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Original article

Efficacy of entomo-pathogenic fungus and botanical pesticides against mustard aphid (*Lipaphis erysimi* Kalt.) at field condition Rupandehi Nepal

Dipak Khanal [a,*], Navaraj Upadhyaya [a], Krishna Poudel [a], Sagar Adhikari [a], Salu Maharjan [b], Pushpa Pandey [a], Milan Nepali Joseph [a]

[a] *Institute of Agriculture and Animal Science, Tribhuvan University, Nepal*
[b] *Agriculture and Forestry University, Chitwan, Nepal*

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ABSTRACT

Mustard aphid is the most concerning pest of rapeseed in warm and humid areas of Nepal because of its widespread prevalence and increasing severity. There is increasing use of chemicals, as the only resort, to manage this pest. The experiment was carried out to evaluate the effectiveness of different bio-friendly management techniques against Mustard aphid, at the Institute of Agriculture and Animal Science, Paklihawa campus. Treatments like "*Jholmal*" (250 ml/L), *Beauveria bassiana* (4gm/L) Abamectin @ 1 ml/L of water, *Metarhizium anisopliae* (2 gm/L), *Verticillium lecanii* 2% A.S (5 ml/L) and Neem oil (5 ml/L) were used at post-infestation condition. Results revealed that the overall performance of Abamectin was found to be remarkably effective as compared to others. However, the performance of "*Jholmal*" and Neem was also found similar for both adult and nymph management. Also, the yield and yield attributing characters in "*Jholmal*", Neem, and Abamectin treated plots were similar. However, Abamectin was not found to be convincing considering its impact on natural enemies and thus "*Jholmal*" and Neem are suggested from the experimental results for the management of mustard aphids at the farmer's level.

1. Introduction

Oilseed crops have been an integral part of farming in the Nepalese context. The total area occupied by oilseed crops in Nepal was 259,101 ha with the production of 287,039 mt (MoAD, 2022). The average productivity of oilseed crops in Nepal was reported to be 1.031 mt/ha which is lower as compared to that of other countries like China and India whose productivity were 1.8 mt/ha and 1.07 mt/ha respectively (Bansal and Kukkar, 2020). Among various oilseed crops, mustard (*Brassica campestris* L. var *tori*) is an important group of oilseed crops that meet the major requirement of oil for human consumption (ORP, 2017). In recent years, the total area covered by rapeseed cultivation is 198,197 ha, production 220,250 mt, and productivity 1.11 mt/ha (MoAD, 2022). The rapeseed mustard seed contains 40–45% oil, 24% protein. Among several limiting factors leading to the reduction of the yield of rapeseed, the mustard aphid is the major one. Many pests are known to attack this crop at its different growth stages among which mustard aphid, *Lipaphis erysimi* (Kalt.) has been reported as the serious pest of rapeseed leading crop loss of 35–75% (Rana, 2005). It has been considered as the major cause of decline in Rapeseed production in Chitwan, Nepal (Kafle and Jaishi, 2020). Chemical pesticides are the only means of controlling the pest in farmers' field condition in Nepal (Pal et al., 2020). Under favorable conditions, it may cause yield losses from 35.4 to 96%, reduce oil content by 2.75%, and can cause seed weight loss by 30.9% (Bakhetia and Sekhon, 1984). Both nymphs and adults of the mustard aphid suck the cell sap from the various parts of plants such as leaves, inflorescences, and immature pods and resulting in extremely poor pod setting and yield. In addition to that, aphid also produces honeydew which encourages the growth of sooty mold that reduces the photosynthetic area and makes the leaves and pods look dirty black (Awasthi, 2016).

Due to its persistent and damaging nature, chemical pesticides are commonly used for the control of aphids. Farmers use different types of pesticides indiscriminately to control these pests which in

* Corresponding author.
E-mail address: dipakababu@hotmail.com (D. Khanal).

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turn lead to several problems such as environmental pollution, pests start acquiring resistance against insecticides (Sharma and Ortiz, 2002), pest resurgence (Dhaliwal et al., 2016; Dutcher, 2007), and also cause adverse effects on beneficial organisms like pollinators (Upadhyaya and Bhandari, 2022a,b), which are very integral and useful part of nature (Ware, 1980), upsetting the balance of nature and human health hazards (Mostafalou and Abdollahi, 2013). So, there is the need for reducing chemical inputs in agricultural practices and searching for eco-friendly and environmentally safe measures for managing pests (Lanting, 2007). Botanicals can be the best alternative to chemical pesticides as they are relatively less toxic, easily available locally, cheaper, and cause no harm to non-targeted organisms prevalent in nature (Guleria and Tiku, 2009).

Entomopathogenic fungi have been commonly used as bio-control agents for the eco-friendly management of mustard aphids (Deka et al., 2017). Different fungal strains of *Metarhizium anisopliae, Beauveria bassiana* and *Verticillium lecanii* produce metabolic compounds that may be toxic to insects and are effective for the control of such pests (Vey et al., 2001). Abamectin (ABA) is a natural friendly insecticide produced by the fermentation of *Streptomyces avermitilis*. Abamectin possesses pesticidal, acaricidal, and nematocidal properties (Mossa et al., 2018). Neem (*Azadirachta indica*) has been identified as a safe insecticide for its insect repellent, anti-feedent, and medicinal properties (Damalas and Koutroubas, 2020; Lokanadhan et al., 2012).

"*Jholmal*" is a natural biofertilizer cum biopesticide and can be prepared from locally available materials on a farm (Rai et al., 2018). These botanicals are ecologically safer, economically cheaper, and easily available to the farmers. Given combating this serious pest of rapeseed mustard, the present study was carried out to compare the efficacy of entomopathogenic fungi and local botanicals at field conditions against mustard aphids in Rupandehi, Nepal. The study also intended to observe the side effects of pesticides in the population of NEs (Natural enemies).

2. Materials and method

2.1. Site selection

A field experiment was conducted at the Institute of Agriculture and Animal Science, Paklihawa campus, Nepal from December 2016 to March 2017. The average temperature was 15° ± 3.8 °C and relative humidity of 52 ± 20% during the research period (NWRP, 2017). The experimental site (Fig. 1) is located on Terai region of Nepal with altitude of 100 masl and possess coordinates latitude 27°28′51.58″N and longitude 83°26′48.67″E (Upadhyaya and Bhandari, 2022a,b).

2.2. Experimental design and treatment details

The experiment was carried out in Randomized Complete Block Design (RCBD) which included seven treatments and four replications. Area of each plot was maintained at 3 m × 2 m (6 m^2) with four plots for each treatment. Local Maghiya variety of rapeseed was sown with the seed rate of 10 kg/ha on 4th December 2016 maintaining row to row distances of 30 cm and plant to plant distance of 10 cm. Each plot consisted of 10 rows and 20 plants in a row i.e., 200 plants per plot. Twenty tons/ha of compost and 60:40:20 kg NPK/ha were applied as a basal dose of plant nutrients in all the plots uniformly. The detail of the treatments is given below in Table 1.

2.3. Agronomic practices

The land was tilled thoroughly to remove the weeds and attain fine tilth. The seeds were directly sowed in the field manually with the spacing of 30 cm × 10 cm. The irrigation and intercultural operations were provided based on the guidelines of National Oilseed Research Center (Nawalpur, Sarlahi).

The nutrients were applied @ 60:40:20; N: P_2O_5: K_2O kg/ha in which Phosphatic & Potassium fertilizer used as a basal dose while nitrogenous fertilizer in a split dose (ORP, 2016).

2.4. Preparation of treatments

For the preparation of "*Jholmal*", leaves and twigs of different botanicals (8 kg) having sour and bitter taste and pungent smell were prepared in cow urine. Mostly neem leaves (2 kg), Malabar nut (2 kg), chinaberry leaves (2 kg), mugwort leaves (1 kg) and crofton weed (1 kg) were selected. The stem and other harder parts were removed and allowed to shade dry overnight. Water and cow urine was mixed in equal proportion (20 L each) and 1 L E.M. (Effective Micro-organism) with trade name Sanjeebani -E.M., produced by Agricultural Sanjeebani-B & Seed Product Center (ASSP), Ramkot, Nagarjun-6, Kathmandu, was added over and mixed thoroughly (Acharya et al., 2020). At the end the botanicals were added into the drum containing the mixture of water, cow urine and EM and sealed airtight. The mixture was stirred clockwise in every 3 days interval for about 3 weeks. After 3 weeks it was ready for use. It was filtered with a cloth sieve and mixed with water at the ratio of 1:4 and sprayed on the foliage.

2.5. Application of the treatment

After about 30% plant population were infested the field, the treatments were formulated based on the guidelines in the package label. The treatments were applied during the evening time. The treatments were applied on the inflorescence and foliage with the help of Knapsack sprayer (Manual Vishwas Shakti Super Knapsack Sprayer, 16 L, manufactured by Nawkar Agro Plast, Gandhinagar, Indore, India). The treatments were applied twice in 15 days interval.

2.6. Data recording

Observations were taken from the top 10 cm of apical central shoot of inflorescence (Khan et al., 2017) from 10 randomly selected plants of each plot. The parameters like plant height, canopy area, number of nymphs per sample plant, number of adults per sample plant, number of other potential insects, number of predators, number of parasitoids, yield/plot, and number of insects in each sticky trap were observed. For the differentiation between nymph and adult Sachan and Bansal (1975) and Sidhu and Singh (1964) were referred. Both pretreatment and post-treatment observations for all the parameters were recorded. Post-treatment observations were recorded after 5 and 10 days of spray.

2.7. Statistical analysis

The experimental data were collected and refined by using Excel 2013 and the Agricolae package of RStudio 4.1.1 was used for analysis. The data on mortality of aphid was arcsine transformed, and Duncan's multiple range test (DMRT) at the 5% level was carried out for pairwise comparison of means.

3. Results

The data on the aphid population after the first and second sprays during research is presented in Table 2. After the first spray, the aphid population was significantly lower in all the treated plots

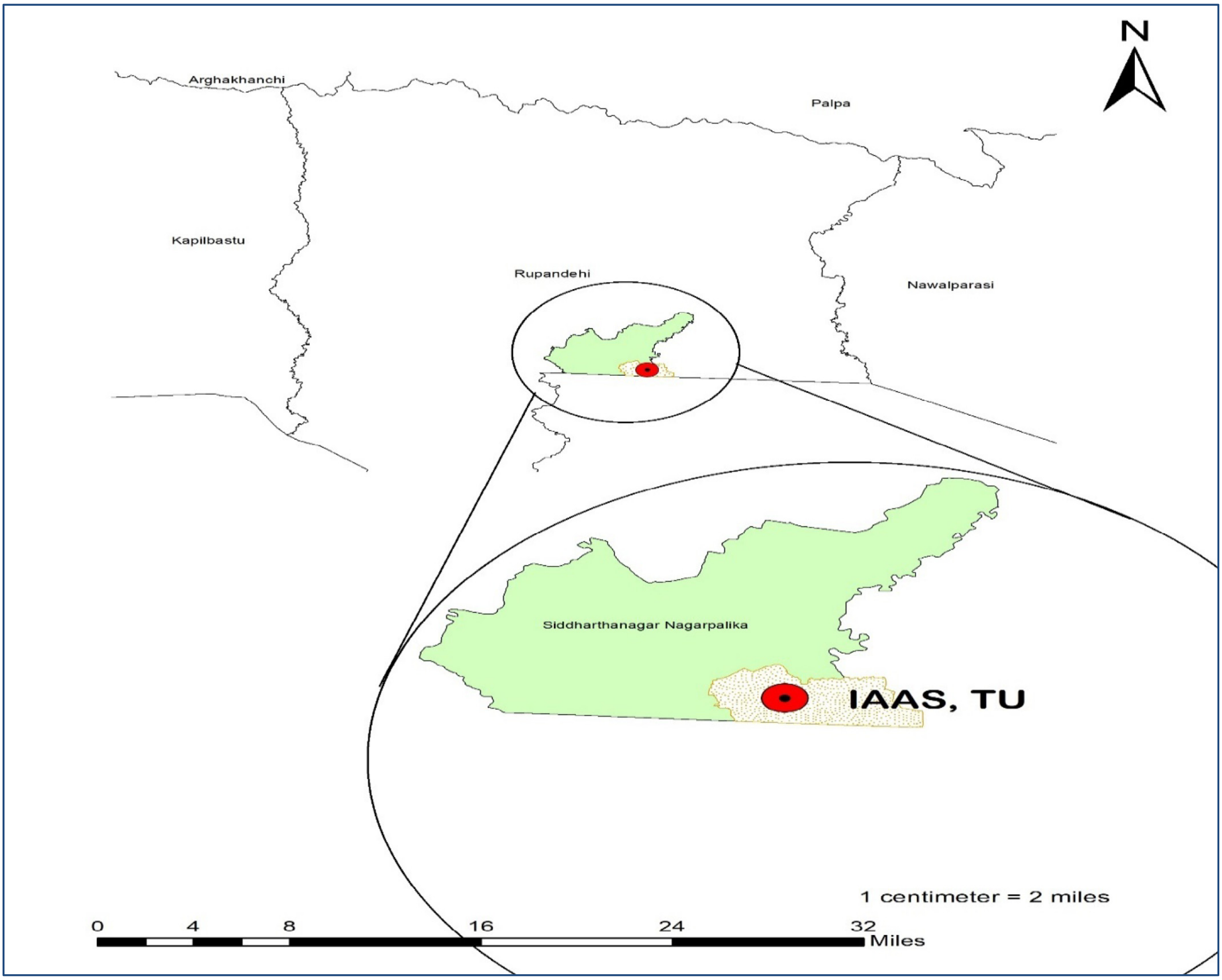

Fig. 1. Map showing experimental site. *Source:* Upadhyaya and Bhandari (2022a,b).

Table 1
Treatment details with dose and concentration of a.i. of tested biocontrol agents.

SN	Name of treatment	Dose	Type	CFU Count
1	*Jholmal*	1:4 (*Jholmal*: water)	Botanical formulation	NA
2	Neem oil (Azadirachtin) (0.3% EC)	5 ml/l water	Botanical insecticide	NA
3	Abamectin (2% EC)	1 ml/l water	Macrocyclic lactone (Xu et al., 2017)	NA
4	Daman (*Beauveria bassiana*) (1% WP)	4 g/l water	Entomopathogenic fungi	1×10^9/gram (minimum)
5	Pacer (*Metarhizium anisopliae*) (1.15% WP)	2 g/l water	Entomopathogenic fungi	1×10^8/gram (minimum)
6	Varunastra (*Verticillium lecanii*) (2% A.S)	5 ml/l water	Entomopathogenic fungi	2×10^8/gram (minimum)
7	Control	NA	Water spray	NA

than in the control. Data recorded on the first count of the nymph population revealed that "*Jholmal*" was the most effective in reducing the nymphal population (18.65). But the efficacy of "*Jholmal*" was statistically at par with Neem (20.56) and Verticillium (22.09). Likewise, the lowest adult population was observed in Abamectin (13) treatment which was statistically at par with Neem (13.13) and Verticillium (13.85).

The comparison of the nymph population on the second count showed that the most effective treatment was "*Jholmal*" (28.67) which was statistically at par with Neem (31.54). The effectiveness

Table 2
Effect of treatments on the nymph and adult population of aphid after 5 and 10 days of spray.

Treatments	First Spray				Second Spray			
	5 days after spraying		10 days after spraying		5 days after spraying		10 days after spraying	
	Nymph	Adult	Nymph	Adult	Nymph	Adult	Nymph	Adult
Metarhizium	35.21^{b} ± 1.39	14.34^{bc} ± 2.05	50.22^{b} ± 2.1	21.19^{c} ± 0.79	36.4^{c} ± 1.29	13.71^{b} ± 1.23	51.47^{b} ± 1.03	26.12^{b} ± 0.72
Verticillium	22.09^{c} ± 2.08	13.85^{c} ± 0.12	32.97^{d} ± 2.09	19.04^{c} ± 1.73	29.58^{d} ± 1.58	9.05^{c} ± 0.60	42.40^{c} ± 1.65	18.36^{d} ± 0.74
Abamectin	33.36^{b} ± 3.53	13.00^{c} ± 0.30	41.14^{c} ± 5.00	19.24^{c} ± 1.95	20.04^{e} ± 2.39	8.75^{c} ± 1.03	28.88^{d} ± 1.86	17.28^{de} ± 0.66
Beauveria	35.96^{b} ± 1.48	16.71^{b} ± 0.37	51.45^{b} ± 1.75	30.72^{b} ± 2.64	46.78^{b} ± 2.09	11.67^{b} ± 0.60	50.87^{b} ± 2.22	21.45^{c} ± 0.60
Jholmal	18.65^{c} ± 1.41	14.27^{bc} ± 0.46	28.67^{d} ± 1.54	16.86^{c} ± 1.84	20.84^{e} ± 1.28	6.37^{d} ± 0.64	29.05^{d} ± 2.71	16.05^{e} ± 0.50
Neem	20.56^{c} ± 1.38	13.13^{c} ± 0.44	31.54^{d} ± 1.30	19.41^{c} ± 2.53	21.55^{e} ± 1.66	7.50 ^{cd} ± 0.39	31.72^{d} ± 2.57	17.06^{de} ± 0.49
Water	65.31^{a} ± 2.00	21.79^{a} ± 0.83	88.52^{a} ± 3.01	48.88^{a} ± 4.57	91.01^{a} ± 2.99	20.36^{a} ± 1.53	113.16^{a} ± 4.53	32.22^{a} ± 0.94
Mean	33.02	15.30	46.36	25.05	36.60	11.06	49.65	21.22
CV	13.58	12.45	11.53	17.64	25.61	15.86	11.37	7.44
LSD	5.85	2.49	6.98	5.77	12.23	2.29	7.37	2.06
F test	63.71	13.37	74.59	33.42	27.27	37.36	137.79	71.08
P value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

Note: the alphabets associated with the numbers exhibits the values in the column is significantly different or not on the basis of Duncan multiple range test (DMRT) at 0.05 level of significance. The data in each cell is written in form of mean value ± SE.

of Verticillium (32.97) was next to "*Jholmal*" and Neem in reducing the nymph population of mustard. The lowest adult population among all treatments was obtained in "*Jholmal*" (16.86). The efficacy of Verticillium (19.04), Abamectin (19.24), and Neem (19.41) was statically at par with "*Jholmal*" in reducing the aphid population.

There was a significant difference among treatments in terms of aphid population compared to control after the second spray. Data recorded on the first count of the nymph population after the second spray of treatments showed that the lowest nymph population was observed in Abamectin (20.04). But the efficacy of Abamectin was statistically at par with "*Jholmal*" (20.84) and Neem (21.55). The count of the adult population revealed that *Jholmal* (6.37) was most effective to control aphids followed by Neem (7.5) and Abamectin (8.75).

In the second count of nymph population after the second spray, the data showed that the lowest nymph population was observed in Abamectin (28.88) followed by *Jholmal* (29.05) and Neem (31.72) treatment. These three treatments were statistically at par with each other but significantly different than other treatments. Similarly, the most effective treatment for adult control was *Jholmal* (16.05) followed by Neem (17.06) and Abamectin (17.28). Neem and Abamectin were statistically at par.

Table 3 reveals that all the treatments performed significantly better than control in terms of the number of branches, pod length, root length, yield/ha· and the number of pod/branches. The data on the number of branches indicated that under different treatments, a significantly higher number of branches was observed in plants treated with Neem followed by Abamectin and *Jholmal*. There was a significant difference of treatments in pod length and the highest pod length was observed in *Jholmal* followed by Neem and Abamectin. Similarly, the highest root length was observed in plants treated with *Jholmal* followed by Abamectin and Neem.

The comparison of yield was done among all treatments and the treatments varied significantly with control. Maximum seed yield was recorded from plots treated with Abamectin followed by *Jholmal* and Neem. Likewise, there was a significant variation in the number of pods/branches of the mustard plant due to different treatments. A significantly higher number of pod/branches was observed in plants treated with Abamectin followed by *Jholmal* and Neem.

Fig. 2 shows that, with the rise in pest population the population of natural enemies also increased in similar pattern in every treatment. The population of lady bird beetle larvae was fairly higher followed by the population of adult ladybird and the syrphid fly larvae. After spraying pesticides, the population of these beneficial insects reduced drastically. After 5 days (Fig. 3) of spraying treatments, there was extreme decline in abamectin sprayed plot followed by *Beauveria, Metarhizium, Verticillium* and Neem extract. There was minor decline in case of *Jholmal* and significant rise in case of water treated plots. After 10 days (Fig. 4) the population was least in case of Verticillium, followed by *Beauveria, Abamectin* and *Metarhizium*. The population rose higher in case of *Jholmal* followed by Neem extract. After 5 days (Fig. 5) of second spray, there were no signs of Natural enemies in case of Abamectin and *Verticillium*. There was low incidence in case of *Metarhizium*

Table 3
Effect of treatments on yield and yield attributing characters.

Treatments	Number of Branches	Pod length	Root length	Yield (t/ha)	Pod/Branch
Metarhizium	3.32^{b} ± 0.16	4.55^{cd} ± 0.27	8.38^{d} ± 0.17	0.278^{b} ± 0.064	24.14^{c} ± 1.25
Verticillium	5.49^{a} ± 0.10	5.63^{b} ± 0.34	9.13^{c} ± 0.08	0.311^{b} ± 0.125	37.68^{b} ± 1.28
Abamectin	5.74^{a} ± 0.07	9.93^{a} ± 0.22	9.65^{ab} ± 0.07	0.877^{b} ± 0.114	48.08^{a} ± 2.73
Beauveria	3.58^{b} ± 0.13	4.98^{bc} ± 0.13	8.32^{d} ± 0.18	0.224^{b} ± 0.019	24.56c ± 1.31
Jholmal	5.81^{a} ± 0.15	10.72^{a} ± 0.46	10.11^{a} ± 0.26	0.229^{b} ± 0.028	45.95^{a} ± 5.42
Neem	5.41^{a} ± 0.18	10.04^{a} ± 0.61	9.28^{bc} ± 0.18	0.283^{b} ± 0.078	40.99^{ab} ± 4.31
Water	2.48^{c} ± 0.21	3.75^{d} ± 0.28	6.59^{e} ± 0.16	0.224^{b} ± 0.019	16.07^{d} ± 0.55
Mean	4.55	7.09	8.78	0.346	33.93
CV	7.11	11.02	4.20	23.86	16.42
LSD	0.42	1.02	0.48	0.108	7.27
F value	90.56	74.04	49.32	40.78	24.46
P value	<0.001	<0.001	<0.001	<0.001	<0.001

Note: the alphabets associated with the numbers exhibits the values in the column is significantly different or not on the basis of Duncan multiple range test (DMRT) at 0.05 level of significance. The data in each cell is written in form of mean value ± SE.

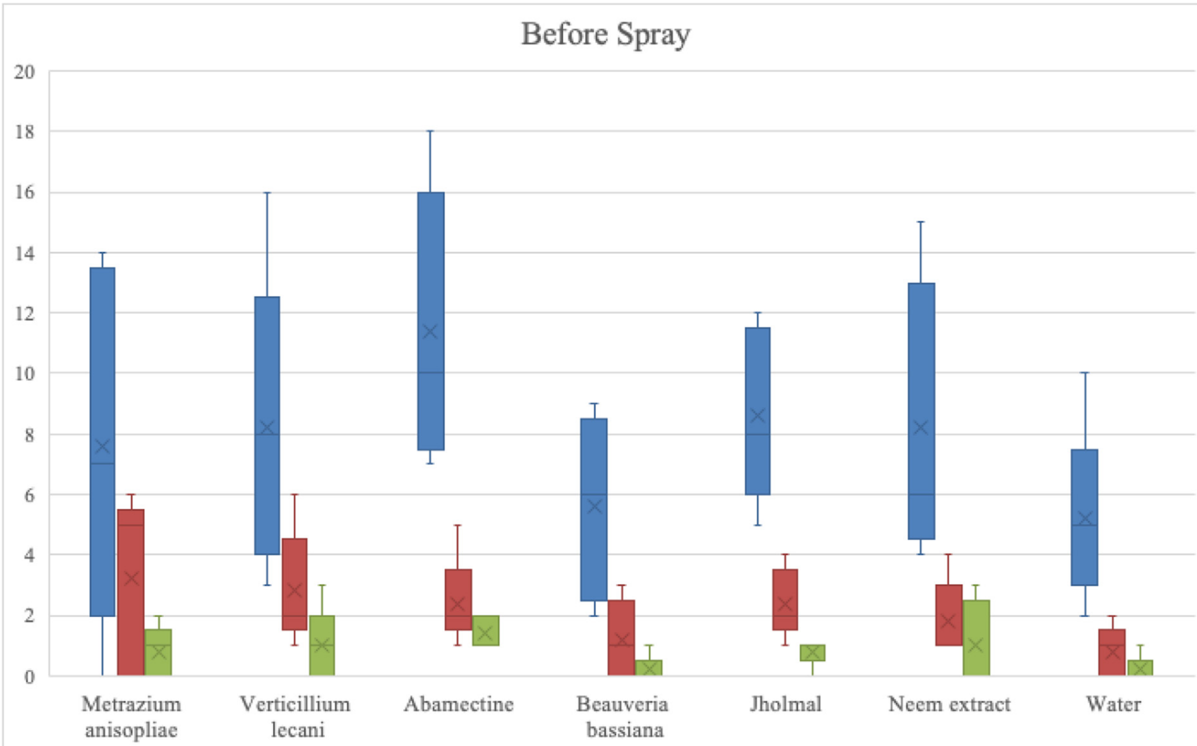

Fig. 2. Population of Natural enemies before applying pesticides (in number). Note: LBB is the abbreviated form of Lady Bird Beetle. The tail on either side of the bar are error bars represent the outliers whereas "x" represents the mean population of NEs before application of pesticides.

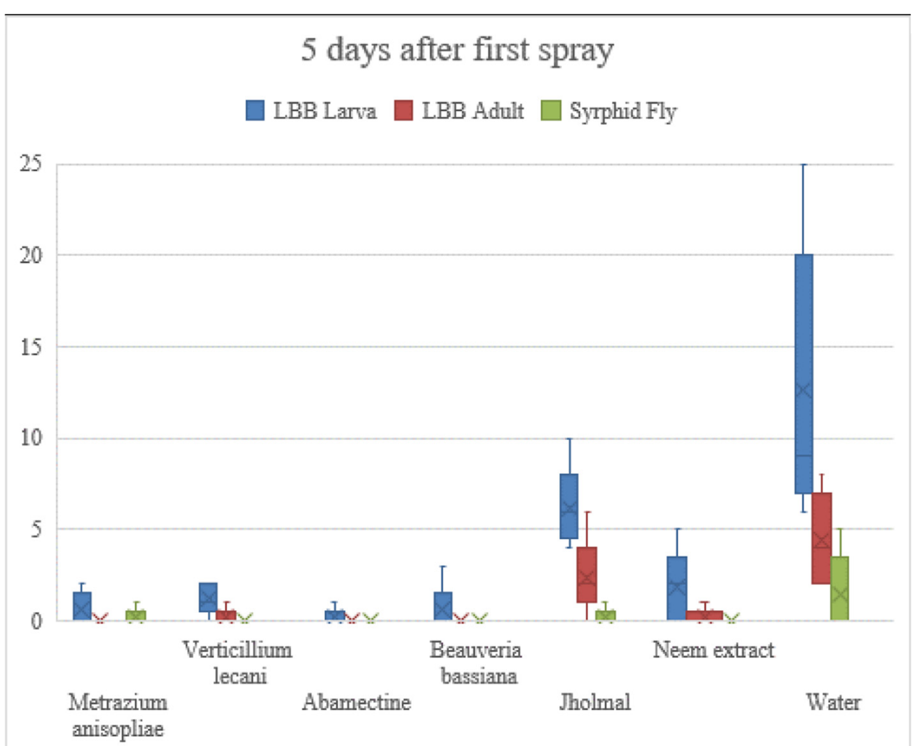

Fig. 3. Population of NEs 5 days after 1st spray of treatments (in number). Note: LBB is the abbreviated form of Lady Bird Beetle. The tail on either side of the bar are error bars represent the outliers whereas "x" represents the mean population of the NEs after application of pesticides.

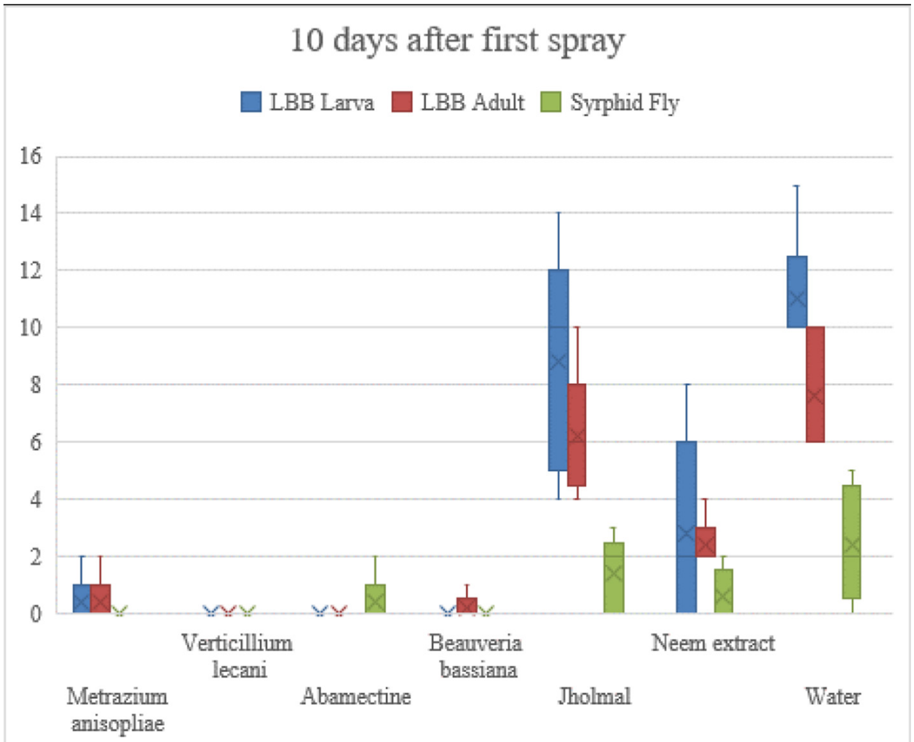

Fig. 4. Population of NEs 10 days after 1st spray of treatments (number).

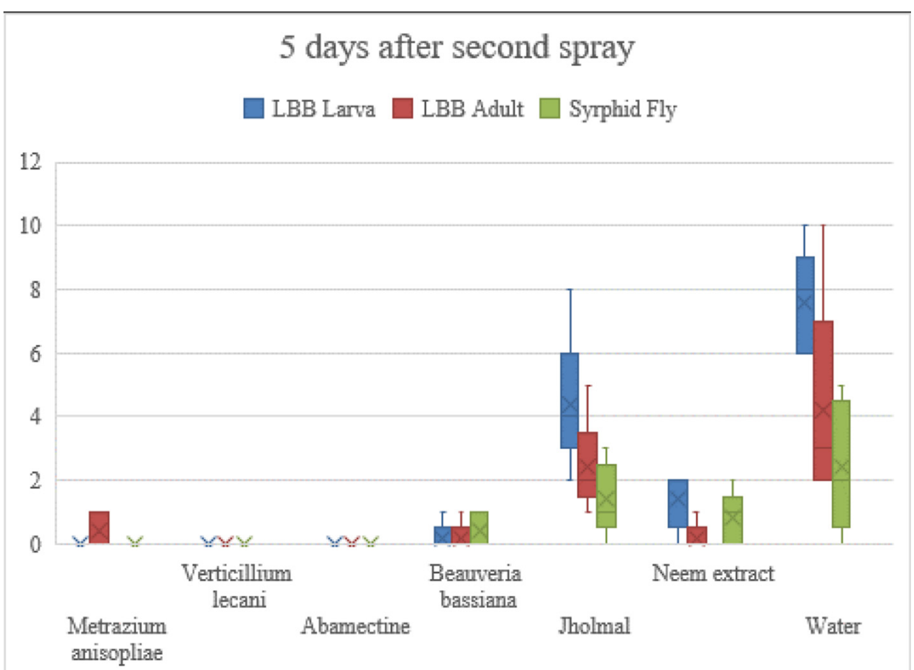

Fig. 5. Population of NEs 5 days after 2nd spray (in number).

and *Beauveria*. The population was fairly higher in *Jholmal* treated plots followed by neem treated plots. As usual the population was highest in case of water sprayed plots. As compared to previous case the population decline was also observed in *Jholmal*, Neem and water sprayed plots as well. After 10 days (Fig. 6) the population of NEs were least in case of Abamectin followed by *Verticillium, Metarhizium* and *Beauveria*. Control plot seemed to have highest population followed by *Jholmal* and Neem extract.

4. Discussion

The results exhibited that the aphid population was consistently lower following treatments with entomopathogens, botanical extracts, *Jholmal*, and abamectin than in control. Abamectin, *Jholmal*, and Neem were found to be highly effective in the control of both adults and nymphs. Entomopathogens, *Metarhizium*, *Beauveria*, and *Verticillium* were comparatively less effective than Aba-

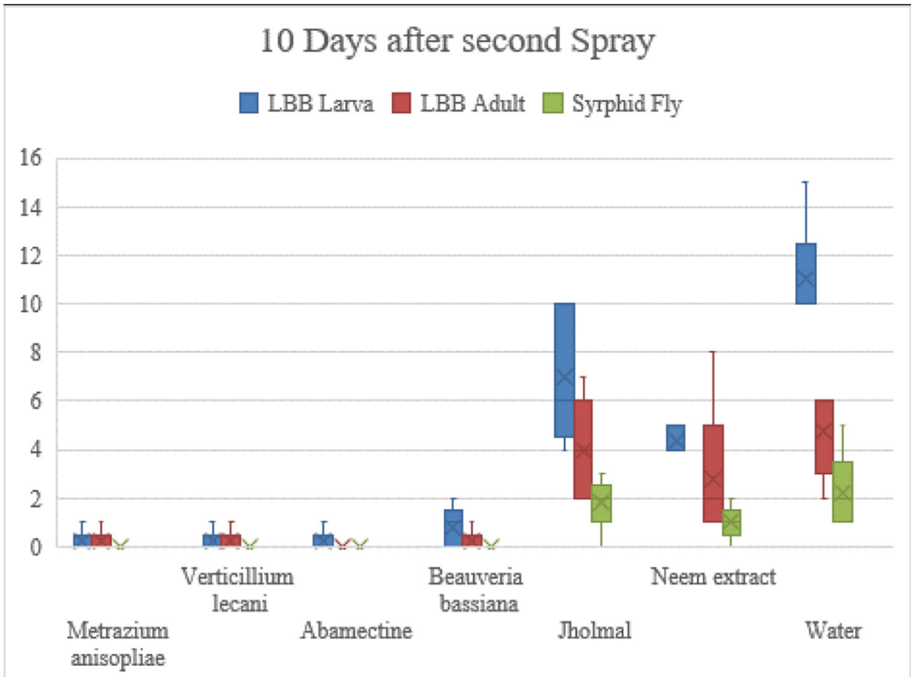

Fig. 6. Population of NEs 10 days after 2nd spray (in number).Note: LBB is the abbreviated form of Lady Bird Beetle. The tail on either side of the bar are error bars represent the outliers whereas "x" represents the mean population of the NEs after application of pesticides.

mectin, *Jholmal*, and Neem but were significant in comparison to control (water spray). Water spray alone wasn't found to be any significance in the reduction of the aphid population.

The application of *Jholmal* achieved the lowest aphid population of mustard aphids.

A study by Malla et al. (2021) reported the reduction in the number of aphids in plots treated with *Jholmal* which is similar to our experiment where *Jholmal* was found efficient for the reduction of aphids. Higher yield was also observed as it works both as a growth promoter and insect repellent. It can be prepared easily at the farmer's level by mixing cow urine, locally available botanicals like Neem, Mugwort, Malabar leaves etc. containing pesticidal or insect repellent properties (Naharki and Jaishi, 2020).

Use of Neem leaves, Mugwort, China berry leaves and Mugwort leaves against mustard aphid was found to be effective in management of mustard aphid in a study by Bhatta et al. (2019). Use of Neem was reported to have best result against *Bactrocera. Dorsalis* and*B. correcta* in mango (Jaleel et al., 2020), and *Leucinodes orbonalis* Guenee in Brinjal (Khanal et al., 2021). Azadirachtin present in neem is responsible for its antifeedant, repellent and repugnant property which also induces sterility in insects (Chaudhary et al., 2017). Chinaberry also possess azadirachtin with properties similar to neem and reported to have larvicidal properties (Trudel and Bomblies, 2011). The property is exhibited by the leaves and seeds of chinaberry with very unlikely chances of emergence of resistance. The insecticidal property of Chinaberry is also discussed by Hammad et al. (2000) for the management of Pea leaf miner. Research by Chandel et al. (2012) also reported the insecticidal property of Malabar nut against the management of mustard aphid adult and nymph exhibiting the mortality rate as high as 63.44% in 12 hrs. and 77.7% in 24 hrs. Partha et al. (2018) reported 44.98% reduction in aphid population after a day of spraying leaf extract of Malabar nut (5% aqueous solution) and in addition increased honey bee population from 2.43 honey bee/m^2 to 2.52 honey bee/m^2.

Presence of Camphene (a derivative of camphene and α-Thujone) in Mugwort is known to have moth repelling properties, insecticidal and larvicidal properties (Pandey and Singh, 2017), and also shows sublethal effects for growth and fecundity of insects (Wang et al, 2006).

A study by Mayanglambam and Rajshekar (2023) exhibited that Crofton weed acts as antifeedant for management (about 85%) of cabbage insects while used in various concentration varying from 1.4% to 2.8%.

Considering the impact of the pesticides against natural enemies Abamectin, Verticillium, *Metarhizium* and *Beauveria*, none of them were convincing. *Jholmal* was exceptionally good followed by Neem extract. Even Neem was not very satisfactory for first count after 5 days and seemed to have recovering the population of beneficial ones on second count. Thus, *Jholmal* can be considered the best option in the ecologically sound management of mustard aphids. The bio-constituents in *Jholmal* affect insect development and survival; cow urine acts as a potential biopesticide while the other plant extracts, due to their phytochemicals can reduce the aphid population (Gahukar, 2013).

The application of Abamectin also achieved a significantly lower aphid population. Successful use of Abamectin (Bermectine) 1.8% EC at 40 ml/100L water against the cabbage aphid *B. brassicae* in the field was applied in Northern Egypt by El-Fakharany (2010). Abamectin is categorized as one of the highly toxic pesticides possessing acute oral and dermal toxicity with very low LC_{50} concentrations for a diverse group of organisms. Despite this, it is gaining popularity because of its effective nature in pest control. The recorded LC_{50} of abamectin for mustard aphid (*Lipaphis erysimi*) was 0.63 mg/L (Ujjan et al., 2014). Abamectin is a neurotoxin with stomach action and contact type of poisoning. It causes adverse effects in the nervous system of the pest as it blocks the ion tropic α-amino butyric acid (GABA) (Kolar et al., 2008).

A significantly lower aphid population was achieved with neem than in control. A similar result was obtained by Ali et al. (2010) who reported the maximum reduction of aphid population with neem among different leaf extracts. Similarly, other studies also highlighted azadirachtin as an effective means of managing the *L. erysimi* population (Khanal et al., 2020; Singh and Lal, 2009). Neem-derived pesticides have Azadirachtin as their prime compound which acts as a toxic, insect repellent, antifeedant, growth-retarding, makes non-preferrable for egg-laying, and also cause sterility (Kumar and Navaratnam, 2013). In addition, the extract of this plant has a strong adverse impact on the behavior, postembryonic development causing high mortality and decreasing fecundity, as well as inhibiting population growth (Hummel et al., 2012; Tang et al., 2002).

The response of the entomopathogenic fungus was significantly better as compared to control but was not good enough like Abamectin, *Jholmal*, and Neem oil neither for pest management nor for good yield. They seem to have reduced the pest load but not well below the level that the plant could express itself to the fullest and result in good yield.

5. Conclusion

The main purpose of the study was to compare the efficacy of different entomopathogens and botanical extracts against mustard aphids. The results reveal that the population of mustard aphids was significantly lower following the treatment with each treatment compared with the control. All the treatments used in the research could be used for the management of mustard aphids. But Abamectin, *Jholmal*, and Neem have shown promising results for the control of aphids. Abamectin is an effective pesticide for the management of aphids however for cost-effective management of aphids *Jholmal* and Neem can be suggested as they are locally available. Considering the impacts of the pesticides on non-targeted beneficial insects, *Jholmal* was very excellent option suggested from this study. Further investigations on using these treatments at the appropriate dose and at the appropriate time are necessary before they can be recommended as novel aphid management techniques.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

Acharya, A.K., Joshi, K.D., Dhungel, S., Acharya, G., 2020. Smart agriculture and safe vegetable production: Key learnings of CEAPRED.

Ali, A., Rizvi, P., Khan, F., 2010. Bio-efficacy of some plant leaf extracts against mustard aphid, *Lipaphis erysimi* kalt. on Indian mustard, *Brassica juncea*. J. Plant Prot. Res..

Awasthi, V.B., 2016. Introduction to General and Applied Entomology. Scientific Publishers.

Bakhetia, D., Sekhon, B., 1984. Review of research work on insect pests of rapeseed-mustard in India. Annual Rabi Oilseeds Workshop on Rapeseed-Mustard, Safflower and Linseed.

Bansal, D.S.K., Kukkar, D.P., 2020. Analysis of oilseed crops scenario in Rajasthan.

Bhatta, K., Chaulagain, L., Kafle, K., Shrestha, J., 2019. Bio-efficacy of plant extracts against mustard aphid (*Lipaphis erysimi* Kalt.) on rapeseed (*Brassica campestris* Linn.) under field and laboratory conditions. Syrian J. Agric. Res. 6 (4), 557–566.

Chandel, B.S., Singh, V., Trevedi, S.S., 2012. Aphidicidal potential of *Azadirachta indica*, *Adhatoda vasica*, *Vitex negundo*, *Parthenium hysterophorus* and *Lantana camara* against mustard aphid, *Lipaphis erysimi* Kaltenbach (Hemiptera: Aphididae). J. Appl. Natural Sci. 4 (2), 181–186.

Chaudhary, S., Kanwar, R.K., Sehgal, A., Cahill, D.M., Barrow, C.J., Sehgal, R., Kanwar, J.R., 2017. Progress on *Azadirachta indica* based biopesticides in replacing synthetic toxic pesticides. Front. Plant Sci. 8, 610.

Damalas, C.A., Koutroubas, S.D., 2020. Botanical pesticides for eco-friendly pest management: Drawbacks and limitations. Pesticides Crop. Prod.: PhysiolBiochem. Action, 181–193.

Deka, A.C., Goswami, N.K., Sarma, I., 2017. Biocontrol prospects of entomopathogenic fungi for management of mustard aphid (*Lipaphis erysimi* Kalt.) on rapeseed-mustard. Adv. Appl. Sci. Res. 8 (4), 21–29.

Dhaliwal, G., Singh, R., Chhillar, B., 2016. Essentials of Agricultural Entomology. Kalyani Publishers.

Dutcher, J.D., 2007. A review of resurgence and replacement causing pest outbreaks in IPM. Gen. Concepts Integr. Pest Dis. Manage., 27–43.

El-Fakharany, S.K., 2010. Population fluctuation of thrips, whitefly and associated predators in cabbage plantations as influenced by weather factors and toxic compounds. J. Plant Protect. Pathol. 1 (11), 885–897.

Gahukar, R., 2013. Cow urine: a potential biopesticide. Indian J. Entomol. 75 (3), 212–216.

Guleria, S., Tiku, A., 2009. Botanicals in pest management: current status and future perspectives. In: Integrated Pest Management: Innovation-development Process. Springer, pp. 317–329.

Hammad, E.A.F., Nemer, N.M., Kawar, N.S., 2000. Efficacy of Chinaberry tree (Meliaceae) aqueous extracts and certain insecticides against the pea leafminer (Diptera: Agromyzidae). J. Agric. Sci. 134 (4), 413–420.

Hummel, H.E., Hein, D., Schmutterer, H., 2012. The coming of age of azadirachtins and related tetranortriterpenoids. J. Biopesticides 5, 82.

Jaleel, W., Wang, D., Lei, Y., Qi, G., Chen, T., Rizvi, S.A.H., Lu, L., 2020. Evaluating the repellent effect of four botanicals against two Bactrocera species on mangoes. PeerJ 8, e8537.

Kafle, K., Jaishi, M., 2020. Farmer's management practices adopted against mustard aphid, *Lipaphis erysimi* (Kalt.): A survey of Chitwan, Nepal. Int. J. Appl. Sci. Biotechnol. 8 (1), 78–82.

Khan, M.M., Akhtar, I., Shah, S.W.H., 2017. Efficacy of different insecticides against aphid on brassica juncea. J. Zool. 19, 95–100.

Khanal, D., Maharjan, S., Lamichhane, J., Neupane, P., Sharma, S., Pandey, P., 2020. Efficacy of biorational compounds against mustard aphid (*Lipaphis erysimi* Kalt.) and English grain aphid (*Sitobion avenae* Fab.) under laboratory conditions in Nepal. Adv. Agric. 2020.

Khanal, D., Pandey, R., Dhakal, R., Neupane, N., Shrestha, A., Joseph, M.N., Pandey, M., 2021. Efficacy of bio-rational pesticides for the management of *Leucinodes orbonalis* Guenee in Rupandehi, Nepal. *Heliyon* 7 (11).

Kolar, L., Eržen, N.K., Hogerwerf, L., van Gestel, C.A., 2008. Toxicity of abamectin and doramectin to soil invertebrates. Environ. Pollut. 151 (1), 182–189.

Kumar, V.S., Navaratnam, V., 2013. Neem (*Azadirachta indica*): prehistory to contemporary medicinal uses to humankind. Asian Pac. J. Trop. Biomed. 3 (7), 505–514.

Lanting, M., 2007. Pest Management: The Art of Mimicking Nature. LEISA-LEUSDEN, p. 6.

Lokanadhan, S., Muthukrishnan, P., Jeyaraman, S., 2012. Neem products and their agricultural applications. J. Biopesticides 5, 72.

Malla, S., Bist, L., Dhanuk, Y. S., Neupane, A., 2021. Integrated Pest Management of Mustard Aphid, *Liaphis Erysimi* (Kalt.) on Rapeseed Crops In Gokuleshwor, Baitadi.

Mayanglambam, S., Rajashekar, Y., 2023. Antifeedant effects of crofton weed, Ageratina adenophora extracts and their phytochemical compounds against three cabbage insect pest species. Entomologia Experimentalis et Applicata..

MoAD, 2022. Statistical Information on Nepalese Agriculture.

Mossa, A.-T.H., Mohafrash, S.M., Chandrasekaran, N., 2018. Safety of natural insecticides: toxic effects on experimental animals. BioMed Res. Int. 2018.

Mostafalou, S., Abdollahi, M., 2013. Pesticides and human chronic diseases: evidences, mechanisms, and perspectives. Toxicol. Appl. Pharmacol. 268 (2), 157–177.

Naharki, K., Jaishi, M., 2020. Documentation of indigenous technical knowledge and their application in pest management in Western Mid Hill of Nepal. SAARC J. Agric. 18 (1), 251–261.

NWRP, 2017. Meterological Statistics of National Wheat Research Center. NWRP.

ORP, 2016. Annual report 2015/16. Nepal Agriculture Research Council.

ORP, 2017. Annual Report 2073/74 (2016/17). Nepal Agriculture Reesarch Council.

Pal, M.K., Kafle, K., Shrestha, J., 2020. Evaluation of different plant leaf extracts against mustard aphid [*Lipaphis erysimi* (Kalt.)] in rapeseed field. Int. J. Appl. Biol. 4 (2), 18–25.

Pandey, A.K., Singh, P., 2017. The genus Artemisia: a 2012–2017 literature review on chemical composition, antimicrobial, insecticidal and antioxidant activities of essential oils. Medicines 4, 68. https://doi.org/10.3390/medicines4030068.

Patra, S., Debnath, P., Pande, R., Layek, J., Ramkrushna, G.I., Bamon, R.N., Majumdar, D., 2018. Evaluation of botanicals against mustard aphid, Lipaphis erysimi (Kaltenbach) in Mid Hills of Meghalaya. J. Oilseeds Res. 35, 283–288.

Rai, R.K., Bhatta, L.D., Acharya, U., Bhatta, A.P., 2018. Assessing climate-resilient agriculture for smallholders. Environ. Dev. 27, 26–33.

Rana, J.S., 2005. Performance of *Lipaphis erysimi* (Homoptera: Aphididae) on different *Brassica* species in a tropical environment. J. Pest. Sci. 78, 155–160.

Sachan, J., Bansal, O.P., 1975. Influence different host plants on the biology of mustard aphid, *Lipaphis erysimi* Kalt.

Sharma, H., Ortiz, R., 2002. Host plant resistance to insects: an eco-friendly approach for pest management and environment conservation. J. Environ. Biol. 23 (2), 111–135.
Sidhu, H., Singh, S., 1964. Biology of the mustard aphid-*Lipaphis erysimi* (Kaltenbach)-in the Punjab. Indian Oilseeds J 8 (4), 348–359.
Singh, C., Lal, M., 2009. Bioefficacy of plant extracts against mustard aphid, *Lipaphis erysimi* (Kalt.) in Brassica oilseed crop. Crop. Res. (Hisar) 37 (1/3), 203–206.
Tang, Y., Weathersbee, A., Mayer, R., 2002. Effect of neem seed extract on the brown citrus aphid (Homoptera: Aphididae) and its parasitoid Lysiphlebus testaceipes (Hymenoptera: Aphidiidae). Environ. Entomol. 31 (1), 172–176.
Trudel, R.E., Bomblies, A., 2011. Larvicidal effects of Chinaberry (Melia azederach) powder on Anopheles arabiensis in Ethiopia. Parasit. Vectors 4, 1–9.
Ujjan, A.A., Khanzada, M., Shahzad, S., 2014. Insecticide and papaya leaf extract toxicity to mustard aphid (*Lipaphis erysimi* Kal.). J. Agri-Food Appl. Sci. 2 (2), 45–48.
Upadhyaya, N., Bhandari, K., 2022a. Assessment of different genotypes of wheat under late sowing condition. Heliyon e08726.
Upadhyaya, N., Bhandari, K., 2022b. A review: Pollinator services and its economic evaluation. Int. J. Food Agric. Nat. Resour. 3, 11–15.
Vey, A., Hoagland, R.E., Butt, T.M., 2001. Toxic metabolites of fungal biocontrol agents. Fungi Biocontrol Agents: Progress Problems Potential 1, 311–346.
Wang, J., Zhu, F., Zhou, X.M., Niu, C.Y., Lei, C.L., 2006. Repellent and fumigant activity of essential oil from *Artemisia vulgaris* to *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). J. Stored Prod. Res. 42, 339–347. https://doi.org/10.1016/j.jspr.2005.06.001.
Ware, G.W., 1980. Effects of pesticides on nontarget organisms. Residue Rev., 173–201.
Xu, Z., Liu, Y., Wei, P., Feng, K., Niu, J., Shen, G., Lu, W., Xiao, W., Wang, J., Xu, Q., He, L., Smagghe, G.J., 2017. High gama-aminobutyric acid contents involved in abamectin resistance and predation, an interesting phenomenon in spider mites. Front. Physiol. 8, 216.

Further Reading

Debnath, P., Pande, R., Patra, S., Layek, J., Ramkrushna, G.I., Bamon, R., Majumdar, D., 2018. Evaluation of botanicals against mustard aphid, *Lipaphis erysimi* (Kaltenbach) in Mid Hills of Meghalaya. J. Oilseeds Res 35, 283–288.