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Effect of different insecticides on control of insect pests of the potato crop

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Introduction

In India, anticipated increased demand for vegetables (350 MT by 2030) generated need to develop technologies that enhance the quality and productivity of vegetables under conditions of reducing land, declining natural resources, and increasing biotic and abiotic stresses. Among the three most widely consumed vegetable crops (potato, onion, tomato) the maximum increase in production has been seen in potato (over 10.6%). Globally, potato (*Solanum tuberosum* L.) is one of the most productive and widely grown food crop and rank fourth after maize, wheat, and rice. Potatoes are grown on ca. 18.3 million hectares with a production of 295 million tons. India ranks third in area and second in production in the world. More than 85 percent of India's potatoes are grown in the vast Indo-Gangetic plains of north India during the winter season (October to March). The Uttar Pradesh, West Bengal, and Bihar account for more than 75% of India's potato-growing area and approximately 80% of total production (Pandey and Kang 2003). Potential for exporting potatoes from India is also very high as seed and food material to neighbouring countries. Even potatoes can be exported to some of the European countries during March-May when fresh potatoes are not available in these countries.

In Indian agriculture, ensuring the sustainable production of potatoes is a critical challenge as insect pests, especially vectors, are major biotic constraints affecting potato yield and tuber quality. Insect pests cause variable and complex problems for potato farmers (Bhatnagar, 2007, Chandel *et al.*, 2013). India has a great diversity of insect pests that attack potatoes from planting to harvest. Because potato crops are vegetative propagated from whole or cut tubers, which easily carry insect pests, many insect pest problems have followed potatoes to areas where they are grown (Chandel et al., 2007). These insect pests can damage potato plants by feeding on leaves and efficiently by attacking stems, weakening them and by attacking potato tubers destined for consumption or use as seed (Chandel et al. 2003). The crop is attacked by a robust complex of phytophagous insects, some of which can destroy the potato crop in the absence of adequate control measures (Bhatnagar, 2007; 2008). In India, approximately 60 billion rupees worth of potato tubers are lost annually due to pest damage accounting 10-20% of total production. The reduction in yield loss by insect pests demands heavy pesticide application at the field level.

The insect pests management in potatoes is predominantly achieved through the application of pesticides. It is estimated that around 13–14% of the total pesticides (50583.47 MT technical grades) used in the country are applied to vegetables. Out of which, insecticides account for two-thirds of the total pesticides used on vegetables. However, productivity trends indicate that application of insecticides will not proportionately increase crop productivity (Misra *et al*., 2003). In view of abovementioned facts, there is urgent need to evaluate the efficacy of various insecticides against insect pests associated with the potatoes in India. The present study aims to find out the seasonal incidence and economical management of important insect pests.

Material and methods

The present study has been conducted over two seasons (2019-19 and 2019-20) at experimental fields near Shri Venkateshwara University, Amroha, UP. The study area lies between 77^0 42’ East longitude and $29^0$17’

North latitude with 237 m above MSL with subtropical, semi-arid climate having hot-dry summer and severe-cold winter. The long-term annual average rainfall is ca. 817 mm and is mostly received in July-September. The soil of the experimental field was sandy loam with an average fertility level.

The experiment was designed in a randomised block design (9 treatments replicated thrice) having plot size 3.0 m x 3.6 m. The seed bed was prepared by the standard methods and ridges were made 45 cm apart having height 15 cm. Seed material (variety *Kufri Pukhraj*) was planted on ridges at 20 cm distance in the first week of November during both years.

The treatments were given by using a knapsack sprayer. The spray solution of insecticides was prepared by using water at the rate of 300–400 litres per hectare as per the height of the crop. The three consecutive sprays were given at a 15-day interval. The first spray was given on the 25th day after emergence, and the second and third sprays were made at 40 and 55 days after emergence, respectively. To compare the efficacy of insecticidal treatments the control (untreated) was established. The details of treatments along with respective doses and methods of application have been described in the Table 1.

Table 1. Information on novel insecticides used in field trials against major insect pests of the potato crop

S. No.	Insecticides	Dose	Trade name	Method of application	Company
1.	*Abamectin benzoate 1.9% EC*	125 ml/ha	Abacin	Foliar spray	Crystalcrop protection Ltd.
2.	*Thiamethoxam25 WG*	150 gm/ha	Actara	Foliar spray	Synganta India Ltd.
3.	*Imidacloprid 17.8 SL*	150 ml/ha	Confidor	Foliar spray	Bayar India Ltd.
4.	*Chlorantraniliprole 18.5% SC*	150 ml/ha	Coragen	Foliar spray	Ei Dupont India
5.	*Indoxacarb 14.5% SC*	250 ml/ha	Avanut	Foliar spray	Kalyani Industries Ltd.
6.	*Flonicamid 50% WG*	150 ml/ha	Ulala	Foliar spray	UPL India
7.	*Flubendiamide 39.35% SC*	125 gm/ha	Fame	Foliar spray	Bharat Agro Chemicals & Fert.
8.	*Spinosad 45% SC*	150 ml/ha	Tracer	Foliar spray	Kalyani Industries Ltd
9.	*Control (wáter spray)*	_	_	-	-

NPK fertilizers were applied at recommended doses (180:80:100 kg ha^{-1}) with condition that whole amount of phosphorus and potassium were applied during the showing but only half nitrogen was applied as a basal dose. The remaining quantity of N was given in two split doses at 30 days and 45 days after planting.

At weekly intervals, the insect pest complex associated with potato crops was recorded right from the germination of the crop till the harvest on 10 randomly selected plants in each plot. The observations on the population build-up of various insect pests were recorded at different stages of crop growth between 7.00 AM and 9.00 AM till the harvesting of the potato crop. Insects were collected by counting adult and immature stages on the upper, middle, and lower compound leaves of potato plants. The flying insects were collected using a sweep net having a 60 cm long cloth bag, 30 cm in diameter at the mouth, and a 65 cm handle, which was used in the present study. The collected insects were separated into different groups according to insect order.

The incidence of major insect pests of potatoes was recorded at weekly intervals from each plot. The observations on the incidence of whitefly, aphids, and leaf hopper nymphs on potato plants were recorded at weekly intervals from 10 randomly selected potato plants from 3 leaves each of the upper, middle, and lower compound leaves of the plant throughout the crop season, and data was obtained on the number of insects per 3leaves/plant.

RESULTS AND DISCUSSION

The whitefly, leafhoppers, aphids are among the most dominant insects pests occurring on potato crops (Table 2). A higher incidence of whitefly was observed on early planted crops. Similarly, leafhoppers infest early potato crops and are active from October to March, depending upon the climatic conditions. The aphid complex stayed with the potato throughout its development. The aphid species *Myzus persicae* (Sulzer) and *Aphis gossypii* Glover are most common on potatoes. The whitefly, *Bemisia tabaci (Gennadius),* is a sap-sucking insect, is also important insect vector for the potato crop in north-central India which transmits potato apical leaf curl (Lakra, 2004).

Table 2 The insect pest complexes associated with the potato crop.

Order and family	Scientific name	Common name	Damaging stage	Associated with	Economic status
Hemiptera					
Aphididae	*Myzus persicae*	Green peach aphid	Adult & Nymph	vegetative stage	Major
Aphididae	*Aphis gossypii*	Cotton aphid	Adult & Nymph	vegetative stage	Major
Cicadellidae	*Empoasca fabae*	Potato Leaf Hopper	Adult & Nymph	Leaves	Minor
Cicadellidae	*Amrasca devastans*	Potato Leaf Hopper	Adult & Nymph	Leaves	Minor
Aleyrodidae	*Bemisia tabaci*	Whitefly	Adult & Nymph	Leaves	Major
Lepidoptera					
Noctuidae	*Agrotis ipsilon*	Cutworm	Larva	Leaves	Stary
Noctuidae	*Spodoptera litura*	Tobacco Caterpillar	Larva	Leaves	Minor
Coleoptera					
Scarabaeidae	*Holotrichia sp.*	White Grub	Grub	Roots and tubers	Stary
Thysanoptera					
Thripidae	*Thrips palmy*	Thrips	Adult & Nymph	vegetative stage	Stary

During both the years of study, insect-pest complexes were recorded right from the crop germination till its final harvest (Table 2). The various insect pests recorded in both the years of experimentation showed an almost similar trend of pest occurrence. During the study period, seven insect species from three different insect orders were recorded, namely Aphididae, Cicadellidae, Aleyrodidae (Hemiptera), Noctuidae, Gelechiidae (Lepidoptera), Scarabaeidae (Coleoptera), and Thripidae (Thysanoptera).

The present study revealed that the stray population of aphids was associated with the vegetative stage of the potato crop (Table 3). Both adults and nymphs of the aphid were damaging stages and caused damage to the potato plant by sucking plant sap. The activity of aphids (*Myzus persicae)* started in November and was constant up to the February month of the crop growing season. It has been reported that activity of aphids started from October through December of the crop (Bhadauri et al. 1998, Patel and Thakur 2005, Khan et al. 2009).

The activity of sucking pest whitefly, *Bemisia tabaci*, started in November and was constant up to the February in the present study. The stray population of whiteflies was associated with the vegetative stage of the potato crop. Whitefly populations are highly diverse and many biotypes have been identified globally in recent years (Chandel *et al*., 2010). Earlier, Bhatnagar (2007) and Kumar *et al.* (2017) also reported an association of Bemisia *tabaci* with the potato crop. Similarly, Kishore *et al.* (2005) studied whitefly population build up on potato crops and found it significantly high during October to the first fortnight of November with two peaks. Thereafter, it declined till the fourth week of January and attained a peak in first week of March. The maximum population of potatoes occurs in November, followed by a sharp decline by December (Chandel *et al.* 2010).

Table 3 Occurrence of pest incidence during different months of the potato crop growing season

S. No.	Order and common name	Scientific name	Month				
			Oct	Nov	Dec	Jan	Feb
	Hemiptera						
1	Aphid	*Myzus persicae*	X	X	✔	✔	✔
	Aphid	*Aphis gossypii*	✔	✔	✔	X	X
2	Potato Leaf Hopper	*Empoasca fabae*	✔	✔	✔	✔	✔
3	Whitefly	*Bemisia tabaci*	✔	✔	✔	✔	✔
	Lepidoptera						
4	Cutworm	*Agrotis ipsilon*	X	✔	✔	X	X
6	Tobacco Caterpillar	*Spodoptera litura*	X	X	X	X	✔
	Coleoptera						
7	White Grub	*Holotrichia sp.*	X	✔	✔	X	X
	Thysanoptea						
8	Thrips	*Thrips palmy.*	✔	✔	✔	X	X

The activity of the potato leaf hopper, *Empoasca fabae*, started in November and was constant up to the February month of the crop growing season. On the potato leaves, the stray population of potato leaf hoppers, *Empoasca fabae,* was observed. Mainly, the incidence of potato leaf hopper occurred in the early stages of the potato crop, causing hopper burn. It has been worked out that 70–80% hopper burn causes a 10–20% yield loss in potatoes. Both nymphs and adults suck sap from the lower side of the leaves, causing extensive damage by direct feeding on the plants. The stray population of thrips was recorded during November and December.

Cutworms are sporadic pests that have major impotence and are cosmopolitan and polyphagous in nature. They are active from October to April in the plains and during the summer in the hills. The tender sprouts/shoots of 20–40 days old are highly susceptible to cutworm damage. The stray population of cutworms was also recorded during November and December moths of the potato crop growing season. The damaging stage (larvae) of cutworm has started to cause damage to the potato crop by feeding on young potato plants and the leaves of older potato plants.

During 2018-19, from mid-November a mixed population of aphids was observed on potato plants in the range of 2.7 to 13.9 aphids per 10 plants. Interestingly, two peaks in the aphid population were observed (Table 4 and 5). The first peak occurred in mid-December with the highest population (12.5 aphid/ 10 plants) and highest peak of the aphid population (13.9 aphid/10 plants) was recorded during the last week of January. In contrast, aphid incidence in 2019–20 began in the last week of November and the aphid population ranged from 4.2 to 12.4 aphids/ten plants. Similarly, two peaks in the aphid population were also observed during this year. The first peak was observed during mid-December with the highest population (12.4 aphid/10). The second and highest peak of the aphid population (13.9 aphid/10 plants) was recorded during the third week of January. The current findings support those of Sain *et al.* (2017), who reported an aphid population appeared in the western part of Uttar Pradesh in the first week of November.

Table 4 Efficacy of insecticides against aphids on potato crops during 2018–19. Values in parentheses are square root transformed values. The DMR test finds that means with similar letters in columns are not significantly different (P = 0.05).

Treatment	Dose	Mean number of aphid /10 plants								
		1st Spray			2nd Spray			3rd Spray		
		1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS
T$_{1}$-*Thiamethoxam25 WG*	150 gm/ha	5.3^{a} (2.5)	1.7^{a} (1.7)	2.2^{a} (1.8)	3.7^{a} (2.1)	1.3^{a} (1.5)	2.2^{a} (1.8)	7.2^{a} (2.9)	1.6^{a} (1.6)	3.6^{a} (2.0)
T$_{2}$-*Imidacloprid 17.8 SL*	150 ml/ha	5.9^{a} (2.6)	2.0^{a} (1.7)	2.9^{b} (2.0)	3.9^{a} (2.2)	2.0^{b} (1.7)	2.7^{a} (1.9)	5.7^{a} (2.6)	2.9^{b} (1.9)	4.7^{b} (2.4)
T$_{3}$-*Flonicamid 50% WG*	150 ml/ha	5.8^{a} (2.5)	2.1^{a} (1.7)	2.8^{b} (1.9)	3.7^{a} (2.0)	2.2^{b} (1.7)	2.6^{a} (1.9)	6.1^{a} (2.7)	3.4^{b} (2.0)	4.8^{b} (2.4)
T$_{4}$-*Abamectin benzoate 1.9% EC*	125 ml/ha	5.3^{a} (2.7)	4.1^{c} (2.3)	4.9^{c} (2.4)	4.1^{a} (2.2)	3.0^{c} (2.0)	3.4^{b} (2.1)	7.0^{a} (2.8)	4.7^{c} (2.4)	4.8^{b} (2.3)
T$_{5}$-*Indoxacarb 14.5% SC*	250 ml/ha	5.7^{a} (2.5)	5.8^{d} (2.6)	6.5^{e} (2.7)	2.9^{a} (2.0)	5.2^{de} (2.5)	5.5^{c} (2.5)	8.1^{a} (3.0)	6.3^{d} (2.7)	8.5^{c} (3.0)
T$_{6}$-*Flubendiamide 39.35% SC*	125 gm/ha	5.9^{a} (2.5)	3.5^{b} (2.1)	5.5^{d} (2.6)	4.1^{a} (2.2)	3.0^{c} (2.0)	3.5^{b} (2.1)	6.9^{a} (2.8)	4.4^{c} (2.3)	5.5^{b} (2.5)
T$_{7}$-*Spinosad 45% SC*	150 ml/ha	5.6^{a} (2.8)	5.9^{d} (2.6)	7.9^{f} (3.0)	3.5^{a} (2.1)	4.7^{d} (2.3)	5.5^{c} (2.6)	7.1^{a} (2.9)	7.3^{e} (2.9)	9.7^{d} (3.3)
T$_{8}$-*Chlorantraniliprole 18.5% SC*	150 ml/ha	5.9^{a} (2.5)	6.0^{d} (2.6)	7.7^{f} (2.9)	4.3^{a} (2.3)	4.9^{de} (2.4)	5.5^{c} (2.5)	6.5^{a} (2.7)	7.9^{e} (2.9)	9.2^{d} (3.2)
T$_{9}$-*Control (wáter spray)*	_	5.9^{a} (2.6)	6.1^{d} (2.7)	7.7^{f} (2.9)	3.9^{a} (2.1)	5.4^{e} (2.5)	6.1^{d} (2.7)	6.8^{a} (2.8)	8.1^{f} (3.0)	9.8^{d} (3.3)
CD at 5%		N.S	0.54	0.58	N.S.	0.67	0.59	N.S.	0.65	0.89
SE(m)±		0.09	0.180	0.19	0.192	0.221	0.19	0.14	0.22	0.29

Table 5. Efficacy of insecticides against aphids on potato crops during 2019–20. Values in parentheses are square root transformed values. The DMR test finds that means with similar letters in columns are not significantly different (P = 0.05).

Treatment	Dose	Mean number of aphid / 10plants								
		1st Spray			2nd Spray			3rd Spray		
		1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS
T_1-*Thiamethoxam25 WG*	150 gm/ha	4.7 ^{a} (2.4)	1.4 ^{a} (1.6)	2.3 ^{a} (1.8)	5.5 ^{a} (2.5)	1.3 ^{a} (1.5)	1.6 ^{a} (1.6)	5.9 ^{a} (2.6)	1.3 ^{a} (1.5)	3.9 ^{a} (2.2)
T_2-*Imidacloprid 17.8 SL*	150 ml/ha	5.2 ^{a} (2.5)	1.7 ^{a} (1.6)	2.7 ^{a} (1.9)	4.1 ^{a} (2.2)	1.7 ^{a} (1.6)	2.7 ^{b} (1.9)	5.7 ^{a} (2.6)	2.8 ^{b} (1.9)	4.5 ^{ab} (2.3)
T_3-*Flonicamid 50% WG*	150 ml/ha	5.1 ^{a} (2.5)	1.7 ^{a} (1.6)	2.7 ^{a} (1.9)	4.5 ^{a} (2.3)	2.2 ^{b} (1.7)	3.3 ^{b} (2.1)	5.8 ^{a} (2.6)	3.6 ^{c} (2.1)	4.8 ^{b} (2.4)
T_4-*Abamectin benzoate 1.9% EC*	125 ml/ha	4.6 ^{a} (2.4)	3.8 ^{c} (2.2)	4.7 ^{c} (2.4)	4.6 ^{a} (2.3)	3.1 ^{c} (2.0)	4.3 ^{c} (2.3)	5.7 ^{a} (2.6)	3.9 ^{c} (2.2)	5.9 ^{c} (2.9)
T_5-*Indoxacarb 14.5% SC*	250 ml/ha	5.1 ^{a} (2.5)	5.5 ^{d} (2.5)	5.9 ^{d} (2.6)	5.4 ^{a} (2.5)	5.2 ^{d} (2.5)	7.3 ^{d} (2.9)	5.9 ^{a} (2.6)	5.3 ^{d} (2.5)	8.7 ^{d} (3.1)
T_6-*Flubendiamide 39.35% SC*	125 gm/ha	5.3 ^{a} (2.5)	3.2 ^{b} (2.0)	3.7 ^{b} (2.2)	5.0 ^{a} (2.4)	3.5 ^{c} (2.1)	3.5 ^{c} (2.1)	6.3 ^{a} (2.7)	3.6 ^{c} (2.1)	5.7 ^{c} (2.5)
T_7-*Spinosad 45% SC*	150 ml/ha	4.9 ^{a} (2.4)	5.5 ^{d} (2.6)	6.0 ^{d} (2.6)	4.9 ^{a} (2.4)	5.5 ^{d} (2.5)	7.4 ^{d} (2.9)	6.3 ^{a} (2.7)	6.4 ^{e} (2.7)	8.8 ^{d} (3.1)
T_8-*Chlorantraniliprole 18.5% SC*	150 ml/ha	5.3 ^{a} (2.5)	5.7 ^{d} (2.6)	6.1 ^{d} (2.7)	4.5 ^{a} (2.3)	5.6 ^{d} (2.6)	7.7 ^{d} (2.9)	5.3 ^{a} (2.5)	6.5 ^{e} (2.7)	8.9 ^{d} (3.1)
T_9-*Control (wáter spray)*	–	5.3 ^{a} (2.5)	5.8 ^{d} (2.6)	6.2 ^{d} (2.7)	5.3 ^{a} (2.5)	6.3 ^{e} (2.7)	7.9 ^{e} (3.0)	5.7 ^{a} (2.6)	6.7 ^{e} (2.8)	9.3 ^{d} (3.2)
CD at 5%		N.S	0.45	0.49	N.S.	0.69	0.59	N.S.	0.55	0.71
SE(m)±		0.14	0.15	0.16	0.15	0.23	0.19	0.17	0.18	0.24

Similarly, the present findings are also in agreement with those of Shrivastava *et al.* (1971), Pandey *et al.* (2007), Sarkar *et al.* (2008), and Shukla (2014), who reported peak activity of aphids during the second fortnight of January. Similarly, Panday *et al.* (2007) reported the peak activity of the aphid population during the third week of January in the Pantnagar region (India). On the contrary, Rashid *et al.* (2013) observed peak activity in the last week of February. Ghosh *et al.* (2004) reported aphid peak activity during early August in the Tarai region of West Bengal, and Meena *et al.* (2013) reported aphid activity during the first fortnight of September on Kharif potatoes.

In the present study, the first incidence of whitefly was recorded in the second week of November and ranged between 1.3-15.7 whitefly per leaf during 2018–19. The highest peak of whitefly incidence (15.7 whiteflies per 10 plants) was observed in the last week of November, during this period. Interestingly, after the highest peak during the last week of November, the whitefly population started to decline subsequently. Similarly, during 2019–20, the incidence of whiteflies also started in the first week of November, during this period Table-4.5 & 4.6. Interestingly, two peaks of whitefly population were observed during 2019–20. The whitefly population ranged between 0.87 and 13.0 whitefly/ten plants, and the first peak was observed during the first week of December with the highest population (13.00 whitefly/leaf). The second peak of the whitefly population (4.13 whiteflies per 10 plants) was recorded during the first week of February. The present findings corroborate those of Paul and Konar (2005), who reported that whiteflies first appeared on the crop during the first week of December, with a peak in the last week of December. Mathur *et al.* (2012) reported peak activity of whiteflies during the second week of January. Similarly, Rashid *et al.* (2013) and Pandey *et al.* (2007) also recorded peak activity during the third week of December. Interestingly, these findings also corroborate those of Nag (2016)**,** who recorded two peaks of whitefly during the third week of December and January. On the contrary, Oomen and Kumar (2004) observed whitefly incidence from mid-july with a peak in the first week of September.

The incidence of leafhopper was first noticed on the crop in the third week of November during 2018-19, and the leafhopper population ranged between 2.33 and 9.13 leafhoppers/10 plants during this period. The leafhopper population reached two peaks: the first during the last week of November with the highest population (9.13 leafhoppers/10), and the second during the last week of January with the lowest population

(8.33 leafhoppers/10; Table 4.3. Similarly, the incidence of leafhoppers during 2019–20 commenced during the last week of November and the leafhopper population ranged between 3.21 and 10.6 leafhoppers/ten plants during this period. Interestingly, two leafhopper population peaks were observed during 2019–20, with the first peak occurring during the first week of December and having the highest population (10.6 leafhoppers/10 plants). Whereas the second peak of the leafhopper population (5.27 leafhoppers/10 plants) was observed during the last week of January. These finding corroborates with those of Mathur *et al*. (2012) and Nag (2016) who have recorded the maximum density of leaf hoppers during December last week and during the third week of January, respectively.

The aphid population ranged from 5.27 to 5.93 aphids/10 plants in different treatments, which differed non-significantly. Data recorded on the 5th day after spraying of all the insecticidal treatments showed that they were reducing the population of aphis beyond control. Minimum numbers of aphids of 1.73 aphids per 10 plants were recorded from T1-Thiamethoxam 25WG @ 150 gm/ha, followed by T2-Imidacloprid 17.8 SL @ 150 ml/ha and T3-Flonicamid 50% WG @ 150 ml/ha, 2.00 and 2.07 aphids per 10 plants, respectively. T_1, T2, and T_3 were found to be statically on par with each other. T_1, T_2 and T_3 were followed by T6-flubendiamide 39.35% SC @125 gm/ha and T4-abamectin benzoate 1.9% EC @125 ml/ha with 3.53 and 4.13 aphids/10 plants, respectively. Whereas T7-Spinosad 45% SC @150 ml/ha and T8-Chlorantraniliprole 18.5% SC @150 ml/ha were statically non-significant and on par with control along with T9-control (water spray). On the other hand, on the 10th day after spraying of treatments, similar trends were also observed. The minimum aphid population was recorded from T1-Thiamethoxam 25WG @ 150 gm/ha, followed by T2-Imidacloprid 17.8 SL @ 150 ml/ha and T3-Flonicamid 50% WG @ 150 ml/ha, resulting in 2.20, 2.87 and 2.80 aphids/plant, respectively. T_1 was significantly different from T_2 and T_3, whereas T_2 and T_3 were statistically on par. These treatments were followed by T_4, T_6, T_5, T7, and T_8 (Table 6).

Interestingly, similar effects of insecticide treatments on the aphid population were observed during the years 2019–20. One day before spraying treatments, aphid populations were found statically non-significant in all experimental plots and ranged from 4.60 to 5.27 aphids/plants.

The minimum aphid population was recorded from T_1 (1.40 aphid/10 plants), followed by T_2 (1.67 aphid/10 plants) and T_3 (1.73 aphid/10 plants), which were statically at par. T6 and T4 recorded 3.20 and 3.80 aphids per 10 plants, respectively, while T5, T7, and T8 were statistically equivalent to the control. On the 10^{th} day after treatment, the lowest aphid population was recorded from T_1 (2.33 aphid/10 plants), followed by T_2 (2.67 aphid/10 plants), T_3 (2.73 aphid/10 plants) and T_6 (3.73 aphid/10 plants). Interestingly, T_1, T_2 and T_3 were statically at par. There was the least effect on the aphid population was observed in T_5, T7, and T_8, which were found statically at par with the aphid population in T_9 (Table 7).

Table 6. Pooled efficacy of insecticides against aphids on potato crops during study period.

Treatment	Dose	Mean number of aphid /10 plants								
		1^{st} Spray			2^{nd} Spray			3^{rd} Spray		
		1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS
T_1-*Thiamethoxam25 WG*	150 gm/ha	5.0 (2.4)	1.6 (1.6)	2.8 (1.8)	4.6 (2.3)	1.3 (1.5)	1.9 (1.7)	6.5 (2.7)	1.5 (1.6)	3.8 (2.1)
T_2-*Imidacloprid 17.8 SL*	150 ml/ha	5.5 (2.6)	1.8 (1.7)	2.8 (1.9)	4.0 (2.2)	1.8 (1.6)	2.7 (1.9)	5.7 (3.0)	2.9 (1.9)	4.6 (2.4)
T_3-*Flonicamid 50% WG*	150 ml/ha	5.5 (2.5)	1.9 (1.7)	2.8 (1.9)	3.9 (2.2)	2.2 (1.7)	2.9 (1.9)	5.9 (2.6)	3.5 (2.1)	4.8 (2.4)
T_4-*Abamectin benzoate 1.9% EC*	125 ml/ha	4.9 (2.4)	3.9 (2.2)	4.8 (2.4)	4.4 (2.3)	3.0 (2.0)	3.9 (2.2)	6.4 (2.7)	4.3 (2.3)	5.3 (2.5)
T_5-*Indoxacarb 14.5% SC*	250 ml/ha	5.4 (2.5)	5.6 (2.6)	6.2 (2.7)	4.1 (3.2)	5.2 (2.5)	6.4 (2.7)	6.9 (2.8)	5.8 (3.0)	8.6 (3.1)
T_6-*Flubendiamide 39.35% SC*	125 gm/ha	5.6 (2.5)	3.4 (2.1)	4.7 (2.4)	4.5 (2.3)	3.2 (2.0)	3.5 (2.1)	6.6 (2.8)	4.0 (2.2)	5.6 (2.5)
T_7-*Spinosad 45% SC*	150 ml/ha	5.3 (2.5)	5.7 (2.6)	6.9 (2.8)	4.2 (2.3)	4.9 (2.4)	6.5 (2.7)	6.7 (2.8)	6.9 (2.8)	9.3 (3.2)
T_8-*Chlorantraniliprole 18.5% SC*	150 ml/ha	5.6 (2.6)	5.8 (2.6)	6.9 (2.8)	4.4 (2.3)	5.2 (2.9)	6.6 (2.7)	5.9 (2.6)	7.2 (2.9)	9.0 (3.2)
T_9-*Control (wáter spray)*	–	6.5 (2.5)	6.0 (2.6)	6.9 (2.8)	4.6 (2.4)	5.9 (2.6)	7.0 (2.8)	6.2 (2.7)	7.4 (2.9)	9.5 (3.2)
CD at 5% SE(m)±		N.S 0.14	0.16 0.23	0.48 0.16	N.S 0.15	0.67 0.22	0.4 0.15	N.S 0.13	0.56 0.183	0.78 0.26

Table 7 Efficacy of whitefly insecticides on potato crop in 2019–20. Values in parentheses are square root transformed values. The DMR test finds that means with similar letters in columns are not significantly different (P = 0.05).

Treatment	Dose	Mean number of whitefly/10 plants								
		1st Spray			2nd Spray			3rd Spray		
		1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS
T_1-*Thiamethoxam25 WG*	150 gm/ha	6.13^{a} (2.67)	1.87^{a} (1.69)	2.73^{a} (1.93)	8.67^{a} (3.10)	1.93^{a} (1.69)	2.30^{a} (1.80)	8.00^{a} (2.99)	3.33^{a} (2.01)	4.27^{a} (2.20)
T_2-*Imidacloprid 17.8 SL*	150 ml/ha	6.93^{a} (2.81)	2.80^{b} (1.90)	3.20^{a} (2.05)	8.00^{a} (2.98)	2.00^{ab} (1.67)	3.67^{a} (2.15)	7.07^{a} (3.00)	3.93^{a} (2.20)	5.33^{bc} (2.49)
T_3-*Flonicamid 50% WG*	150 ml/ha	6.27^{a} (2.70)	2.33^{b} (1.80)	3.07^{a} (2.01)	7.60^{a} (2.93)	2.87^{b} (1.90)	4.13^{b} (2.26)	6.80^{a} (2.71)	3.87^{a} (2.10)	5.47^{bc} (2.46)
T_4-*Abamectin benzoate 1.9% EC*	125 ml/ha	6.07^{a} (2.66)	4.93^{c} (2.43)	5.07^{b} (2.46)	8.20^{a} (3.02)	4.93^{c} (2.43)	5.73^{c} (2.55)	7.67^{a} (2.78)	5.87^{b} (2.58)	5.47^{bc} (2.49)
T_5-*Indoxacarb 14.5% SC*	250 ml/ha	6.20^{a} (2.68)	6.67^{d} (2.77)	8.00^{ef} (3.05)	9.07^{a} (3.15)	7.40^{d} (2.89)	9.40^{d} (3.21)	8.80^{a} (2.93)	8.60^{f} (3.09)	9.20^{d} (3.19)
T_6-*Flubendiamide 39.35% SC*	125 gm/ha	6.73^{a} (2.76)	5.00^{c} (2.43)	5.87^{c} (2.16)	8.67^{a} (3.12)	4.73^{c} (2.36)	5.60^{c} (2.56)	7.73^{a} (3.09)	6.33^{b} (2.67)	6.13^{c} (2.64)
T_7-*Spinosad 45% SC*	150 ml/ha	6.40^{a} (2.72)	7.07^{de} (2.82)	7.87^{e} (2.95)	8.80^{a} (3.12)	7.40^{d} (2.89)	9.13^{d} (3.18)	7.80^{a} (3.17)	7.40^{e} (2.89)	10.40^{d} (3.37)
T_8-*Chlorantraniliprole 18.5% SC*	150 ml/ha	6.60^{a} (2.76)	7.53^{ef} (2.92)	7.33^{d} (2.88)	7.03^{a} (3.07)	8.20^{e} (3.03)	10.20^{e} (3.34)	7.13^{a} (2.79)	8.67^{f} (3.11)	9.87^{d} (3.28)
T_9-*Control (wáter spray)*	–	6.47^{a} (2.73)	7.73^{f} (2.95)	8.40^{f} (2.98)	9.00^{a} (3.14)	9.67^{f} (3.25)	10.47^{e} (3.37)	7.47^{a} (2.96)	9.07^{f} (3.17)	10.47^{d} (3.37)
CD at 5% SE(m)±		N.S 0.082	0.580 0.192	0.514 0.170	N.S. 0.119	0.699 0.231	0.638 0.211	N.S. 0.176	0.755 0.250	0.864 0.286

The leaf hopper population ranged from 4.40 to 5.07 leaf hoppers/10 plants in different treatments, which differed non-significantly (Table 8) . Data recorded on the 5th day after spraying of all the insecticidal treatments showed that they were reducing the population of leaf hoppers over control. The lowest numbers of leaf hoppers, 1.60 leaf hoppers/10 plants, were recorded from T_1 (Thiamethoxam @150 gm a.i./ha), followed by T_2 (imidacloprid @150 gm a.i./ha) and T3-Flonicamid 50% WG @ 150 ml/ha, 1.73 and 2.07 leaf hoppers/10 plants, respectively. T_1, T2, and T_3 were found to be statically on par with each other. T_1, T_2 and T_3 were followed by T4-Abamectin benzoate 1.9% EC @125 ml/ha and T6-Flubendiamide 39.35% SC @125 gm/ha with 4.07 and 4.40 leaf hopper/10 plants, respectively, whereas T5-Indoxacarb 14.5% SC @

250 ml/ha, T7-Spinosad 45% SC @ 150 ml/ha and T8-Chlorantraniliprole 18.5% SC @ 150 ml/ha were statically on par with (control) T_9. On the other hand, on the 10th day after spraying of treatments, similar trends were also observed. The lowest leaf hopper population was recorded from T_1 (Thiamethoxam @ 150 gm a.i./ha), followed by T_2 (imidacloprid @ 150 gm a.i./ha) and T_3 (Emamectin benzoate @ 125 gm a.i./ha), yielding 2.13, 2.20, and 2.0 leaf hopper/10 plants, respectively. T_2 and T_3 were statistically on par with T1. Among other treatments, a minimum population was recorded from T_4 (4.0 leaf hopper/10 plants), T_6 (4.67 leaf hopper/10 plants), T_7 (5.20 leaf hopper/10 plants), T_8 (5.93 leaf hopper/10 plants) and T_5 (6.13 leaf hopper/10 plants), respectively.

Table 8 Effectiveness of insecticides against leaf hoppers on potato crops.

Treatment	Dose	Mean number of leaf hopper/ 10 plants								
		1st Spray			2nd Spray			3rd Spray		
		1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS	1 DBS	5 DAS	10 DAS
T_1-*Thiamethoxam25 WG*	150 gm/ha	4.60 a (2.34)	1.60 a (1.60)	2.13 a (1.76)	3.20 a (2.04)	0.93 a (1.39)	2.00 a (1.70)	6.20 a (2.68)	1.93 a (1.71)	2.47 a (1.81)
T_2-*Imidacloprid 17.8 SL*	150 ml/ha	4.73 a (2.36)	1.73 a (1.62)	2.20 a (1.77)	3.53 a (2.09)	1.67 b (1.60)	2.67b (1.84)	5.00 a (2.31)	2.80b (1.94)	3.67b (2.14)
T_3-*Flonicamid 50% WG*	150 ml/ha	4.40 a (2.30)	2.07 a (1.73)	2.80 b (1.94)	3.27 a (2.05)	2.00b (1.72)	3.13b (2.02)	6.00 a (2.64)	2.93b (1.92)	4.27b (2.24)
T_4-*Abamectin benzoate 1.9% EC*	125 ml/ha	4.40 a (2.30)	4.07 b (2.25)	4.53 c (2.35)	4.00 a (2.22)	3.40c (2.07)	4.07c (2.22)	5.60 a (2.55)	4.87c (2.41)	5.27c (2.42)
T_5-*Indoxacarb 14.5% SC*	250 ml/ha	5.07 a (2.43)	5.27 c (2.49)	6.13 e (2.66)	4.13 a (2.49)	4.60d (2.34)	5.67d (2.55)	6.27 a (2.68)	6.60d (2.75)	8.73d (3.11)
T_6-*Flubendiamide 39.35% SC*	125 gm/ha	4.47 a (2.33)	4.40 b (2.32)	4.67 c (2.37)	4.07 a (2.23)	3.47c (2.09)	4.00c (2.21)	6.47 a (2.73)	5.20c (2.48)	5.33c (2.51)
T_7-*Spinosad 45% SC*	150 ml/ha	4.40 a (2.30)	5.07 c (2.43)	5.20 d (2.45)	4.13 a (2.25)	4.87d (2.35)	6.27e (2.68)	6.67 a (2.75)	6.40d (2.70)	9.33de (3.21)

T 8-*Chlorantraniliprole 18.5% SC*	150 ml/ha	4.87 [a] (2.41)	5.00 [c] (2.45)	5.93 [e] (2.62)	4.40 [a] (2.32)	5.07[e] (2.44)	6.73[e] (2.73)	6.13 [a] (2.63)	7.33[d] (2.86)	9.07[de] (3.13)
T 9-*Control (wáter spray)*	_	4.53 [a] (2.32)	5.33 [c] (2.51)	6.60 [f] (2.75)	4.87 [a] (2.37)	5.73[e] (2.59)	7.07[f] (2.81)	6.33 [a] (2.30)	7.40[e] (2.83)	9.80[e] (3.26)
CD at 5%		N.S	0.482	0.498	N.S.	0.711	0.684	N.S.	0.763	0.910
SE(m)±		0.245	0.159	0.165	0.234	0.252	0.226	0.218	0.252	0.321

Imidacloprid application (either as seed treatment or as foliar application) early in the crop season significantly suppress the population of whiteflies (*B. tabaci*) on potatoes in the present study. Khan *et al.* (2011) also reported that imidacloprid 1.6 FS and thiamethoxam 25 WG were significantly superior in suppressing the population of aphids (*M. persicae*) on potatoes by 67.79–74.92 percent, respectively. Similarly, Bhatnagar (2012) observed that imidacloprid 17.8 SL @ 0.04 % drenching was highly effective in reducing the population of thrips, whiteflies and jassid on potatoes up to 45 to 55 days after planting, which is in accordance with our present findings. Moreover, Jamshid *et al.* (2012) and Malik *et al.* (2012) reported similar results that sequential sprays of imidacloprid and thiamethoxam were effective against sucking pests of potatoes. Anand *et al.* (2013) and Gavkare et al. (2013) reported that Thiamethoxam was most effective against aphids, followed by Imidacloprid on potatoes. Similarly, Ghosal and Chatterjee (2013) observed that Imidacloprid was superior against whitefly with the lowest pest population and the highest marketable tuber yield. Bhatnagar (2013) reported that Imidacloprid as a seed treatment and spray effectively suppressed the sap feeder population in potato crops.

CONCLUSIONS

The present study determining the insect pest complex associated with potato crop and its population build-up, along with the efficacy of new group of insecticides against insect pests. The study revealed that the stray population of aphids (*Myzus persicae)* started in November and was constant up to February during both cropping years. Similarly, the activity of sucking pest whitefly (*Bemisia tabaci*) initiated in November and was constant up to the February. The activity of potato leaf hopper (*Empoasca fabae*) started in November and was constant up to the February. The stray population of cutworms was also recorded during November and December months of potato crop growing season. Similarly, the minor population of tobacco caterpillars (*Spodoptera liturawas*) was observed during the February moths of the potato crop growing season. The stray population of white grub was observed during November and December of the crop growing season. Interestingly, the stray population of thrips was also recorded during the November and February months of the potato crop growing season.

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