.

INTRODUCTION

Pesticides have gained popularity since their advent in enhancing crop yields to meet food demands. But these benefits have come at the cost of negative consequences on ecosystems, environment, human health and non-target organisms especially those providing biocontrol services, particularly at farm levels owing to non-judicious applications in recent decades, even then their usage is increasing in developing nations to meet rising demands for food (Matilda, 2023; Popp *et al*., 2013). Although evaluations, assessments and reconsiderations continue for synthetic chemicals in terms of controlling biotic stresses (pests, pathogens, weeds), their adverse effects persist (Bonner and Alavanja, 2017; Verger and Boobis, 2013) which demands the usage of safer alternatives. Therefore, to counter their consequences it is necessary to offload the burden of insecticides from agroecosystems by using environmentally friendly tactics (Saleem *et al*., 2025). As we cannot completely abandon insecticides due to the inability of any other promising control measure to mitigate pests, modern chemical control needs their effective use (Razaq *et al*., 2019). Biopesticides or botanicals represent the most suitable and recent synthetic insecticide alternatives. They are not only specific, effective but easy to process and apply (Shah *et al*., 2017, 2019, 2020).

Okra, *Abelmoschus esculentus* L. (Malvaceae) is a good source of micro and macronutrients, and fibers which makes it an important vegetable crop concerning consumption and nutrition (Jan *et al*., 2022). Prospects of okra production and consumptions are undermined by several challenges, including pests and diseases (Nawaz *et al*., 2020). Seventy-two pest species pose serious threats to okra (Rahman *et al*., 2013) including leaf hopper, *Amrasca biguttula* (Ishida), whitefly, *Bemisia tabaci* (Gennadius), dusky cotton bug, *Oxycarenus hyalinipennis* (Costa). Leaf hopper can inflict yield losses of up to 55% by sucking sap from early to crop maturation stages (Devi *et al*., 2018; Ghosal *et al*., 2013) causing pale, blackish (burnt-like) and reddish colouration of leaves (Cabrera-Asencio *et al*., 2023) with wrinkling and twisting them (Chandrasekaran *et al*., 2021). Whiteflies spread the okra mosaic virus (OMV) and okra yellow vein

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mosaic virus (OYVMV), which significantly reduces crop yield (Appiah *et al*., 2020; Kumar and Vashisth, 2024). Similarly, dusky cotton bug also damages okra and both nymphs and adults suck lipid contents of seeds leaving them underweight with reduced germination (El-Rahim *et al*., 2015). To tackle these pests farmers employ a variety of synthetic insecticides (Prithiva *et al*., 2024).

Recently, sustainable pest management focuses the incorporation of new chemicals molecules in to the pest management systems as these have no resistance like insecticides being applied in the past (Barman *et al*., 2022; Sandhi *et al*., 2017), and have less negative effects on beneficial insect populations and also have low health risks (Adilakshmi *et al*., 2010). Botanicals/biopesticides are the alternate/most recent and are also safer and effective to the synthetics. Unfortunately, higher market prices and need of repeated applications limit utility botanicals specially when it comes to resource poor farmers of developing countries (Guleria and Tiku, 2009; Moustafa *et al*., 2024). Plants extracts of locally available plants have proved to be efficacious as their productions and applications can provide respite to small farmers (Akhter *et al*., 2023; Amoabeng *et al*., 2014). Like other plant-based substances, *Moringa oleifera* Lam. leaf extract is being tested for insecticidal properties. Although some studies have explored the insecticidal potential of moringa leaves and moringa leaf extract (MLE) against different harmful insects, literature is scarce regarding the evaluation of insecticidal effects of MLE for okra pests (Coelho *et al*., 2009; Kaur *et al*., 2021; Shah *et al*., 2017; Tridiptasari *et al*., 2019).

Here we hypothesized that MLE reduces populations of hemipterans insect pests in okra crops while also preserving natural enemies due to its non-toxic profile. To confirm this, we compared the effects of MLE, and other insecticides currently used in okra crops including deltamethrin, imidacloprid, flubendiamide and flonicamid on the population abundance of different hemipteran pests of okra crops and their natural enemies. We planned current study with aim that whether MLE can effectively reduce hemipterans damaging okra comparable with insecticides.

MATERIALS AND METHODS

Experimental site

The experiments were conducted in the entomology research field of the Department of Entomology, Bahauddin Zakariya University, Multan, Punjab, Pakistan (32.20° N and 71.45° E). The Multan region is predominantly flat with a semi-arid climate, featuring an average annual temperature of 32.59 °C and receives 175 mm of precipitation (Shahid *et al*., 2023).

Experimental design

We applied randomized complete block design (RCBD) for all the field experiments. For each trial, the entire field (0.0406 ha) was divided into three blocks of equal size (21m × 3.5m) and then each was subdivided into six treatment plots measuring 3.5m × 3.5m with a 1.5m buffer among adjacent plots and blocks. In each plot, ridges were prepared at distance of 0.75m. Seeds of the okra variety “Sabz Pari” were sown using the dibbling method on both sides of ridges in each plot at a depth of 2 cm with of 0.15m spacing, on March 21, 2022, September 10, 2022, and March 22, 2023. Flood irrigation was applied usually at 7-day intervals and hoeing/weeding was carried out manually 3 to 4 times after sowing. Recommended doses of fertilizers were applied at the rate of 62:87:62 kg (NPK) per ha.

Insecticide application and sampling

To compare pest control provided by synthetic insecticides and MLE four plots received synthetic insecticide treatments including Decis 10EC (Deltamethrin), Ulala 50% WG (Flunicamid), Belt 480SC (Flubendiamide) and Confidor 20SL (Imidacloprid) while fifth plot received MLE @ 2%, and sixth plot was used as control (untreated). Insecticides were applied at recommended doses while the control was sprayed with an equal quantity of water (Table I). Insecticides were sprayed using a hand-operated 20 L knapsack sprayer (Syngenta) fitted with a hollow cone nozzle on May 15, 2022, and

Table I. Sources and mode of action of synthetic insecticides and moringa leaf extract.

Trade name	Common name	Mode of action	Source	Doses/ha
Deltamethrin	Decis 10EC	Sodium channel modulators	Bayer Crop Sci.	300 ml/ha
Flonicamid	Ulala50%WG	Chordotonal organ nicotinamidase inhibitors	ICI	200 g/ha
Flubendiamide	Belt480SC	Ryanodine receptor modulators	Bayer Crop Sci.	25 ml/ha
Imidacloprid	Confidor20SL	Nicotinic acetylcholine receptor competitive modulators	Bayer Crop Sci.	625 ml/ha
Leaf extract	Moringa leaf extract	Anti-microbial activity	Moringa	12 L/ha
Control	Control		Water	

June 03, 2022 (trial: spring 2022), Oct 07, 2022, and Oct 21, 2022 (trial: autumn 2022) and May 22, 2023, and June 09, 2023 (trial: spring 2023). The populations of pests (leaf hopper, *Amrasca biguttula*, whitefly, *Bemisia tabaci*, and dusky cotton bug, *Oxycarenus hyalinipennis* (Costa) and predators (ladybird beetle, *Coccinella septempunctata* L., striped lady beetle, *Brumoides suturalis* (F.) and predatory spiders (arachnids) were counted from five plants selected randomly from each treatment. Populations of insects were recorded 48, 72, 96, and 120 h after applying chemicals.

Preparation of MLE

We applied Sanjhi (Hexon Chemicals (Private) Limited) a registered product of MLE, preparation methods are well documented for extract (Yasmeen, 2011), however, extraction method is briefly described here. Young shoots with leaves of Moringa were collected and ground with a small amount of water (1L per 10 kg of fresh material) using a locally fabricated extraction machine. The extract is then sieved through muslin cloth and centrifuged to remove any suspended particles.

Data analysis

To evaluate the effect of synthetic insecticides and MLE on the populations of pest species including *A. biguttula, B. tabaci* and *O. hyalinipennis* and natural enemies including *C. septempunctata, O. hyalinipennis* and arachnids, ANOVA was performed. Before analysis, data were subjected to normality evaluation to meet requirements of homogeneity by Shapiro-Wilk test. Non-normal data were transformed to log (x + 1). All data were analyzed using Statistix 8.1 and SPSS version 21.

RESULTS

Effect of insecticides and MLE on pest densities

Pest densities were significantly affected by the experimental treatments viz., insecticides and MLE (see Table II for statistics) as compared to the control.

Amrasca biguttula

MLE consistently reduced *A. biguttula* populations during all three seasons. However, there was no significant difference in populations between MLE and other insecticide-treated plots, except during autumn 2022, when flunicamid and flubendiamide treated plots showed the lowest *A. biguttula* density after 2nd spray (Table III).

Bemisia tabaci

During spring 2022, MLE did not significantly lower populations of *B. tabaci* compared to control or insecticides. However, during autumn 2022 and spring 2023, MLE-treated plots significantly lowered whitefly density or was equal as compared to insecticides after both sprays, except during autumn 2022, when the highest *B. tabaci* density reduction was observed in flunicamid-treated plots after 1st spray. Additionally, during spring 2023 lowest density was observed due to flubendiamide after 1st spray (Table III).

Table II. Analysis of variance (ANOVA) in experiments conducted to evaluate toxicity of different insecticides on the populations of *Amrasca biguttula*, *Bemicia tabaci* and *Oxycarenus hyalinipennis* in spring season 2022, autumn 2023 and spring 2023.

Season	Pest	Spray	F-value	P-value
Spring 2022	*A. biguttula*	1st	116.24	<0.001
		2nd	117.50	<0.001
	B. tabaci	1st	9.39	<0.001
		2nd	7.18	0.004
	O. hyalinipennis	1st	4.38	0.022
		2nd	440.76	<0.001
Autumn 2022	*A. biguttula*	1st	32.71	<0.001
		2nd	49.50	<0.001
	B. tabaci	1st	22.90	<0.001
		2nd	5.48	0.011
	O. hyalinipennis	1st	27.32	<0.001
		2nd	224.52	<0.001
Spring 2023	*A. biguttula*	1st	28.49	<0.005
		2nd	100.40	<0.001
	B. tabaci	1st	5.22	0.012
		2nd	24.98	<0.001
	O. hyalinipennis	1st	32.21	<0.001
		2nd	24.98	<0.001

*Degrees of freedom for treatments and error were 5 and 10, respectively.

Oxycarenus hyalinipennis

During spring 2022, in MLE-treated plots, *O. hyalinipennis* populations were similar to control and other insecticides after 1st spray, while after 2nd spray population reduction by MLE was intermediate to control and insecticides. However, after 1st spray lowest density was observed in imidacloprid and flunicamid while after 2nd spray flubendiamide plots had the lowest *O. hyalinipennis* populations followed by imidacloprid and flunicamid. Similarly, during autumn 2022, MLE-treated plots had a population intermediate to control and other insecticides after both sprays, with flunicamid showing the highest reduction in population after 2nd spray. However,

Table III. Effect of different insecticides on number (Mean ± SE) of hemipteran pests in spring 2022, autumn 2022 and spring 2023 after first and second application.

	Treatments					
	Deltamethrin	**Flonicamid**	**Flubendiamide**	**Imidacloprid**	**Moringa extract**	**Control**
Spring 2022						
1st Application						
Amrasca biguttula	13.53 ± 2.78 b	8.00 ± 1.22 b	13.00 ± 3.56 b	9.33 ± 1.16 b	16.60 ± 0.2 b	106.13 ± 4.76 a
Bemisia tabaci	6.27 ± 1.25 b	6.80 ± 0.61 b	10.67 ± 1.97 ab	9.8 ± 0.92 ab	15.13 ± 0.48 a	15.40 ± 1.29 a
Oxycarenus hyalinipennis	9.47 ± 5.44 ab	2.87 ± 1.22 b	9.60 ± 2.87 ab	2.20 ± 0.83 b	5.87 ± 1.45 ab	21.33 ± 3.84 a
2nd Application						
Amrasca biguttula	10.20 ± 3.25 b	14.93 ± 5.82 b	13.13 ± 0.48 b	12.67 ± 2.32 b	12.87 ± 2.34 b	47.87 ± 4.48 a
Bemisia tabaci	9.80 ± 0.95 b	11.80 ± 0.23 b	11.40 ± 2 b	10.73 ± 0.53 b	16.27 ± 0.18 ab	24.00 ± 4.11 a
Oxycarenus hyalinipennis	10.00 ± 0.33 de	15.20 ± 0.23 c	8.13 ± 0.47 e	12.13 ± 0.57 d	26.73 ± 0.41 b	30.33 ± 0.52 a
Autumn 2022						
1st Application						
Amrasca biguttula	27.27 ± 5.96 b	5.93 ± 0.52 b	6.00 ± 0.81 b	6.47 ± 0.81 b	23.13 ± 8.55 b	77.47 ± 6.077 a
Bemisia tabaci	8.93 ± 1.34 bc	4.80 ± 1.51 c	12.60 ± 1.21 b	11.07 ± 1.39 b	12.73 ± 0.59 b	20.53 ± 0.52 a
Oxycarenus hyalinipennis	3.20 ± 0.35 c	2.67 ± 0.07 c	3.33 ± 0.58 c	3.47 ± 0.41 c	7.33 ± 0.29 b	10.87 ± 1.01 a
2nd Application						
Amrasca biguttula	46.00 ± 13.16 b	8.87 ± 1.47 c	10.27 ± 0.81 c	18.73 ± 2.42 bc	18.93 ± 2.05 bc	126.8 ± 9.72 a
Bemisia tabaci	8.13 ± 2.04 b	3.87 ± 0.59 b	6.20 ± 1.17 b	6.00 ± 0.92 b	7.47 ± 1.12 b	23.53 ± 6.94 a
Oxycarenus hyalinipennis	4.27 ± 0.44 cd	3.07 ± 0.13 d	4.87 ± 0.18 c	4.33 ± 0.07 cd	10.53 ± 0.57 b	15.93 ± 0.47 a
Spring 2023						
1st Application						
Amrasca biguttula	9.53 ± 1.07 b	4.40 ± 0.2 b	3.73 ± 0.47 b	6.93 ± 0.55 b	10.47 ± 1.55 b	41.33 ± 6.51 a
Bemisia tabaci	2.13 ± 0.37 ab	1.93 ± 0.24 ab	0.93 ± 0.29 b	1.93 ± 0.68 ab	1.80 ± 0.3 b	4.00 ± 0.40 a
Oxycarenus hyalinipennis	1.20 ± 0.72 c	1.07 ± 0.47 c	2.93 ± 0.41 bc	2.20± 0.58 c	4.87 ± 0.47 ab	7.07 ± 0.18 a
2nd Application						
Amrasca biguttula	15.73 ± 1.51 b	9.87 ± 0.24 b	17.2 ± 2.42 b	10 ± 0.35 b	16.8 ± 2.96 b	100.2 ± 6.99 a
Bemisia tabaci	2.73 ± 0.07 b	3.40± 0.42 b	2.13 ± 0.18 b	3 ± 0.2 b	2.73 ± 0.18 b	10.13 ± 1.28 a
Oxycarenus hyalinipennis	1.80 ± 0.23 b	4.93 ± 0.94 b	2.4 ± 0.42 b	2.67 ± 0.44 b	8.33 ± 0.27 a	11.4 ± 1.27 a

*Means in rows sharing common letters are not different at P < 0.05 (Tukey's HSD test).

MLE failed to reduce *O. hyalinipennis* populations after both sprays during spring 2023 and insecticide treatments led to similar *O. hyalinipennis* density reduction except flubendiamide and imidacloprid and deltamethrin after 1st spray (Table III).

Effect of insecticides and MLE on densities of predators

In all the experiments application of insecticides as well as MLE significantly affected populations of all the predators as noted in the results of the analysis of variance (see Table IV for statistics).

Coccinella septempunctata

Treating okra with MLE kept ladybird beetle populations significantly higher than other insecticides and similar to the control after both sprays during all seasons except after 2nd spray during spring 2023, where *C. septempunctata* populations were intermediate to insecticides and control. However, there was no significant difference in *C. septempunctata* populations between insecticides during all three seasons (Table V).

Brumus suturalis

During spring 2022, MLE treatment kept populations of *B. suturalis* similar to control but higher than insecticides. During autumn 2022, MLE lowered populations compared to control, but they were still higher than insecticides. During spring 2023, MLE kept populations higher to insecticides but similar to control after 1st spray, however, there was intermediate trend for toxicity of MLE and insecticides as compared to control after 2nd spray. Insecticides other than MLE had similar populations during all seasons (Table V).

Table IV. Results of analysis of variance (ANOVA) in experiments conducted to evaluate toxicity of different insecticides on the populations of *C. septempunctata*, *B. suturalis* and Arachnid in spring season 2022, autumn 2023 and spring 2023.

Season	Predators	Spray	F-value	P-value
Spring 2022	*C. septempunctata*	1st	133.03	<0.001
		2nd	25.35	<0.001
	B. suturalis	1st	41.60	<0.001
		2nd	38.18	<0.001
	Arachnid	1st	19.53	<0.001
		2nd	39.19	<0.001
Autumn 2022	*C. septempunctata*	1st	115.45	<0.001
		2nd	16.94	<0.001
	B. suturalis	1st	32.68	<0.001
		2nd	27.45	<0.001
	Arachnid	1st	9.47	<0.001
		2nd	18.19	<0.001
Spring 2023	*C. septempunctata*	1st	23.36	<0.001
		2nd	84.03	<0.001
	B. suturalis	1st	22.54	<0.001
		2nd	13.27	<0.001
	Arachnid	1st	18.44	<0.001
		2nd	17.28	<0.001

*Degrees of freedom for treatments and errors were 5 and 10, respectively.

Arachnids

Okra sprayed with MLE had spider densities lower to control and similar to insecticides after both sprays in all seasons. However, after the second spray of spring 2022, the MLE plot exhibited spider densities higher than insecticides. Insecticides other than MLE had similar densities during all seasons except flonicamid after 2nd spray for spring 2022 experiments (Table V).

DISCUSSION

We noted that pest populations in MLE sprayed plots were typically lower to untreated plots (control). Populations of pests similar to insecticides treated plots were noted in MLE treated plots in half of the sampling events after different time intervals of application of treatments. These results are comparable with those of Shah *et al*. (2017), as they proved that MLE reduced densities of three species of aphids as compared to untreated plots on wheat crop. Populations of *Oxycarenus* spp. were reduced to 59% @ concentrations of 1.25 to 2.50% by application of MLE (Abbas *et al*., 2015). MLE reduced populations of *B. tabaci* up to 28% after 3 days of application (Hameed *et al*., 2023). Powdered moringa leaves have been proved to act as an oviposition deterrent (Anita *et al*., 2012) and also causes reduce fitness and numbers of stored grain pests in the next generation (Ojo *et al*., 2013). Equivalent populations of pests of okra in half our trials in MLE treated plots with those of synthetic insecticides treated plots might be due to development of resistance to insecticides. Resistance to imidacloprid has been reported in field populations of *A. biguttula* (Saeed *et al*., 2018), *B. tabaci* (Razaq *et al*., 2019) and *O. hyalinipennis* (Ijaz *et al*., 2023). Pyrethroids have long history of application to these pests and resistance has also been documented (Razaq *et al*., 2019). In our study, flunicamid and flubendiamide typically proved to be more effective mostly for *B. tabaci* and *O. hyalinipennis* in comparison with deltamethrin and imidacloprid in sampling observations. This might be due to the susceptibility of new chemicals to pests as these have been introduced in pest management systems of Pakistan (Razaq, 2006; Razaq *et al*., 2013, 2019).

Moringa leaf extracts contain several phytochemicals like flavonoids, alkaloids, saponins, phenols (e.g. lectins) (Abhang *et al*., 2024; Imohiosen *et al*., 2014). These compounds exhibit insecticidal properties, e.g. alkaloids are proved to inhibit digestion in insects, leading to reduced growth and are also neurotoxic (Matsuura and Fett-Neto, 2015). Flavonoids and saponins possess antifeeding activities, cause moulting disturbance and affect growth regulation leading to mortality in insects (Chaieb, 2010; Tridiptasari *et al*., 2019). Saponins (terpenoids) particularly disrupt prothoracicotropic hormone, juvenile hormone and ecdysone hormone leading to increased development period in insects (Tridiptasari *et al*., 2019). Due to these multiple mechanisms for toxicity to insects MLE can change the trajectory of insect resistance unlike chemical pesticides which only have a single mode of action (Ayilara *et al*., 2023; Gonzalez-Coloma *et al*., 2013). However, the fact that these compounds possessing insecticidal properties reduced populations of insect pests in our experiments shall remain provisional, as we did not quantify them in MLE applied.

In more than half of samplings of our study we noted lower populations of all predatory arthropods in MLE treated plots as compared to control. However, MLE treated plots typically sustained greater predator densities as those recorded in plots where synthetic insecticides were applied. Almost all the insecticides have similar toxicity for

Table V. Mean (± SE) per plant of predator species from okra crops recorded in spring 2022, autumn 2022 and spring 2023 in different treatments after first and second application.

	Treatments					
	Deltamethrin	**Flonicamid**	**Flubendiamide**	**Imidacloprid**	**Moringa extract**	**Control**
Spring 2022						
1st Application						
Coccinella septempunctata	2.93 ± 0.27 b	3.80± 0.2 b	4.00 ± 0.31 b	3.80 ± 0.2 b	10.13 ± 0.24 a	11.13 ± 0.47 a
Brumus suturalis	0.27 ± 0.18 c	1.67 ± 0.41 b	0.73 ± 0.07 c	0.13 ± 0.13 c	2.4 ± 0.12 ab	3.07 ± 0.24 a
Arachnids	1.13 ± 0.18 b	0.87 ± 0.07 b	0.93 ± 0.07 b	0.80 ± 0.12 b	0.40 ± 0.12 b	3.07 ± 0.47 a
2nd Application						
Coccinella septempunctata	4.60 ± 0.2 b	4.27 ± 0.35 b	4.33 ± 0.35 b	4.93 ± 0.71 b	8.33 ± 0.52 a	9.2 ± 0.53 a
Brumus suturalis	0.53 ± 0.29 b	0.40± 0.2 b	0.67 ± 0.24 b	0.47 ± 0.13 b	3.07 ± 0.37 a	4.2 ± 0.2 a
Arachnids	0.47 ± 0.13 c	0.60± 0.12 c	0.47 ± 0.07 c	0.47 ± 0.13 c	1.27 ± 0.13 b	2.07 ± 0.07 a
Autumn 2022						
1st Application						
Coccinella septempunctata	2.60 ± 0.23 b	3.00 ± 0.31 b	3.87 ± 0.27 b	3.33 ± 0.18 b	8.93 ± 0.13 a	10 ± 0.46 a
Brumus suturalis	0.33 ± 0.07 c	0.47 ± 0.13 c	0.67 ± 0.13 c	0.20 ± 0.20 c	1.53 ± 0.35 b	2.47 ± 0.13 a
Arachnids	0.53 ± 0.13 b	0.47 ± 0.18 b	0.53 ± 0.13 b	0.53 ± 0.07 b	0.53 ± 0.13 b	1.47 ± 0.07 a
2nd Application						
Coccinella septempunctata	3.00 ± 0.12 b	2.93 ± 0.35 b	3.00 ± 0.35 b	3.40 ± 0.53 b	6.07 ± 0.48 a	6.87 ± 0.52 a
Brumus suturalis	0.80 ± 0.20 c	0.80 ± 0.31 c	0.47 ± 0.18 c	0.47 ± 0.13 c	1.93 ± 0.18 b	3.20 ± 0.31 a
Arachnids	0.40 ± 0.12 bc	0.27 ± 0.07 c	0.60± 0.12 bc	0.53 ± 0.07 bc	0.73 ± 0.18 b	1.40± 0.12 a
Spring 2023						
1st Application						
Coccinella septempunctata	1.00 ± 0.23 b	0.87 ± 0.27 b	1.13 ± 0.13 b	1.00 ± 0.12 b	3.60± 0.42 a	4.40 ± 0.53 a
Brumus suturalis	0.87 ± 0.18 b	0.87 ± 0.18 b	0.87 ± 0.13 b	0.60 ± 0.2 b	1.80± 0.12 a	2.20± 0.12 a
Arachnids	0.53 ± 0.07 b	0.53 ± 0.07 b	0.53 ± 0.07 b	0.73 ± 0.07 b	0.80 ± 0.12 b	1.47 ± 0.18 a
2nd Application						
Coccinella septempunctata	0.73 ± 0.13 c	0.93 ± 0.13 c	0.93 ± 0.07 c	1.2 ± 0.23 c	3.87 ± 0.18 b	5 ± 0.4 a
Brumus suturalis	1.2 ± 0.2 b	1.47 ± 0.07 b	1 ± 0.2 b	0.93 ± 0.18 b	1.8 ± 0.2 ab	2.67 ± 0.13 a
Arachnids	0.2 ± 0.12 b	0.33 ± 0.18 b	0.2 ± 0.12 b	0.27 ± 0.07 b	0.8 ± 0.2 b	1.6 ± 0.12 a

*Means in rows sharing common letters are not different at $P < 0.05$ (Tukey's HSD test).

predators in all the experimental trials. It is well-established that botanicals/ natural plant extracts produce specific and sub-lethal effects on pests and may not necessarily kill them (Ayilara *et al.*, 2023). This prevents pests from crop damage and allows natural enemies to use them for nutritional benefits and increase their effectiveness. Natural products also favour biocontrol agents for being specific, leaving negligible residues (Khursheed *et al.*, 2022) and having very low drift potential. This might be why we observed higher natural enemies in MLE-treated plots, compared to other insecticides.

MLE is recommended as bio stimulant as it contains plant growth enhancers including zeatin (cytokinin), a natural plant growth promoter and ascorbic acid, phenols, potassium, calcium, prolines, auxins, gibberellins and antioxidants and proteins (Yasmeen *et al.*, 2013) but we evaluated it as biopesticide. For instance, potassium improves resistance in plants for insect pests (Amtmann *et al.*, 2008) hence the potassium and other components of MLE might have reduced pest infestation indirectly by improving plant health. MLE can be particularly useful for resource poor farmers as botanical insecticide, plant growth promoter being cheaper and can be easily prepared (Mashamaite *et al.*, 2022). Furthermore, biopesticides can be used with other chemicals, including those which proved to be effective in our experiment, in rotation to control pests. This will dilute resistance by decreasing selection of resistant individuals due to continuous application of synthetics and thus will enhance susceptibility of insecticides to manage pests (Razaq *et al*., 2019).

Biopesticides have a short shelf-life and limited effectiveness, requiring research to improve stability and persistence. This may explain why MLE did not significantly reduce pests. Developing bio-carriers and ensuring compatibility between biopesticides is crucial. Their nutritional impact also needs further evaluation as it has been argued that not all "natural" compounds in botanicals are beneficial for humans from nutritional point of view (Popp *et al*., 2013). For instance, saponins can have negative effects on humans and animals due to anti-nutritive properties but their quantity in MLE is too low to cause any substantial harm so moringa leaves can be applied in control practices without any health concerns (Makkar and Becker, 1996). Thus, quantifying compounds in MLE is paramount to evaluate its usage. This would involve detailed analysis and chemical profiling of MLE from our country with advanced analytical tools to unravel all the compounds in MLE and their effects on pests, humans and environment.

CONCLUSION

In conclusion, our study indicates that MLE can effectively reduce pest populations compared to untreated control plots but plots treated with synthetics had similar or lower populations of pests. The observed efficacy of MLE may be attributed to the diverse range of phytochemical compounds present in moringa leaves, which not only deter pests but also disrupt their growth and development. This broad-spectrum activity of MLE represents a significant advantage over chemical pesticides, which typically rely on a single mode of action and often lead to the development of resistance among pest populations. Furthermore, MLE's favorable impact on beneficial predatory arthropods highlights its potential role in integrated pest management systems, where it can support natural enemies and promote ecological balance.

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The authors have declared that no generative AI or AI-assisted technologies were used to create this manuscript.

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