Biological Forum – An International Journal **14(1): 121-130(2022)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

How Susceptible are the Indian, Himalayan Populations of Insect Pests to Novel Groups of Insecticides

Amit Umesh Paschapur[1]*, Avupati RNS Subbanna[1], J.P. Gupta[2], Krishna Kant Mishra[3] and Lakshmi Kant[4]

[1]Scientist (Agricultural Entomology),
ICAR-Vivekananda Parvatiya Krishi Anusandhana Sansthana, Almora, (Uttarakhand), India.
[2]Senior Technical Assistant, Crop Protection Section,
ICAR-Vivekananda Parvatiya Krishi Anusandhana Sansthan, Almora, (Uttarakhand), India.
[3]Principle Scientist (Plant Pathology),
ICAR-Vivekananda Parvatiya Krishi Anusandhana Sansthana, Almora, (Uttarakhand), India.
[4]The Director, ICAR-Vivekananda Parvatiya Krishi Anusandhana Sansthana,
Almora, (Uttarakhand), India.

(Corresponding author: Amit Umesh Paschapur)*
(Received 07 October 2021, Accepted 07 December, 2021)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: The insect pests like *Helicoverpa armigera* Hubner, *Spilarctia obliqua* (walker), *Raphidopalpa foveicollis* (Lucas), *Chauliops choprai* and *Lipaphis erysimi* Kaltenbach cause severe yield losses to hill crops in the Indian Himalayas. Farmers in the Himalayas mainly rely on traditional form of organic farming and rarely use any insecticides for insect pest management. In case of severe pest infestation, they spray conventional insecticides in high dosages, thus leading to insecticide resistance and reduced control of insect population. Considering the pest severity and dependence on conventional insecticides, a total of 23 insecticides (conventional and novel groups, botanicals and microbials) were screened against five target insects. The insecticides belonging to diamide, spinosyn and avermectin group were highly toxic against lepidopteran pests. Emamectin benzoate and Flubendiamide recorded lowest LC_{50} value of 97.49 and 22.8 ppm against the 3rd instars of *H. armigera* and *S. obliqua* respectively. Moreover, for management of sucking pests, insecticides belonging to thiourease, neonicotinoid and Pyiridine azomethine group were found to be effective with Difenthiuron recording lowest LC_{50} value of 20.61 and 0.703 ppm against *C. choprai* and *L. erysimi* respectively. For management of *R. foveicollis,* two insecticides belonging to synthetic pyrethroid group Deltamethrin and Lamdacyhalothrin were found effective with LC_{50} value 12.97 and 21.33 ppm respectively. However, the botanicals and microbial insecticides did not show promising results as their median lethal values were much higher than other green label insecticides.

Keywords: Indian Himalayas, insect pests, yield losses, conventional and novel insecticides, LC_{50} values, baseline susceptibility.

INTRODUCTION

Agriculture contributes a minor land use in the forest ecosystem of Indian Himalayas with a net sown area of only 10% of total area and subsistence farming is the basis of livelihood and backbone of rural economy (Rao and Saxena 1996; Tripathi and Sah 2001; Semwal *et al.,* 2004). In the present scenario of global warming and climate change, insect pests in the Indian Himalayas have gained the status of major biotic stress causing agents of hill crops. The insect pests like *Helicoverpa armigera, Spilarctia obliqua, Raphidopalpa foveicollis, Chauliops choprai* and *Lipaphis erysimi* cause severe yield losses in cereals, pulses, oilseeds and vegetables.

H. armigera is a notorious polyphagous pest of tomato, maize, wheat and pulses in the Indian Himalayas. It has developed resistance to most conventional and few novel groups of insecticides (, Torres-Vila *et al*., 2002; Nauen and Bretschneider 2002; Wang *et al.*, 2009; Alvi *et al*., 2012; Qayyum *et al.*, 2015; Sene *et al.*, 2020). So far, the insect is known to have developed resistance to chlorinated hydrocarbons (Ahmad *et al.*, 1995), organophosphates (Gunning *et al.*, 1999; Qayyum *et al.*, 2015), carbamates (Gunning, 1996), pyrethroids (Forrester *et al.*, 1993; Badiane *et al.*, 2015) and spinosyns (Wang *et al.,* 2009). Along with *H. armigera*, the bihar hairy caterpillar is an important pest of pulses in the Indian Himalayas and it is known to cause yield loss up to 30% in soybean crop alone (Paschapur et al. unpublished data). The pest is hard to manage with the conventional insecticides because of its high fecundity (Selvaraj *et al.,* 2015) and gregarious and voracious nature of feeding. It has developed resistance to organophosphates and carbamate group of insecticides (Attique *et al*., 2006; Ahmad *et al*., 2009) and needs continuous evaluation of novel chemistry insecticides for timely management of the pest.

One of the major pests of cucurbitaceous crops in the Indian Himalayas is the pumpkin beetle, wherein both the adults and grubs infest the crop and cause severe yield losses in summer squash and cucumber (Mahato, 2017). The management practice mainly involves cultural, mechanical and chemical pest management through conventional insecticides (Ratnakar *et al*., 2016; Rahman, 2018; Miah, 2019). But, the data on use of novel chemistry insecticides against *R. foveicollis* is rarely available and this drawback forces the farmers to choose hazardous conventional insecticides in the IPM programmes of cucurbits.

Sucking pests are the hard to manage pests in hill agriculture because of their hidden feeding nature and negligence of farmers towards their management. The mustard aphid (*L. erysimi*) alone is capable of causing 35-95% yield loss in mustard crop under severe infestation conditions (Sahoo 2012). The aphid infestation also reduces the seed weight by 31% and oil content by 2.75% (Patel *et al.,* 2017; Vishal and Kumar, 2019; Kumar and Sharma, 2020; Sharma and Sharma, 2021). The soybean sucking bug (*C. choprai*), although is a minor pest in Indian plains, its infestation is very severe in the Indian Himalayan region. If the infestation of *C. choprai* starts early in the cropping season, the crop yield of soybean as well as quality of oil is bound to diminish drastically (Sharma *et al.,* 2010; Kumar *et al.,* 2014).

There are a large number of insecticides screened and tested against these five insect pests in the Indian subcontinent, but no clear data is available regarding the baseline susceptibility of different novel and conventional insecticides to all the above mentioned insects of Uttarakhand, Himalayas. Keeping in mind the lack of information, a total 23 insecticides including novel molecules, conventional insecticides, botanicals and microbials were screened to test their toxicity and efficacy against these insect pests. Once the baseline susceptibility of insecticides is set, they can be scientifically recommended to farmers for pest management and can be included in the package of practices of various crops cultivated in the Indian Himalayas.

MATERIALS AND METHODS

A. Test insect cultures

All the test insects used for insecticide evaluation were collected from the fields of ICARVPKAS (Vivekananda Parvatiya Krishi Anusandhana Sansthan), Experimental farm, Hawalbagh, Almora, Uttarakhand, India (29.63°N and 79.63°E, 1250 m) (Table 1).

Table 1: Test insects used for the insecticide bioassay.

Sr. No.	Test insects		Host plant	Insect stage collected from field	Insect stage used for the bioassay
	Common name	Scientific name			
1.	Tomato fruit borer	*Helicoverpa armigera*	Tomato	5th and 6th instar larvae (reared on semisynthetic wheat germ based diet)	3rd instar larvae (F1 population)
2.	Bihar hairy caterpillar	*Spilosoma oblique*	Soybean	Gregarious 1st instar larvae	3rd instar larvae
3.	Red pumpkin beetle	*Raphidopalpa foveicollis*	Summer squash	Adult beetles	Adult beetles
4.	Soybean sucking bug	*Chauliops choprai*	Soybean	Adult bugs	Adult bugs
5.	Mustard aphid	*Lipaphis erysimi*	Mustard	Adult aphids	Adult aphids

B. Insecticides evaluated

In order to test the efficacy of insecticides and fix the baseline susceptibility, a total of 23 insecticides were evaluated (details in Table 2). The test insecticides belonging to conventional groups, botanicals, entomopathogenic based, microbial based, insect growth regulators and novel groups were used for the study. A minimum of 10 insecticides belonging to different modes of action were used against a single test insect. A thorough market survey was conducted in the Indian Himalayas before selecting the insecticide for bioassay and due care was taken to select only those insecticides and formulations that were commercially available in the market and widely used by farmers for pest management in hill agriculture.

C. Bioassay studies

Different concentrations (in ppm) of technical grade insecticides were prepared by serial dilution in double distilled water and leaf dip bioassay technique was followed against all the insect pests as recommended by Insecticide Resistance Action Committee (Anonymous 1990). The leaf discs of 90 mm diameter were cut and dipped in the insecticide solution for 60 seconds and after thorough incubation the leaves were transferred to an autoclaved Petri dish and 10 numbers of insects was released in each plate. Whereas, in case of *H. armigera*, diet contamination method was followed (Rafiei *et al.*, 2008) and the treated diet was placed in small 50 mm Petri plates and single 3rd instar larvae was released into each plate to avoid cannibalism. The treated insects were placed in a temperature (25±2°C) and relative humidity (70±5%) controlled chamber for 72 hours and the mortality data was recorded after every 12 hours. The insects were counted dead when they showed no visible moments after gentle probing with a brush or blunt probe. A minimum of three replicates for seven insecticide concentrations and one control (untreated) was used for each test insecticide.

D. Data analysis

The mortality data of the treated insects recorded after 48 hours of insecticide exposure was corrected by Abbott's (1925) formula and the obtained data was subjected to probit analysis (Finney 1971) using the software package PoloPlus (LeOra Software 2013).

Table 2: Insecticides used for testing the baseline susceptibility against major insect pests of hill crops.

Sr. No.	Insecticide	Chemical group	Trade name	Manufacturer	Mode of action	Label colour
1.	Acephate 75% SP	Organophosphates	Acemain	Adama India Pvt. Ltd.	Acetyl Choline esterase inhibitors	**B**
2.	Monocrotophos 36% SL		Chetak	Crop Chemicals India Ltd.		**R**
3.	Diclorovos 76% EC		Nuvan	Insecticides india Ltd.		**R**
4.	Malathion 50% EC		Tusk	Shivalik Crop Sci. Pvt. Ltd		**B**
5.	Chloropyriphos 20% EC		Chlorguard	Gharda Chemicals Ltd.		**Y**
6.	Deltamethrin 2.8% EC	Synthetic pyrethroid	Decis	Bayer Crop Sci. Ltd.	Axonic sodium channel modulator	**Y**
7.	Lamdacyhalothrin 5% EC		Deva Shakti	Dhanuka Agritech Ltd.		**Y**
8.	NSK EC Azadirachtin 0.15% (1500ppm)	Botanical	Vanguard	Agriland Biotech Ltd.	Multiple modes of action	**G**
9.	*Metarhizium anisopliae* 2 × 10^5	Entomopathogenic fungi based	Green meta	Green Life Bio tech. Laboratory	Direct penetration through cuticle and haemolymph poisoning	**G**
10.	*Beauveria bassiana* 2 × 10^5		Green *Beauveria*	Green Life Bio tech.Laboratory		**G**
11.	Acetamiprid 20% SP	Chlornicotinyl group	Ennova	NACL industries Ltd.	Nacetyl choline receptor agonist / antagonists	**Y**
12.	Imidacloprid 17.8% SL		Maharaja	Gharda Chemicals Ltd.		**Y**
13.	Thiomethaxam 25% WG	Thionicotinyl group	Sahib Sitara	Sahib Pesticides		**B**
14.	Cartap hydrochloride 50% SP	Nereis toxin	Sanvex sp	Sumitomo Chemical India Pvt. Ltd.	Nacetyl choline receptor agonist / antagonists	**Y**
15.	Emmamectin benzoate 5% SG	Avermectin	Procline	Safex Chemical (India) Ltd.	Chloride channel activators	**G**
16.	Spinosad 45% SC	Spinosyn	Conserve	Nagarajuna Agritech Ltd.	N Acetyl Choline receptor modulators	**B**
17.	Indoxacarb 14.5% EC	Oxadiazine	King doxa	Gharda Chemicals Ltd.	Voltage dependent sodium channel blocker	**Y**
18.	Chlorantraniliprole 18.5% SC	Diamide group	Coragen	EIDupont India Pvt. Ltd.	Ryanodine receptor modulator	**G**
19.	Flubendiamide 39.35% SC		Fame	Bayer India Ltd.		**G**
20.	Cyntraniliprole 10.26 OD		Benevia	Dupont India Ltd.		**G**
21.	Difenthiuron 50% WP	Thiourea group	Pegasus	Syngenta India Ltd.	Inhibitors of oxidative phosphorylation	**G**
22.	Pymetrozine 50% WG	Pyiridine azomethine group	Simca	Syngenta Korea Ltd.	Selective feeding blockers	**B**
23.	Buprofezin 25% SC	Thiadiazinone	Hakko	Insecticides India Ltd.	Chitin synthesis inhibitors	**B**

$$\text{Abbott's corrected mortality} = \frac{\text{\% mortality in treatment (T)} \quad \text{\% mortality in control (C)}}{\text{100\% mortality in control (C)}} \times 100$$

RESULTS

A. Toxicity of insecticides to Helicoverpa armigera

Out of the 10 insecticides tested against the 3rd instar larvae of *H. armigera*, Emamectin benzoate 5% SG was found to be highly toxic with LC_{50} values as low as 97.49 ppm, while Cartap hydrochloride 50% SP was the least toxic insecticide with LC_{50} values of 1618.08 ppm (details in Table 3). The best five insecticides with higher toxicity to the 3rd instar larvae were Emmamectin benzoate 5% SG> Spinosad 45% SC> Indoxacarb 14.5% EC> Lamdacyhalothrin 5% EC> Chlorantraniliprole18.5% SC. Although the novel green molecules like Flubendiamide 39.35% SC and Cyntraniliprole 10.26 OD are specifically recommended for the management of Lepidopteran pests, they showed least toxicity to the field populations of *H. armigera* in the Indian Himalayas.

Table 3: Toxicity of insecticides against 3rd instar larvae of tomato fruit borer *(H. armigera)*.

Sr. No.	Insecticides	Linear equation (Y=ax±c)	Slope±SE	LC_{50}	LC_{90}	R^2 values	Lower FL @ 5%	Upper FL @ 95%
1.	Emmamectin benzoate 5% SG	Y= 1.92x+1.18	1.92± 0.65	97.49	452.89	0.68	13.65	698.23
2.	Spinosad 45% SC	Y= 1.63x+1.69	1.63±0.17	107.39	654.64	0.96	10.59	1088.93
3.	Indoxacarb 14.5% EC	Y= 2.18x+0.55	2.18± 0.58	109.9	424.62	0.78	19.45	622.30
4.	Lamdacyhalothrin 5% EC	Y= 1.81x+1.07	1.81± 0.18	148.25	755.09	0.96	18.41	1193.98
5.	Chlorantraniliprole18.5% SC	Y=1.57x+1.59	1.57± 0.33	148.59	970.51	0.85	13.39	1648.16
6.	Flubendiamide 39.35% SC	Y= 1.61x+1.24	1.61± 0.25	216.27	1348.963	0.92	20.75	2259.44
7.	Cyntraniliprole 10.26 OD	Y= 1.38x+1.67	1.38± 0.17	258.82	2192.81	0.94	16.79	3990.25
8.	Deltamethrin2.8% EC	Y= 1.61x+0.75	1.61± 0.25	435.51	2716.44	0.91	41.78	4549.89
9.	Malathion 50% EC	Y= 1.46x+0.61	1.46± 0.05	1013.91	7655.97	0.99	76.56	13489.63
10.	Cartap hydrochloride 50% SP	Y= 1.29x+0.86	1.29± 0.08	1618.08	15885.47	0.98	86.69	30269.13

*FL-Fiducial limits, SE-Standard error, LC-Lethal Concentration

B. Toxicity of insecticides to Spilosoma obliqua

A total of 11 insecticides were tested against the field populations of third instar larvae of *S. obliqua* infesting soybean crop. Flubendiamide 39.35% SC was the most toxic insecticide with LC_{50} value of 22.8 ppm, followed by Emmamectin benzoate 5% SG (23.99 ppm), Chlorantraniliprole18.5% SC (25.64 ppm), Spinosad 45% SC (32.28 ppm) and Cyntraniliprole 10.26 OD (38.55 ppm) were among the top five toxic insecticides. The botanical insecticide NSK EC Azadirachtin 0.15% (1500ppm) recorded the highest LC_{50} value of 647.14 ppm and was identified as the least toxic insecticide (details in Table 4). Although other novel group of insecticides like Indoxacarb 14.5% EC and synthetic pyrethroids caused good mortality, their LC50 values were higher than the novel green molecules like diamides and avermectins.

Table 4: Toxicity of insecticides against 3rd instar larvae of bihar hairy caterpiller (*S. obliqua*).

Sr. No.	Insecticide	Linear equation (Y=ax±c)	Slope±SE	LC50	LC90	R^2 values	Lower FL @ 5%	Upper FL @ 95%
1.	Flubendiamide 39.35% SC	Y=1.73x+2.65	1.73± 0.39	22.8	125.31	0.82	2.57	202.3
2.	Emmamectin benzoate 5% SG	Y= 2.00x+2.24	2.00± 0.25	23.99	104.71	0.94	3.63	158.49
3.	Chlorantraniliprole18.5% SC	Y=1.88x+2.35	1.88± 0.36	25.64	123.03	0.87	3.44	191.43
4.	Spinosad 45% SC	Y=1.53x+2.69	1.53± 0.05	32.28	221.82	0.99	2.74	381.94
5.	Cyntraniliprole 10.26 OD	Y=1.40x+2.78	1.40± 0.18	38.55	316.23	0.94	2.59	571.48
6.	Indoxacarb 14.5% EC	Y=1.73x+2.17	1.73± 0.33	43.25	237.68	0.85	4.88	383.71
7.	Lamdacyhalothrin 5% EC	Y=1.81x+2.0	1.81± 0.31	45.39	231.74	0.87	8.47	366.43
8.	Deltamethrin2.8% EC	Y=2.01x+1.61	2.01± 0.25	48.64	210.38	0.93	7.43	317.68
9.	Malathion 50% EC	Y=1.43x+1.71	1.43± 0.09	199.98	1570.36	0.97	14.25	2805.43
10.	Cartap hydrochloride 50% SP	Y=1.19x+2.04	1.19± 0.11	306.9	3655.95	0.95	12.85	7345.14
11.	NSK EC Azadirachtin 0.15% (1500ppm)	Y=2.75x2.73	2.75± 0.32	647.14	1887.99	0.94	164.06	2552.7

C. Toxicity of insecticides to Raphidopalpa foveicollis

A total of 12 insecticides, including botanicals and microbe based insecticides were tested against the adults of red pumpkin beetle (*R. foevicollis*). It was observed that synthetic pyrethroids recorded the lowest LC_{50} values of 12.97 ppm for Deltamethrin 2.8% EC and 21.33 ppm for Lamdacyhalothrin 5% EC and were the most toxic insecticides. The botanicals and microbe based insecticides were the least toxic with LC_{50} values of 966.05 ppm for NSK EC Azadirachtin 0.15% (1500ppm), followed by 2152.78 ppm for *Metarhizium* *anisopliae* 2 × 10^5 and 2685.34 for *Beauveria bassiana* 2 × 10^5 (details in Table 5). Although, other insecticides of organophospate group, spinosyn and avermectin group were effective in managing the adults of *R. foevicollis*, their median lethal doses were little higher than the synthetic pyrethroids and thus can be considered only after synthetic pyrethroids for pumpkin beetle management in summer squash in the Indian Himalayas.

Table 5: Toxicity of insecticides against adults of red Pumpkin beetle (*R. foevicollis*).

Sr. No.	Insecticide	Linear equation (Y=ax±c)	Slope±SE	LC_{50}	LC_{90}	R^2 values	Lower FL @ 5%	Upper FL @ 95%
1.	Deltamethrin2.8% EC	Y=2.84x+1.84	2.84± 0.22	12.97	36.56	0.97	3.43	48.98
2.	Lamdacyhalothrin 5% EC	Y=2.83x+1.24	2.83± 0.57	21.33	60.39	0.86	5.61	80.91
3.	Indoxacarb 14.5% EC	Y=2.53x+1.27	2.53± 0.61	29.78	95.49	0.81	6.69	132.74
4.	Cartap hydrochloride 50% SP	Y=2.62x+1.03	2.62± 0.62	32.73	100.93	0.82	7.74	138.36
5.	Diclorovos 76% EC	Y=2.7x+0.83	2.70± 0.61	34.99	104.47	0.83	8.49	141.91
6.	Chloropyriphos 20% EC	Y=1.79x+1.92	1.79±0.43	52.61	272.89	0.81	6.37	438.53
7.	Emmamectin benzoate 5% SG	Y=2.36x+0.82	2.36±0.38	59.02	206.06	0.91	11.91	292.41
8.	Malathion 50% EC	Y=3.57x3.42	3.57± 0.50	228.03	521.19	0.91	79.25	657.66
9.	Spinosad 45% SC	Y=4.85x8.82	4.85± 0.85	706.32	1297.18	0.89	321.37	1541.7
10.	NSK EC Azadirachtin 0.15% (1500ppm)	Y=2.06x1.15	2.06± 0.15	966.05	4045.76	0.97	154.53	6053.41
11.	*Metarhizium anisopliae* 2 × 10^5	Y=2.82x4.40	2.82± 0.67	2152.78	6123.51	0.81	564.94	8222.43
12.	*Beauveria bassiana* 2 × 10^5	Y=2.82x4.67	2.82 ± 0.55	2685.34	7638.35	0.87	704.69	10256.52

D. Toxicity of insecticides to Chauliops choprai

Considering the severity of infection of *C. choprai* in Soybean, a total of 11 insecticides were tested against the adults of sucking bug to identify the most efficient chemical for pest management (details in Table 6). Difenthiuron 50% WP was identified as the most toxic insecticide with LC_{50} values of 20.61 ppm, followed by Cartap hydrochloride 50% SP (38.19 ppm), Pymetrozine 50% WG (44.87 ppm) and Thiomethaxam 25% WG (48.75 ppm) among the top four toxic insecticides.

Table 6: Toxicity of insecticides against soybean sucking bug (*Chauliops choprai*).

Sr. No.	Insecticide	Linear equation (Y=ax±c)	Slope±SE	LC50	LC90	R^2 values	Lower FL@ 5%	Upper FL@ 95%
1.	Difenthiuron 50% WP	Y= 2.36x+1.90	2.36±0.42	20.61	71.78	0.88	4.16	101.86
2.	Cartap hydrochloride 50% SP	Y=2.13x+1.63	2.13± 0.39	38.19	152.41	0.88	6.49	224.91
3.	Pymetrozine 50% WG	Y= 2.27x+1.25	2.27± 0.39	44.87	164.44	0.89	8.49	235.59
4.	Thiomethaxam 25% WG	Y=2.31x+1.10	2.31± 0.40	48.75	174.58	0.89	9.51	250.03
5.	Imidacloprid 17.8% SL	Y=1.84x+1.66	1.84± 0.16	65.31	324.34	0.97	8.39	509.33
6.	Buprofezin 25% SC	Y=1.64x+1.85	1.64± 0.11	83.37	502.34	0.98	8.34	833.68
7.	Acephate 75% SP	Y=1.80x+1.44	1.80± 0.16	95.06	488.65	0.97	11.67	774.46
8.	Acetamiprid 20% SP	Y= 1.88x+1.28	1.80± 0.08	116.68	599.79	0.99	14.32	950.6
9.	Monocrotophos 36% SL	Y=1.79x+1.29	1.79± 0.05	118.304	613.762	0.99	14.32	974.99
10.	Indoxacarb 14.5% EC	Y=1.87x+0.56	1.87± 0.11	236.59	1145.51	0.99	31.41	1782.38
11.	NSK EC Azadirachtin 0.15% (1500ppm)	Y=1.68x+0.57	1.68± 0.15	433.51	2506.11	0.97	45.81	4102.04

The botanical insecticide NSK EC Azadirachtin 0.15% (1500ppm) showed the least toxicity with the highest LC_{50} value of 433.51 ppm. Moreover, the insecticides belonging to organophosphate group and neonicotinoid group were effective in causing the bug mortality, but they recorded higher median lethal values.

E. Toxicity of insecticides to Lipaphis erysimi

Out of the 11 insecticides tested against field populations of mustard aphid; Difenthiuron 50% WP, Thiomethaxam 25% WG, Imidacloprid 17.8% SL, Pymetrozine 50% WG and Acetamiprid 20% SP proved to be very toxic and effective insecticides with LC_{50} values of 0.703 ppm, 0.82 ppm, 1.15 ppm, 1.36 ppm and 1.87 ppm respectively. While the insecticides with novel modes of action like Buprofezin 25% SC, Cartap hydrochloride 50% SP and Indoxacarb 14.5% EC although showed good mortality rate, but their median lethal toxicity were much higher. The botanical insecticide NSK EC Azadirachtin 0.15% (1500ppm) was the least toxic with LC_{50} value of 208.93 ppm (details in Table 7). Moreover, the organophosphate group of insecticides were found to be less effective in managing the mustard aphid with greater LC_{50} values compared to other novel group of insecticides.

Table 7: Toxicity of insecticides against mustard aphid (*Lipaphis erysimi*).

Sr. No.	Insecticide	Linear equation (Y=ax±c)	Slope± SE	LC_{50}	LC_{90}	R^2 values	Lower FL @ 5%	Upper FL @ 95%
1.	Difenthiuron 50% WP	Y=1.77x+5.27	1.77± 0.24	0.703	3.724	0.93	0.08	5.94
2.	Thiomethaxam 25% WG	Y=1.78x+5.15	1.78± 0.32	0.824	4.315	0.89	0.087	6.87
3.	Imidacloprid 17.8% SL	Y=1.46x+4.91	1.46± 0.35	1.153	8.669	0.81	0.087	15.31
4.	Pymetrozine 50% WG	Y=1.64x+4.78	1.64± 0.34	1.361	8.222	0.85	0.14	13.61
5.	Acetamiprid 20% SP	Y=1.69x+4.54	1.69± 0.36	1.87	10.69	0.84	0.2	17.49
6.	Cartap hydrochloride 50% SP	Y=1.44x+3.76	1.44± 0.26	7.261	56.23	0.89	0.53	100
7.	Buprofezin 25% SC	Y=1.31x+3.65	1.31± 0.11	10.739	101.9	0.97	0.6	191.42
8.	Acephate 75% SP	Y=1.67x+2.32	1.67± 0.18	40.272	235	0.95	4.19	388.15
9.	Indoxacarb 14.5% EC	Y=2.21x+1.21	2.21± 0.37	51.88	196.8	0.9	9.39	286.42
10.	Monocrotophos 36% SL	Y=1.73x+1.63	1.73± 0.15	88.716	487.5	0.97	10	787.04
11.	NSK EC Azadirachtin 0.15% (1500ppm)	Y=2.03x+0.29	2.03± 0.08	208.93	891.3	0.99	32.51	1342.77

DISCUSSION

The laboratory bioassay studies against the field populations of 3rd instar larvae of *H. armigera* showed highly variable and amusing results. The LC_{50} values for most novel group of insecticides were very high ranging from 97.49 ppm for Emmamectin benzoate 5% SG to 435.51 ppm for Deltamethrin 2.8% EC. The studies conducted by Hussain *et al*., (2014) showed that the LC_{50} values for Emmamectin benzoate ranged between 0.13 to 0.52 ppm, Lambda cyhalothrin ranged between 15.68 to 55.02 ppm and Deltamethrin ranged between 96.46 to 241.04ppm against the field populations of *H. armigera* in Pakistan, these results were in contradiction of our study. While, the bioassay results of Qayyum *et al.,* (2015); Bird *et al.,* (2015) showed that, Emamectine benzoate was the most toxic insecticide, followed by spinosad and chlorantraniliprole in Pakistan and Australia respectively. Moreover, studies of Sreekanth *et al.,* (2021) reported that, insecticidal module consisting of chlorantraniliprole, followed by flubendiamide and dimethoate highly effective in managing the pigeon pea pod borer (*H. armigera*), which were in close conformity with our results.

Although the hill agriculture in Indian Himalayas is mostly organic based subsistence farming with least emphasis on chemical pest and disease management and the *H. armigera* populations have rarely been exposed to any insecticides. But, it was really amusing to note such higher LC_{50} values for most insecticides tested in the study. Based on the bioassay results, it can be assumed that due to shift in intensive farming, polyhouse cultivation and increasing interests in chemical pest management for commercial production may have lead to increased baseline susceptibility of local field populations of *H. armigera* to most novel groups of insecticides.

The field populations of *S. obliqua* were tested for their baseline susceptibility to commonly used insecticides. It was interesting to note that the median lethal concentrations recorded for most insecticides were very low. Out of the 11 insecticides Flubendiamide proved to be the most toxic (LC_{50}, 22.8 ppm), followed by Emamectin benzoate (23.99 ppm) and Chlorantraniliprole (25.64 ppm). Our results were in close accordance with the results of Selvaraj *et al*., (2015) who showed that Flubendiamide was the most toxic insecticide followed by Emamectin benzoate 5 SG and chloranatraniliprole 18.5 EC. Moreover, the studies of Kumar *et al.*, (2013);Sharma *et al.*, (2015); Painkra (2020); Rahman *et al.* (2021) showed that, novel group of insecticides like spinosad, Emamectin benzoate, Lambda cyhalothrin, deltamethrin, cypermethrin and fipronil were highly toxic against larvae of *S. obliqua* in comparison to organophosphate insecticides like triazophos and chlopyriphos. These results formed close conformity to our studies, wherein, the organophosphate insecticide Malathion 50% EC recorded the LC_{50} value of 199.98 ppm, which was much higher than the LC_{50} values of other novel group of insecticides.

Red pumpkin beetle (*R. foevicollis*) is a serious threat to summer squash and cucumber cultivation in the Indian Himalayas. The pest is usually managed by farmers through spray of dust formulations of Malathion or carbaryl or EC formulations of organophosphate insecticides (monocrotophos and chlorpyriphos). But, use of novel group of insecticides is rarely practiced by farmers. So, the laboratory bioassay was conducted to fix the baseline susceptibility of *R. foevicollis* to various insecticides. Based on the data obtained, it was observed that synthetic pyrethroids were the most toxic insecticides followed by Indoxacarb, cartap hydrochloride and organophosphates. Our results were in close accordance with the results of Mahato *et al*., (2017) who showed that novel insecticides like Indoxacarb, cartap hydrochloride and chloantraniliprole caused 74.59 to 82.59% mortality of adult pumpkin beetle in cucumber crop. The studies of Rathodi *et al.,* (2009); Parajuli *et al*., (2020) on studying the efficacy of neem based insecticides showed that a good feeding deterrence and mortality rate was recorded against the adults, these studies formed close concurrence with our results, wherein, the neem based insecticide NSK EC Azadirachtin 0.15% (1500ppm) recorded a good median lethal concentration of 966.05 ppm, which was far better and lower than the LC_{50} values of microbial insecticides. Moreover, the studies conducted by Ratnakar *et al.* (2016), Halder and Rai (2020) and Sahu and Samal (2020) concluded that novel insecticides belonging to synthetic pyrethroid and neonicotnoid groups were found to manage the beetle population efficiently. In addition, the integrated model of use of both biocontrol agents and novel group of insecticides was also found to be a highly efficient control measure against red pumpkin beetle infecting Cucumbers at Varanasi, Uttar Pradesh (Halder and Rai 2020) Soybean sucking bug (*Chauliops choprai*) has recently gained the status of major insect pest of soybean in the Indian Himalayas (Paschapur *et al.,* unpublished data). The management of this sucking pest is not only difficult, but also very painstaking because of its hidden feeding habits. In order to select an effective and toxic insecticide against the sucking bug, a total of 11 insecticides were selected and out of these Difenthiuron, cartap hydrochloride, pymetrozine and thiomethaxam were the most efficient insecticides that recorded lower LC_{50} values when compared to other organophosphate, neonicotinoid and botanical insecticides. This was the first study carried out to fix the baseline susceptibility of *C. choprai* to novel groups of insecticides in the Indian Himalayas. However, the previous studies conducted by Sood *et al*. (2004) mainly concentrated on conventional insecticides like organophosphates and novel chemicals like synthetic pyrethroids, their results concluded that monocrotophos 36 SL caused 33.37% bug mortality, while deltamethrin and fenvelerate caused 72.47% and 69.16% bug mortality 5 days after foliar spray in kidney bean. The studies of Premchand *et al.* (2021) proved that, the combination of novel group of insecticides can successfully manage the sucking pest menace in commercial crops like oilseeds, vegetables and fruits.

L. erysimi is a hard to manage pest of mustard crop in the Indian Himalayas (Singh and Sachan 1995). There are a wide variety of insecticides commercially available in the Indian markets for effective management of aphid pests of various crops. But there was no basic information of which insecticides are more toxic to the field populations of mustard aphid in the Indian Himalayas. So, the study conducted to fix the baseline susceptibility of 11 different insecticides against mustard aphid showed that, novel group of insecticides like difenthiuron, thiomethaxam, Imidacloprid and pymetrozine were highly toxic with LC_{50} values as low as 0.7 to 1.3 ppm. Our results showed close conformity with the results of Ujjan *et al.,* (2014); Seni and Naik (2017); Ali *et al.,* (2020); who reported that novel insecticides like Imidacloprid, acetamiprid, bifenthrin and pymetrozine were highly toxic against mustard aphids with LC_{50} values as low as 0.67 ppm, 0.82 ppm, 2.0 ppm and 25.59 ppm respectively. Moreover, the LC_{50} values of organophosphate insecticides in the studies of Panwar and Singh (2007) ranged from 32 ppm and 112 ppm and coincided with our results wherein the LC_{50} values of acephate and monocrotophos were 40.27 ppm and 88.72 ppm respectively. This study was first of its kind in the Indian Himalayan region in order to fix the baseline susceptibility of group of insecticides including both novel and conventional ones against five major insect pests of hill crops.

FUTURE SCOPE

The agriculture in the Indian Himalayas has been the traditional subsistence system of crop-livestock farming for ages. But, due to increasing demand for agricultural produce of Himalayan origin in the metropolitan and cosmopolitan cities of India and abroad, the farmers of hill states are shifting their interest towards commercial production system, which includes intensive farming, contract farming and polyhouse cultivation. These new cultivation systems not only give high yields but also create very favourable environmental conditions for pest and disease survival and dispersion, thus forcing farmers to adapt chemical pest management practices. Therefore, in order to fix the baseline susceptibility to various novel chemistry insecticides and provide safer alternatives for hazardous conventional organophosphate and carbamate insecticides, the present study was conducted and novel insecticides were screened against major insect pests of hill crops at laboratory level. Based on our results we can scientifically recommend farmers a suitable insecticide for management of specific insect pest in a particular crop. Such types of studies to continuously evaluate novel chemistry insecticides for timely management of the insect pests are essential to reduce the problems of insecticide resistance, pest resurgence and pesticide residue accumulation and biomagnifications in the Himalayan ecosystem.

Acknowledgements. The authors are thankful to Indian Council of Agricultural Research (ICAR) and ICAR-VPKAS, Almora for the financial assistance and providing facilities for conducting experiments successfully.

Conflict of Interest. None.

REFERENCES

Abbott, W. S. (1925). Abbott's formula. *Journal of Economic Entomology*, *18*: 267-268.

Ahmad, M., Saleem, M. A. and Sayyed, A. H. (2009). Efficacy of insecticide mixtures against pyrethroid- and organophosphate-resistant populations of *Spodoptera litura* (Lepidoptera: Noctuidae). *Pest Management Science, 65*(3): 266-274.

Ahmad, M., Arif, M. I. and Ahmad, Z. (1995). Monitoring insecticide resistance in *Helicoverpa armigera* (Lepidoptera: Noctuidae) in Pakistan. *Journal of Economic Entomology, 88*: 771-776.

Ali, Q., Amer-Rasul, M. S., Majeed, B. and Farooqi, M. A. (2020). Comparative efficacy of four insecticides and two indigenous plant extracts against wild crucifer aphid, *Lipaphis erysimi* (Hemiptera: Aphididae). *Pure and Applied Biology (PAB), 9*(3): 1773-1779.

Alvi, A. H., Sayyed, A. H., Naeem, M. and Ali, M. (2012). Field evolved resistance in *Helicoverpa armigera* (Lepidoptera: Noctuidae) to *Bacillus thuringiensis* toxin Cry1Ac in Pakistan, *PLoS ONE, 7*(10): e47309.

Anonymous (1990). Proposed insecticide/acaricide susceptibility tests, International Resistance Action Committee Method No.7. *Bulletin of European Plant Protection Organization, 20*: 399-400.

Attique, M. N. R., Khaliq, A. and Sayyed, A. H. (2006). Could resistance to insecticides in *Plutella xylostella* (Lepidoptera: Plutellidae) be overcome by insecticide mixtures. *Journal of Applied Entomology, 130*: 122-127.

Badiane, D., Gueye, M. T., Coly, E. V. and Faye, O. (2015). Gestion intégrée des principaux ravageurs du cotonnier au Sénégal et en Afrique occidentale. *International Journal of Biological and Chemical Science, 9*: 2654-2667.

Bird, L. J. (2015). Baseline susceptibility of *Helicoverpa armigera* (Lepidoptera: Noctuidae) to indoxacarb, emamectin benzoate, and chlorantraniliprole in Australia. *Journal of Economic Entomology, 108*(1): 294-300.

Finney, D. J. (1971). Statistical logic in the monitoring of reactions to therapeutic drugs. *Methods of Information in Medicine, 10*(04): 237-245.

Forrester, N. W. (1993). Designing, implementation and servicing an insecticide resistance management program. *Pesticide Science, 28*: 167-179.

Gunning, R. V. (1996). Bioassay for detecting pyrethroid nerve insensitivity in Australian *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Journal of Economic Entomology, 89*(4): 816-819.

Gunning, R. V., Moores, G. D. and Devonshire, A. L. (1999). Inhibition of Resistance related Esterases by Piperonyl Butoxide in *Helicoverpa armigera* (Lepidoptera: Noctuidae) and *Aphis gossypii* (Hemiptera: Aphid). *Academic Press*, 215-226.

Habib-ur-Rehman., Qurban, A., Amer, R., Muhammad, S., Beenish, M. and Muhammad, A. F. (2020). Comparative efficacy of four insecticides and two indigenous plant extracts against wild crucifer aphid, *Lipaphis erysimi* (Hemiptera: Aphididae). *Pure and Applied Biology, 9*(3): 1773-1779.

Halder, J. and Rai, A. B. (2020). Synthesis and development of pest management modules against major insect pests of pumpkin (*Cucurbita moschata*). *Indian Journal of Agricultural Sciences, 90*(9): 1673-1677.

Hussain, D., Saleem, H. M., Saleem, M. and Abbas, M. (2014). Monitoring of insecticides resistance in field populations of *Helicoverpa armigera* (hub.) (Lepidoptera: Noctuidae). *Journal of Entomology and Zoology, 2*(6): 16.

Kumar, A., Bhatnagar, S. and Sharma, R. K. (2013). Toxicity of some commonly used insecticides against *Spilarctia Obliqua* (walker). *Indian Forester, 139*(3): 260-263.

Kumar, N. (2014). College of horticulture (Doctoral dissertation, Dr Yashwant Singh Parmar University of Horticulture and Forestry).

Kumar, S. and Sharma, R. (2020). Field efficacy of insecticides against two different feeding guilds: the sap sucking *Lipaphis erysimi* (Kaltenbach) and foliage feeder *Pieris brassicae* (L.) infesting Indian mustard. *Journal of Oilseed Brassica, 11*(1): 29-33.

Mahato, S. (2017). Evaluation of newer insecticides on pest complex of Cucumber (Doctoral dissertation).

Miah, M. R. (2018). Damage potentiality and ecofriendly management of red pumpkin beetle and cucurbit fruit fly on squash vegetable (Doctoral dissertation, Department of Entomology, Sher-E-Bangla Agricultural University, Dhaka1207).

Nauen, R. and Bretschneider, T. (2002). New modes of action of insecticides. *Pesticide Outlook, 13*: 241-245.

Painkra, K. L. (2020). Bio-efficacy of modern insecticides against Bihar hairy caterpillar, *Spilosoma obliqua* (Walker) under laboratory condition. *Journal of Entomology and Zoology Studies, 8*(6): 756-758

Panwar, S. S. and Singh, C. P. (2007). Fitness cost of resistance to chlorpyrifos in *Lipaphis erysimi* (Homoptera: aphididae). In the 12th International Rapeseed Congress, 262.

Parajuli, S., Shrestha, B., Dulal, P. R., Sapkota, B., Gautam, S. and Pandey, S. (2020). Efficacy Of Various Insecticides Against Major Insect Pests Of Summer Squash (*Cucurbita pepo*) In Dhading District, Nepal. *Science Heritage Journal (GWS)*, *4*(1): 35-42.

Patel, S., Yadav, S. K. and Singh, C. P. (2017). Bio-efficacy of insecticides against *Lipaphis erysimi* (Kalt.) in mustard ecosystem. *Journal of Entomology and Zoology Studies*, *5*(2), 1247-1250.

Premchand, U., Mesta, R. K., Basavarajappa, M. P., Waseem, M. A., Mahesh, Y. S., Cholin, S. and Prakash, D. P. (2021). Management of Papaya Ringspot Virus (PRSV) using Insecticides and bio Rationals under Field Conditions. *Biological Forum – An International Journal*, *13*(3a): 743-748.

Qayyum, M. A., Wakil, W., Arif, M. J., Sahi, S. T., Saeed, N. A. and Russell, D. A. (2015). Multiple resistances against formulated organophosphates, pyrethroids, and newer chemistry insecticides in populations of *Helicoverpa armigera* (Lepidoptera: Noctuidae) from Pakistan. *Journal of Economic Entomology, 108*(1): 286-293.

Qayyum, M. A., Wakil, W., Arif, M. J., Sahi, S. T., Saeed, N. A. and Russell, D. A. (2015). Multiple resistances against formulated organophosphates, pyrethroids, and newer-chemistry insecticides in populations of *Helicoverpa armigera* (Lepidoptera: Noctuidae) from Pakistan. *Journal of Economic Entomology*, *108*(1): 286-293.

Rafiei, D. H., Hejazi, M. J., Nouri, G. G. and Saber, M. (2008). Toxicity of some biorational and conventional insecticides to cotton bollworm, *Helicoverpa armigera* (Lepidoptera: Noctuidae) and its ectoparasitoid, *Habrobracon hebetor* (Hymenoptera: Braconidae). *Journal of Entomological Society of Iran, 1*(42): 27-37.

Rahman, M. M. (2018). Evaluation of different traps and some nonchemical options against the infestation of fruit fly and red pumpkin beetle on ridge gourd (Doctoral dissertation, Department of Entomology, Sher-E-Bangla Agricultural University, Dhaka 1207).

Rahman, M. S., Islam, M. N., Polan, M. S., Talukder, F. U. and Mukul, M. M. (2021). Relative toxicity of some chemical pesticides against jute hairy caterpillar (*Spilosoma Obliqua* W.) in tossa jute (*Corchorus olitorius* L.). *Sustainable Agriculture, 5*(2): 115-122.

Rao, K. S. and Saxena, K. G. (1996). Minor forest products' management: problems and prospects in remote high altitude villages of Central Himalaya. *International Journal of Sustainable Development and World Ecology, 3*(1): 60-70.

Rathodi, S. T., Borad, P. K. and Bhat, N. A. (2009). Bioefficacy of neem based and synthetic insecticides against red pumpkin beetle, *Aulacophora foveicollis* (Lucas) on bottle gourd. *Pest Management in Horticultural Ecosystems, 15*(2): 150-154.

Ratnakar, V., Vijayaraghavendra, R. S., Reddy, S. and Padmasri, A. (2016). Efficacy of certain insecticides to Red Pumpkin Beetle, *Aulacophora foevicolis* on Cucmber, *Cucumis sativus*. *Progressive Research: An International Journal Society for Scientific Development, 2*: 478-480.

Sahoo, S. K. (2012). Incidence and management of mustard aphid (*Lipaphis erysimi* Kaltenbach) in West Bengal. *The Journal of Plant Protection Sciences, 4*(1): 20-26.

Sahu, B. K. and Samal, I. (2020). Pest complex of Cucurbits and their management: A review. *Journal of Entomology and Zoology Studies, 8*(3): 89-96.

Selvaraj, K., Babu, V. R., Gotyal, B. S. and Satpathy, S. (2015). Toxicity and bioefficacy of individual and combination of diversified insecticides against jute hairy caterpillar, *Spilarctia obliqua*. *Journal of Environmental Biology, 36*(6): 1409-1414.

Semwal, R., Nautiyal, S., Sen, K. K., Rana, U., Maikhuri, R. K., Rao, K. S. and Saxena, K. G. (2004). Patterns and ecological implications of agricultural land use changes: a case study from central Himalaya, India. *Agricultural Ecosystem and Environment*, *102*(1): 81-92.

Sene, S. O., Tendeng, E., Diatte, M., Sylla, S., Labou, B., Diallo, A. W. and Diarra, K. (2020). Insecticide resistance in field populations of the tomato fruitworm, *Helicoverpa armigera*, from Senegal. *International Journal of Biological and Chemical Sciences, 14*(1): 181-191.

Seni, A. and Naik, B. S. (2017). Bioefficacy of some insecticides against mustard aphid, *Lipaphis erysimi* (Kalt.) (Hemiptera: Aphididae). *Journal of Entomology and Zoology Studies, 5*(6): 541-543.

Sharma, H. C., Srivastava, C. P., Durairaj, C. and Gowda, C. L. L. (2010). Pest management in grain legumes and climate change. *In Climate change and management of cool season grain legume crops*. Springer, Dordrecht, 115-139.

Sharma, P., Geetanjly, G. and Rai, V. L. (2015). Toxicity of some insecticides against seven day old larvae of Bihar hairy caterpillar, *Spilarctia obliqua* Walker. *Journal of Applied and Natural Science*, *7*(2): 960-963.

Sharma, R. K. and Sharma, K. K. (2021). Relative incidence of aphid (*Lipaphis erysimi*) and Alternaria blight on mustard in sub-mountainous region of Punjab. *Journal of Environmental Biology*, *42*(3): 694-699.

Singh, C. P. and Sachan, G. C. (1995). Estimation of losses in yield of rapeseed, *Brassica campestris*, by the mustard aphid, *Lipaphis erysimi* (Kalt.) in Tarai, India. *International Journal of Tropical Insect Science,16*(34): 283-286.

Sreekanth, M., Rao, G. M. V. P., Lakshmi, M. S. M. and Ramana, M. V. (2021). Impact of Different Insecticidal Modules on Pod Borer Complex in Pigeonpea. *Biological Forum – An International Journal*, *13*(3a): 374-379.

Torres-Vila, L. M., Rodriguezmolina, M. C., Lacasaplasencia, A. and Bielzalino, P. (2002). Insecticide resistance of *Helicoverpa armigera* to endosulfan, carbamates and organophosphates: the Spanish case. *Crop Protection, 21*(10): 1003-1013.

Tripathi, R. S. and Sah, V. K. (2001). Material and energy flows in high hill, mid hill and valley farming systems of Garhwal Himalaya. *Agriculture Ecosystem and Environment*, *86*(1): 75-91.

Ujjan, A. A., Khanzada, M. and Shahzad, S. (2014). Insecticide and papaya leaf extract toxicity to mustard

aphid (*Lipaphis erysimi* kal). *Journal of AgriFood and Applied Sciences, 2*(2): 45-48.
Vishal, H. S. and Kumar, A. (2019). Efficacy and economics of some newer insecticides against mustard aphid, *Lipaphis erysimi* (Kalt). *Journal of Pharmacognosy and Phytochemistry, 8*(3): 785-788.
Wang, D. G. P., Li, M., Qiuand, X. and Wang, K. (2009). Sub-lethal effects of spinosad on survival, growth and reproduction of *Helicoverpa armigera* (Lepidoptera: Noctuidae). *Pest Management Science, 65*: 223-227.

How to cite this article: Paschapur, A. U.; Subbanna, A. R.N.S.; Gupta, J. P.; Mishra, K. K. and Kant, L. (2022). How Susceptible are the Indian, Himalayan Populations of Insect Pests to Novel Groups of Insecticides. *Biological Forum – An International Journal, 14*(1): 121-130.