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Bio-efficacy, persistence and residual toxicity of greener insecticides against predominant flea beetles on cabbage crop in Kashmir

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Abstract: The flea beetles, *Phyllotreta striolata* (Fabricius, 1803) and *Altica himensis* (Shukla, 1960) (Coleoptera: Chrysomelidae: Alticinae) are one of the most serious pests of *Brassica oleracea* L. in Kashmir. In order to find eco-friendly control against these pests, bio-efficacy, persistence and residual toxicity of some newer insecticides *viz*., Emamectin benzoate 5SG @ 0.002 and 0.004 per cent, Spinosad 45SC @ 0.0035 and 0.007 per cent was evaluated against *P. striolata* and *A. himensis* infesting cabbage crop. Mortality caused by these insecticides was recorded in all the treatments. The result revealed that spinosad 45SC @ 0.007 per cent exhibited significantly lowest pest population and the highest efficacy against cabbage flea beetles. The persistence and residual toxicity of these insecticides was worked and it was found that spinosad 45SC @ at 0.007 per cent revealed the highest PT value of (346.11 & 321.43) for *P. striolata* and (299.57 & 322.38) for *A. himensis* compared to other insecticides. LT_{50} values of (4.13 & 3.38) for *P. striolata* and (3.08 & 3.84) for *A. himensis* were the highest for Spinosad 45SC @ 0.007 per cent. It was concluded that spinosad 45SC @ 0.007 per cent offers a feasible choice for the management of *P. striolata* and *A. himensis.*

Key words: bio-efficacy, persistence, residual toxicity, *Phyllotreta striolata, Altica himensis*, Spinosad 45SC, emamectin benzoate 5SG

Biološka učinkovitost, obstojnost in rezidualna toksičnost bolj zelenih insekticidov pri zatiranju prevladujočih hroščev bolhačev na zelju v Kašmirju

Izvleček: Hrošči bolhači, kot sta vrsti *Phyllotreta striolata (*Fabricius, 1803) in *Altica himensis* (Shukla, 1960) (Coleoptera: Chrysomelidae: Alticinae), so najnevarnejši škodljivci na zelju v Kašmirju. Z namenom najti okolju prijazni nadzor, biološko učinkovitost, obstojnost in rezidualno toksičnost nekaterih novih incekticidov sta bila pri zatiranju teh *škodljivcev* na zelju preiskušena emamktin benzoat 5SG @ 0,002 in 0,004 % in spinosad 45SC @ 0,0035 in 0,007 %. Smrtnost, ki sta jo povzročila ta dva insekticida je bila zabeležena pri vseh obravnavanjih. Rezultati so pokazali, da je spinosad 45SC @ 0,007 % povzročil značilno manjšo populacijo škodljivca in je imel večjo učinkovitost pri zatiranju hroščev bolhačev na zelju. Preučeni sta bili obstojnost in rezidulana toksičnost teh dveh insekticidov, pri čemer je bilo ugotovljeno, da je imel spinosad 45SC @ pri 0,007 % največjo PT vrednost (346,11 & 321,43) za vrsto *P. striolata* in (299,57 & 322,38) in za vrsto *A. himensis* v primerjavi z drugimi insekticidi. LT_{50} vrednosti (4,13 & 3,38) za vrsto *P. striolata* in (3,08 & 3,84) in za vrsto *A. himensis* so bile največje za spinosad 45SC @ 0,007 %. Zaključeno je bilo, da ponuja spinosad 45SC @ 0,007 % primerno izbiro za upravljanje s škodljivcema *P. striolata* in *A. himensis.*

Ključne besede: bio-učinkovitost, obstojnost, rezidulana toksičnost, *Phyllotreta striolata, Altica himensis,* spinosad 45SC, emamektin benzoat 5SG

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1 INTRODUCTION

Vegetables are an important component of the human diet and cruciferous crops are among the important vegetables grown in many parts of the world. Vegetables have a vital role in feeding the world population and have economic and commercial worth due to their nutritional, crop rotation, bio-industrial and biocontrol properties (Ahuja et al., 2010). Cabbage (*Brassica oleracea* var. *capitatata* L.) commonly known as Pata Kopi or Bhadha Kopi are important vegetables produced in Kashmir. Cabbage is a highly exported vegetable in Kashmir and offers a source of living to all those who are intricated in cabbage production from its cultivation till it goes to the final user. Cabbage is well-known as the king of curries and is used in salads. Several biotic and abiotic factors reduce the yield of cabbage crops. Among biotic factors, insect pests are one of the major constraints and impose severe limitations on profitable cabbage production in India. Flea beetles are one of the key insect pests that attack vegetables specifically brassicaceous crops (Feeny et al., 1970; Palinswamy and Lamb, 1992). Alticine beetles attack agricultural, horticultural, floricultural and ornamental crops. They represent an important group, as they cause enormous injury to seedlings and nibble small round holes into leaves slowing the growth of a plant and decreasing assimilation. Flea beetles in enormous number can even kill the plant in an early phase of their development and also affect the yield of a plant (Anderson & Walker, 1934; Feeny et al., 1970). The adult beetle produces massive economic damage as they feed on different plant parts including leaves and non-woody stems (Konstantinov & Tishechkin, 2004). Present crop production is reliant heavily on insecticidal application against pests in the field condition (Way and Van Embden, 1999). Management by insecticides in the world of agricultural practices has led to chemical resistance, residue problem (Mandal et al*.,* 2006), pest resurgence (Metcalf, 1994) and are harmful to natural enemies (Desneux et al*.,* 2011). At the ecosystem level, they cause loss of biodiversity (Tilman et al., 2002). On the other hand, there is an increase in the demand for residue-free food. Thus, there is a need for switching from chemical insecticides to greener insecticides. Greener insecticides are a safer choice than chemical insecticides and are eco-friendly as they remain viable in the environment for short time compared to conventional insecticides. Unlike chemical insecticides, they prevent the development of resistance (Copping & Menn, 2000). Many greener insecticides have been used for the management of pests as a substitute to conventional insecticides (Shrestha & Reddy, 2017) including flea beetles (Antwi & Reddy, 2016). The present study was aimed to evaluate the effect of some greener insecticides against flea beetles on cabbage crop both in the field and the laboratory.

2 MATERIALS AND METHODS

2.1 FIELD ASSAY

The effectiveness of greener insecticides against flea beetles on cabbage was evaluated during the year 2019-20 and 2020-21 at Mirgund, Baramulla Kashmir with latitude $34^0 13'79''$ and longitude of $74^0 65'66''$. Cabbage seedlings were sown on the 29^{th} of February 2019 and the 9^{th} of March 2020 in well-raised nursery beds. The nursery beds were irrigated regularly till transplantation. Beds were made as per the design and dimensions to start transplantation. Cabbage seedlings (F1 hybrid) were transplanted after 30 days of sowing. There were five treatments including an untreated check with four replications *viz.*, emamectin benzoate 5SG @ 0.002 and 0.004 per cent, spinosad 45SC @ 0.0035 and 0.007 per cent. In control, only water was used for investigation. The plot size for each treatment was 4 x 3 m per replication. A buffer zone of 1.25 m was maintained between different treatments. In each plot crop spacing of 50 x 50 cm was maintained. The crop was raised as per recommended packages of practices. When the flea beetle population exceeded ETL of 3 beetles/leaf, the crop was sprayed with insecticides having a spray volume of 500 l ha^{-1} using the foot-pump sprayer. For control plots, only water was used. A buffer area of 1.5 m was kept around each experimental plot to protect against possible drift during the spraying operation. The pre-count was taken one day prior to application and mortality of pests was recorded at 1, 3, 7, 14 and 21 days. Data obtained on mean per cent mortality of adult flea beetles in different treatments were subjected to statistical analysis using Analysis of Variance (ANOVA) and Duncan's Multiple Range Test (DMRT).

2.2 LABORATORY BIOASSAY

2.2.1 Leaf dip method

For determining laboratory bio-assay, untreated leaves were collected from the tagged plants. Test liquid was prepared followed by agitation. Individual leaves were dipped for 5 seconds in the insecticidal solution. The surface liquid was dried from leaves in ambient condition before placing them in Petri-plates. The stalk of leaves was covered with paraffin wax to maintain their turgidity for 24 hours of exposure. Leaf discs were placed upside down over moist filter paper in Petri-plates in a laboratory. Adult beetles were collected using an aspirator. Ten numbers of flea beetles of the same size were released on each leaf disc by using a sable brush (Fig. 1a). These Petri-plates were kept in B.O.D at 28 ± 1 ^{0}C and 70 ± 2 % relative humidity (Fig. 1b). Observations on mortality was recorded after 24 hours and continued till mortality reached less than 10 %. Mortality was assessed by tapping the insect and looking for beetle movement. The insects not able to make coordinated movements were counted as dead. Each treatment was replicated thrice. Control mortality of test insects was also observed by releasing insects on untreated leaves.

2.3 STATISTICAL ANALYSIS

2.3.1 Corrected mortality

The per cent mortality was worked out using Abbott's formula (Abbott, 1925).

$$Corrected\ \%\ mortality = \left(1 - \frac{n\ in\ T\ after\ treatment}{n\ in\ Co\ after\ treatment}\right) \times 100$$

Where *n* = no of insects
T = Treated
Co = control

2.3.2 Calculation of persistent residual toxicity

Persistent residual toxicity (PT) was determined as per the method given by Pradhan (1967) and Sarup et al. (1970). The average persistent toxicity (T) was determined by adding the values of corrected per cent mortalities of each observation and dividing the total by the total number of observations.

Persistent toxicity (PT) = Average residual toxicity x *period for which toxicity was observed*

Based on PT values the order of efficacy of each treatment was determined. Relative persistence of each insecticide was determined as per Bharti et al. (2015), by taking PT values of least toxic insecticide as unity

$$Relative\ persistence\ (RP) = \frac{PT \text{ value of insecticides}}{\text{Insecticide with lowest } PT \text{ value}}$$

2.3.3 Relative efficacy of insecticides based on PT and LT_{50} values

The relative efficacy of each insecticide based on LT_{50} and persistent toxicity (PT) values were determined. The data were subjected to probit regression analysis (Finney, 1971) for determining LT_{50} values.

3 RESULTS

3.1 BIO-EFFICACY

3.1.1 Bio-efficacy of insecticides against *Phyllotreta striolata* during 2019-20 and 2020-21

All insecticidal treatments were found significantly superior over untreated control in minimizing the pest

Figure 1a: Release of flea beetles on cabbage leaves

Figure 1b: Maintaining insects in a B.O.D incubator

population. Statistically, a non-significant difference was noted in the pre-treatment count of the flea beetle population. Perusal of the data (Table 1) revealed that the highest cumulative mean per cent mortality of 78.20 ± 18.59 was recorded in Spinosad 45SC @ 0.007 per cent, followed by 65.56 ± 24.89 @ 0.0035 per cent. Cumulative mean per cent mortality of 65.24 ± 25.17 was recorded in emamectin benzoate @ 0.004 per cent followed by 52.46 ± 17.28 @ 0.002 per cent. Untreated check (water spray) recorded the lowest cumulative mean per cent mortality of 8.36 ±3.58 per cent. All the treatments were statistically different from untreated control, whereas the treatments of emamectin benzoate 5SG @ 0.004 and spinosad 45 SC @ 0.0035 per cent were statistically at par with each other and statistically different with rest of the concentrations when tested at $p = 0.05$ at 21 days after application of treatment. However, the treatments of emamectin benzoate 5SG @ 0.002 and 0.004 per cent, spinosad 45SC @ 0.0035 and 0.007 per cent were statistically different from each other. Among the treatments, emamectin benzoate 5SG @ 0.002 and spinosad 45SC @ 0.0035 per cent were also statistically different from each other when tested at $p = 0.05$ at 21 days after application of treatment. The order of efficacy was observed as spinosad 45SC @ 0.007 per cent > spinosad 45SC @ 0.0035 per cent > emamectin benzoate 5SG @ 0.004 per cent and emamectin benzoate 5SG @ 0.002 per cent respectively.

Data recorded in (Table 2) revealed that the highest cumulative mean per cent mortality of 78.16 ± 18.29 was recorded in spinosad 45SC @ 0.007 per cent followed by 65.60 ± 18.29 @ 0.0035 per cent. Cumulative mean per cent mortality of 63.95 ± 26.29 was recorded in emamectin benzoate @ 0.004 per cent followed by 51.95 ± 17.70 @ 0.002 per cent. Untreated check (water spray) recorded the lowest pooled mean per cent mortality of 8.43 ±3.20. All the treatments were statistically different from untreated control, whereas the treatments of emamectin benzoate 5SG @ 0.004 and spinosad 45 SC @ 0.0035 per cent were statistically at par with each other and statistically different with rest of the concentrations when tested at $p = 0.05$ at 21 days after application of treatment. However, the treatments of emamectin benzoate 5SG @ 0.002 and 0.004 per cent, spinosad 45SC @ 0.0035 and 0.007 per cent were statistically different from each other. Among the treatments, emamectin benzoate 5SG @ 0.002 and spinosad 45SC @ 0.0035 per cent were also statistically different from each other when tested at $p = 0.05$ at 21 days after application of treatment. The order of efficacy was observed as spinosad 45SC @ 0.007 per cent > spinosad 45SC @ 0.0035 per cent > emamectin benzoate 5SG @ 0.004 per cent and emamectin benzoate 5SG @ 0.002 per cent respectively.

3.1.2 Bio-efficacy of insecticides against *Altica himensis* during 2019-20 and 2020-21

All insecticidal treatments were found significantly superior over untreated control in minimizing the pest population. Statistically, a non-significant difference was noted in the pre-treatment count of the flea beetle population. Perusal of the data (Table 3) revealed that the highest cumulative mean per cent mortality of 77.30 ± 19.64 was recorded in spinosad 45SC @ 0.007 per cent, followed by 69.18 ± 18.93 @ 0.0035 per cent. Cumulative mean per cent mortality of 64.12 ± 23.17 was recorded in emamectin benzoate @ 0.004 per cent followed by 54.26 ± 28.0 @ 0.002 per cent. Untreated check (water spray) recorded the lowest cumulative mean per cent mortality of 12.92 ± 5.93. All the treatments were statistically different from untreated control, whereas the treatments of emamectin benzoate 5SG @ 0.004 and spinosad 45 SC @ 0.0035 per cent were statistically at par with each other and statistically different with rest of the concentrations when tested at $p = 0.05$ at 21 days after application of treatment. However, the treatments of emamectin benzoate 5SG @ 0.002 and 0.004 per cent, spinosad 45SC @ 0.0035 and 0.007 per cent were statistically different from each other. Among the treatments, emamectin benzoate 5SG @ 0.002 and spinosad 45SC @ 0.0035 per cent were also statistically different from each other when tested at $p = 0.05$ at 21 days after application of treatment. The order of efficacy was observed as spinosad 45SC @ 0.007 per cent > spinosad 45SC @ 0.0035 per cent > emamectin benzoate 5SG @ 0.004 per cent and emamectin benzoate 5SG @ 0.002 per cent respectively.

Data recorded from (Table 4) revealed that the highest cumulative mean per cent mortality of 75.11 ± 18.43 was recorded in spinosad 45SC @ 0.007 per cent followed by 69.69 ± 18.42 @ 0.0035 per cent. Cumulative mean per cent mortality of 62.34 ± 24.54 was recorded in emamectin benzoate @ 0.004 per cent followed by 54.24 ± 26.54 @ 0.002 per cent. Untreated check (water spray) recorded the lowest pooled mean mortality of 11.42 ± 5.39. All the treatments were statistically different from untreated control, whereas the treatments of emamectin benzoate 5SG @ 0.004 and spinosad 45 SC @ 0.0035 per cent were statistically at par with each other and sta-

Table 1: Effect of different insecticides on the population of *Phyllotreta striolata* on cabbage during 2019-20

Treatment	Concentration (%)	Pretreatment count/10 leaves	Percent mortality of *Phyllotreta striolata* (Days after treatment) 1	3	7	14	21	Cumulative mean mortality (%) ± SD
Emamectin benzoate 5 SG	0.002	43.57 $ (6.60)	*24.88 **(29.92)	53.01 (46.72)	52.60 (46.49)	59.92 (50.72)	71.91 (57.99)	52.46 (± 17.28)
	0.004	44.77 (6.69)	31.95 (34.41)	48.17 (43.95)	68.58 (55.90)	85.85 (67.90)	91.66 (73.21)	65.24 (± 25.17)
Spinosad 45 SC	0.0035	45.20 (6.72)	32.63 (34.83)	48.68 (44.24)	68.82 (56.05)	86.22 (68.20)	91.46 (73.01)	65.56 (± 24.89)
	0.007	42.87 (6.55)	52.00 (46.14)	66.87 (54.85)	83.27 (65.85)	91.76 (73.32)	97.12 (80.23)	78.20 (± 18.59)
Untreated control	0	44.33 (6.66)	4.04 (11.59)	6.96 (15.29)	8.16 (16.59)	8.76 (17.21)	13.88 (21.87)	8.36 (± 3.58)
C.D ($p \leq 0.05$)		1.03	1.11	0.89	1.08	1.24	1.32	

*mean of three replications
**Figures in parenthesis indicate Arc transformed value
$ Figures in parenthesis indicate SQRT transformed value

Table 2: Effect of different insecticides on the population of *Phyllotreta striolata* on cabbage during 2020- 21

Treatment	Concentration (%)	Pretreatment count/10 leaves	Percent mortality of *Phyllotreta striolata* (Days after treatment) 1	3	7	14	21	Cumulative mean mortality (%) ± SD
Emamectin benzoate 5 SG	0.002	43.23 $ (6.58)	*23.67 **(29.24)	51.39 (45.79)	53.64 (47.08)	59.13 (50.26)	71.93 (58.00)	51.95 (± 17.70)
	0.004	44.07 (6.61)	29.50 (32.89)	45.54 (42.44)	67.70 (55.36)	85.40 (67.53)	91.60 (73.15)	63.95 (± 26.29)
Spinosad 45 SC	0.0035	45.53 $ (6.75)	32.50 (34.75)	48.98 (44.41)	69.04 (56.19)	86.24 (68.22)	91.22 (72.76)	65.60 (± 18.29)
	0.007	42.93 (6.55)	52.70 (46.55)	66.68 (54.74)	82.83 (65.52)	91.54 (73.08)	97.05 (80.11)	78.16 (± 18.29)
Untreated control	0	44.33 (6.66)	4.12 (11.71)	6.54 (14.81)	8.93 (17.38)	10.14 (18.56)	12.40 (20.61)	8.43 (± 3.20)
C.D ($p \leq 0.05$)		2.62	2.31	1.24	1.54	1.46	2.62	

*mean of three replications
**Figures in parenthesis indicate Arc transformed value
$ Figures in parenthesis indicate SQRT transformed value

tistically different with rest of the concentrations when tested at $p = 0.05$ at 21 days after application of treatment. However, the treatments of emamectin benzoate 5SG @ 0.002 and 0.004 per cent, spinosad 45SC @ 0.0035 and 0.007 per cent were statistically different from each other. Among the treatments, emamectin benzoate 5SG @ 0.002 and spinosad 45SC @ 0.0035 per cent were also statistically different from each other when tested at $p = 0.05$ at 21 days after application of treatment. The order of efficacy was observed as spinosad 45SC @ 0.007 per cent > spinosad 45SC @ 0.0035 per cent > emamectin benzoate 5SG @ 0.004 per cent and emamectin benzoate 5SG @ 0.002 per cent respectively.

Table 3: Effect of different insecticides on the population of *Altica himensis* on cabbage during 2019-20

Treatment	Concentration (%)	Pretreatment count/10 leaves	Percent mortality of *Altica himensis* (Days after treatment) 1	3	7	14	21	Cumulative mean mortality (%)± SD
Emamectin benzoate 5 SG	0.002	30.47 $ (5.52)	*25.82 **(30.53)	28.38 (32.19)	51.49 (45.85)	79.62 (63.16)	85.98 (68.00)	54.26 (± 28.0)
	0.004	29.87 (5.47)	35.03 (36.28)	48.52 (44.15)	64.17 (53.22)	80.90 (64.08)	91.97 (73.53)	64.12 (± 23.17)
Spinosad 45 SC	0.0035	34.33 (5.86)	48.64 (44.22)	54.65 (47.66)	65.34 (53.93)	84.85 (67.09)	92.43 (74.02)	69.18 (± 18.93)
	0.007	44.50 (6.67)	48.74 (44.27)	67.18 (55.05)	81.35 (64.41)	92.36 (73.95)	96.85 (79.78)	77.30 (±19.64)
Untreated control	0	30.67 (5.54)	4.97 (12.88)	9.19 (17.64)	13.76 (21.77)	16.94 (24.30)	19.76 (26.39)	12.92 (± 5.93)
C.D ($p \leq 0.05$)			2.23	2.61	1.95	1.85	1.74	

*mean of three replications
**Figures in parenthesis indicate Arc transformed value
$ Figures in parenthesis indicate SQRT transformed value

Table 4: Effect of different insecticides on the population of *Altica himensis* on cabbage during 2020- 2021

Treatment	Concentration (%)	Pretreatment count/10 leaves	Percent mortality of *Altica himensis* (Days after treatment) 1	3	7	14	21	Cumulative mean mortality (%) ± SD
Emamectin benzoate 5 SG	0.002	30.53 $ (5.52)	*25.99 **(30.65)	28.55 (32.29)	51.18 (45.67)	79.67 (63.19)	85.80 (67.86)	54.24 (± 26.54)
	0.004	33.87 (5.82)	27.34 (31.52)	50.20 (45.11)	64.47 (53.41)	81.79 (64.73)	87.89 (69.63)	62.34 (± 24.54)
Spinosad 45 SC	0.0035	34.40 (5.87)	49.23 (44.55)	55.72 (48.28)	66.48 (54.62)	84.97 (67.19)	92.05 (73.62)	69.69 (± 18.42)
	0.007	32.23 (5.68)	50.43 (45.24)	63.61 (52.89)	76.83 (61.22)	89.01 (70.63)	95.64 (77.95)	75.11 (± 18.43)
Untreated control	0	31.00 (5.54)	3.66 (11.02)	8.92 (17.37)	12.37 (20.59)	14.41 (22.30)	17.74 (24.90)	11.42 (±5.39)
C.D ($p \leq 0.05$)			1.06	2.22	2.67	1.48	1.37	

*mean of three replications
**Figures in parenthesis indicate Arc transformed value
$ Figures in parenthesis indicate SQRT transformed value

3.1.3 Persistent toxicity of various insecticides against *Phyllotreta striolata* and *Altica himensis* on cabbage

The persistent toxicity of different insecticides *viz*., emamectin benzoate @ 0.002, 0.004 per cent and spinosad @ 0.0035 and 0.007 per cent was computed revealing important data. Perusal of data (Table 5) revealed that mortality with emamectin benzoate 5SG was observed up to 8 days at both concentrations of 0.002 and 0.004 per cent. The average residual toxicity was found to be 24.74 and 30.90 for emamectin benzoate 5SG @ 0.002 and 0.004 with the persistent toxicity index of 197.94 and 247.2. The mortality with spinosad 45SC was observed up to 9 days at both concentrations of 0.0035 and 0.007 per cent. The average residual toxicity was found to be

28.56 and 38.45 for spinosad 45SC @ 0.0035 and 0.007 with the persistent toxicity index of 257.1 and 346.11. The order of relative efficacy of insecticides based on the index of persistent toxicity is 1, 2, 3 and 4 for spinosad @ 0.007, 0.0035 and emamectin benzoate @ 0.004, 0.002 per cent. Relative persistence values for emamectin benzoate @ 0.004, spinosad @ 0.0035 and 0.007 per cent were 1.24, 1.29 and 1.74 times more persistent than emamectin benzoate @ 0.002. Overall spinosad 45SC @ 0.007 was having maximum mortality against *Phyllotreta striolata* (79.32) after one day with higher persistence > spinosad 45SC @ 0.0035 (71.51) > emamectin benzoate 5SG @ 0.004 (69.20) > emamectin benzoate 5SG @ 0.002 (56.55) as depicted from (Fig. 2).

Perusal of data (Table 6) revealed that mortality with emamectin benzoate 5SG was observed up to 7 days at both concentrations of 0.002 and 0.004 per cent. The average residual toxicity was found to be 26.32 and 28.81 for emamectin benzoate 5SG @ 0.002 and 0.004 with the persistent toxicity index of 184.24 and 201.7. The mortality with spinosad 45SC was observed up to 8 and 9 days at concentrations of 0.0035 and 0.007 per cent. The average residual toxicity was found to be 29.9 and 35.71 for spinosad 45SC @ 0.0035 and 0.007 with the persistent toxicity index of 239.24 and 321.43. The order of relative efficacy of insecticides based on the index of persistent toxicity is 1, 2, 3 and 4 for spinosad @ 0.007, 0.0035 and emamectin benzoate @ 0.004, 0.002 per cent. Relative persistence values for emamectin benzoate @ 0.004, spinosad @ 0.0035 and 0.007 per cent were 1.09, 1.29 and 1.74 times more persistent than emamectin benzoate @ 0.002. Overall spinosad 45SC @ 0.007 was having maximum mortality against *P. striolata* (80.60) after one day with higher persistence > spinosad 45SC @ 0.0035 (70.60) > emamectin benzoate 5SG @ 0.004 (66.21) > emamectin benzoate 5SG @ 0.002 (60.79) as depicted from (Fig. 3).

3.1.4 Persistent toxicity of various insecticides against *Altica himensis* on cabbage during 2019-2020 and 2020-2021

Perusal of data (Table 7) revealed that mortality with emamectin benzoate 5SG was observed up to 8 days at both concentrations of 0.002 and 0.004 per cent. The average residual toxicity was found to be 20.84 and 24.86 for emamectin benzoate 5SG @ 0.002 and 0.004 with the persistent toxicity index of 166.77 and 198.89. The mortality with spinosad 45SC was observed up to 8 days at both concentrations of 0.0035 and 0.007 per cent. The average residual toxicity was found to be 29.92 and 37.44 for spinosad 45SC @ 0.0035 and 0.007 with the persistent toxicity index of 209.49 and 299.57. The order of relative efficacy of insecticides based on the index of persistent toxicity is 1, 2, 3 and 4 for spinosad @ 0.007, 0.0035 and emamectin benzoate @ 0.004, 0.002 per cent. Relative persistence values for emamectin benzoate @ 0.004, spinosad @ 0.0035 and 0.007 per cent were 1.19, 1.25 and 1.79 times more persistent than emamectin benzoate @ 0.002. Overall spinosad 45SC @ 0.007 was having maximum mortality against *A. himensis* (82.46) after one day with higher persistence > spinosad 45SC @ 0.0035 (71.32) > emamectin benzoate 5SG @ 0.004 (65.88) > emamectin benzoate 5SG @ 0.002 (56.49) as depicted from (Fig. 4).

Perusal of data (Table 8) revealed that mortality with emamectin benzoate 5SG was observed up to 8 and 7 days at a concentration of 0.002 and 0.004 per cent. The average residual toxicity was found to be 19.68 and 28.55 for emamectin benzoate 5SG @ 0.002 and 0.004 with the persistent toxicity index of 157.51 and 199.91. The mortality with spinosad 45SC was observed up to 9 days at both concentrations of 0.0035 and 0.007 per cent. The average residual toxicity was found to be 27.95 and 35.82 for spinosad 45SC @ 0.0035 and 0.007 with the persistent toxicity index of 251.55 and 322.38. The order of relative efficacy of insecticides based on the index of persistent toxicity is 1, 2, 3 and 4 for spinosad @ 0.007, 0.0035 and emamectin benzoate @ 0.004, 0.002 per cent. Relative persistence values for emamectin benzoate @ 0.004, spinosad @ 0.0035 and 0.007 per cent were 1.26, 1.59 and 2.04 times more persistent than emamectin benzoate @ 0.002. Overall spinosad 45SC @ 0.007 was having maximum mortality against *A. himensis* (80.11) after one day with higher persistence > spinosad 45SC @ 0.0035 (69.79) > emamectin benzoate 5SG @ 0.004 (68.11) > emamectin benzoate 5SG @ 0.002 (55.00) as depicted from (Fig. 5).

Table 5: Persistent residual toxicity of different insecticides against *P. striolata* on cabbage during 2019-20

Insecticide	Concentration %	Corrected percent mortality									P	ART	PT	ORE	RP
		(Days after treatment)													
		1	2	3	4	5	6	7	8	9					
Emamectin benzoate 5 SG	0.002	56.55	46.20	34.21	22.31	18.60	13.62	4.83	1.62	0	8	24.74	197.94	4	1
Emamectin benzoate 5 SG	0.004	69.20	58.79	42.10	35.94	20.01	14.76	5.46	1.01	0	8	30.90	247.27	3	1.24
Spinosad 45 SC	0.0035	71.51	53.65	46.42	32.41	22.21	17.79	8.02	3.3	1.79	9	28.56	257.10	2	1.29
Spinosad 45 SC	0.007	79.32	72.49	64.06	56.39	38.79	21.02	9.26	3.67	1.11	9	38.45	346.11	1	1.74

P = Period for which toxicity
ART = Average residual toxicity
PT = Index of persistent toxicity
ORE = Order of relative efficacy based on PT values

Table 6: Persistent residual toxicity of different insecticides against *P. striolata* on cabbage during 2020-21

Insecticide	Concentration %	Corrected percent mortality									P	ART	PT	ORE	RP
		(Days after treatment)													
		1	2	3	4	5	6	7	8	9					
Emamectin benzoate 5 SG	0.002	60.79	48.10	35.94	20.01	11.79	5.46	2.20	0	0	7	26.32	184.24	4	1
Emamectin benzoate 5 SG	0.004	66.21	50.11	39.78	21.75	14.26	7.11	2.49	0	0	7	28.81	201.71	3	1.09
Spinosad 45 SC	0.0035	70.60	59.79	42.79	30.01	20.48	11.20	3.36	1.01	0	8	29.90	239.24	2	1.29
Spinosad 45 SC	0.007	80.60	68.14	56.56	48.20	34.11	20.70	10	2.11	1.01	9	35.71	321.43	1	1.74

P = Period for which toxicity
ART = Average residual toxicity
PT = Index of persistent toxicity
ORE = Order of relative efficacy based on PT values

Table 7: Persistent residual toxicity of different insecticides against *A. himensis* on cabbage during 2019-20

Insecticide	Concentration %	Corrected percent mortality									P	ART	PT	ORE	RP
		(Days after treatment)													
		1	2	3	4	5	6	7	8	9					
Emamectin benzoate 5 SG	0.002	56.49	40.48	31.79	17.89	10.02	5.88	3.11	1.11	0	8	20.84	166.77	4	1
Emamectin benzoate 5 SG	0.004	65.88	56.23	36.49	22.49	12.11	3.46	1.23	1.00	0	8	24.86	198.89	3	1.19
Spinosad 45 SC	0.0035	71.32	51.23	42.32	23.82	12.11	6.23	1.42	1.01	0	8	26.18	209.49	2	1.25
Spinosad 45 SC	0.007	82.46	70.03	58.79	41.36	29.18	11.32	5.32	1.11	0	8	37.44	299.57	1	1.79

P = Period for which toxicity
ART = Average residual toxicity
PT = Index of persistent toxicity
ORE = Order of relative efficacy based on PT values

Table 8: Persistent residual toxicity of different insecticides against *A. himensis* on cabbage during 2020-21

Insecticide	Concentration %	Corrected percent mortality									P	ART	PT	ORE	RP
		(Days after treatment)													
		1	2	3	4	5	6	7	8	9					
Emamectin benzo-ate 5 SG	0.002	55.00	38.40	31.20	12.11	10.00	6.46	3.11	1.23	0	8	19.68	157.51	4	1
Emamectin benzo-ate 5 SG	0.004	68.11	50.03	39.63	24.11	11.11	5.83	1.09	0	0	7	28.55	199.91	3	1.26
Spinosad 45 SC	0.0035	69.79	58.11	52.41	32.76	17.11	14.23	4.5	1.63	1.01	9	27.95	251.55	2	1.59
Spinosad 45 SC	0.007	80.11	72.56	64.30	47.86	29.11	18.14	6.83	2.46	1.01	9	35.82	322.38	1	2.04

P = Period for which toxicity
ART = Average residual toxicity
PT = Index of persistent toxicity
ORE = Order of relative efficacy based on PT values

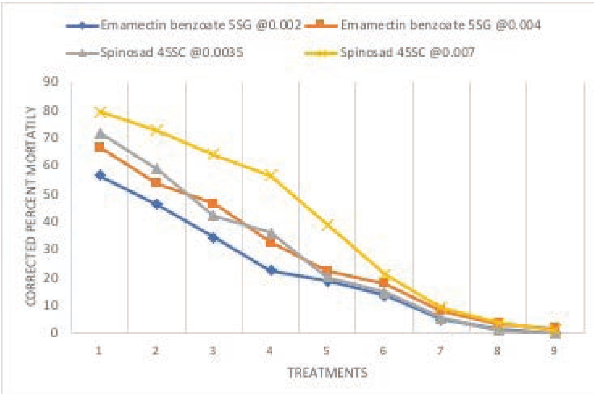

Figure 2: Persistence of toxicity of different insecticides in terms of corrected per cent mortality of P. striolata on cabbage during 2019-20

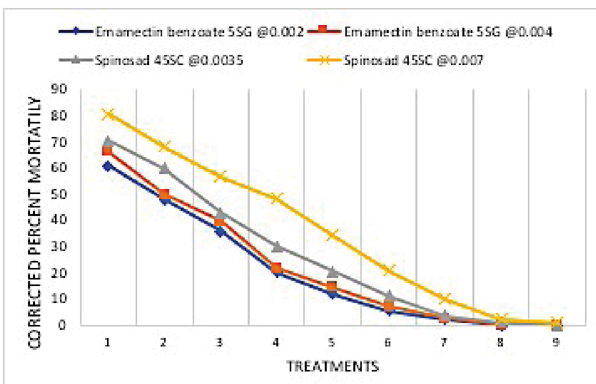

Figure 3: Persistence of toxicity of different insecticides in terms of corrected per cent mortality of P. striolata on cabbage during 2020-21

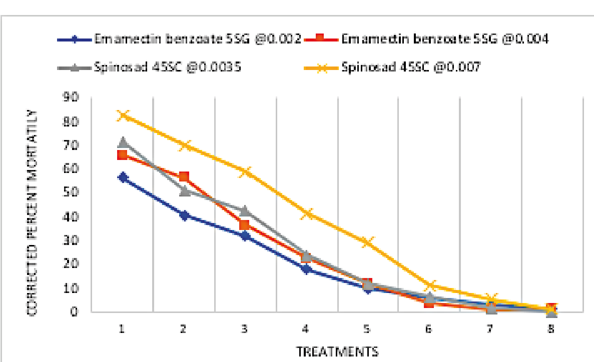

Figure 4: Persistence of toxicity of different insecticides in terms of corrected per cent mortality of A. himensis on cabbage during 2019-20

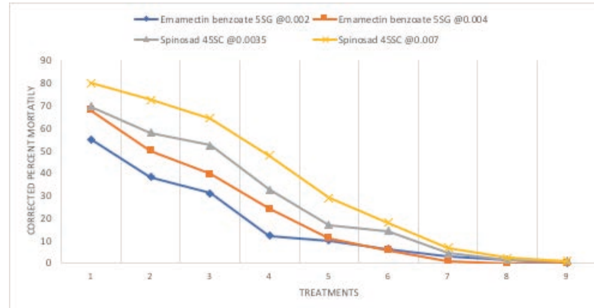

Figure 5: Persistence of toxicity of different insecticides in terms of corrected per cent mortality of A. himensis on cabbage during 2020-21

3.2 LT_{50} VALUES

3.2.1 LT_{50} of various insecticides against *P. striolata* on cabbage during 2019-2020 and 2020-2021

From Table 9 it is clear that during 2019-2020, residual toxicity in terms of LT_{50} values for *P. striolata* was found to be the highest for spinosad 45SC @ 0.007 per cent (4.13) > spinosad 45SC @ 0.0035 (2.26) > emamectin benzoate 5SG @ 0.002 (2.17) > emamectin benzoate 5SG @ 0.004 (1.88). From Table 10 it is clear that during 2020-2021 residual toxicity in terms of LT_{50} values for *P. striolata* was found to be the highest for spinosad 45SC @ 0.007 (3.38) > spinosad 45SC @ 0.0035 (2.40) > emamectin benzoate 5SG @ 0.002 (2.10) > emamectin benzoate 5SG @ 0.004 (1.99). Overall spinosad 45SC @ 0.007 per cent had maximum LT_{50} against *P. striolata.*

3.2.2 LT_{50} of various insecticides against *Altica himensis* on cabbage during 2019-2020 and 2020-2021

From Table 11 it is clear that during 2019-2020, residual toxicity in terms of LT_{50} values for *A. himensis* was found to be the highest for spinosad 45SC @ 0.007 (3.08) > spinosad 45SC @ 0.0035 (1.97) > emamectin benzoate 5SG @ 0.004 (1.88) > emamectin benzoate 5SG @ 0.002 (0.92). From Table 12 it is clear that during 2020-2021, residual toxicity in terms of LT_{50} values for *A. himensis* was found to be the highest for spinosad 45SC @ 0.007 (3.84) > spinosad 45SC @ 0.0035 (3.05) > emamectin benzoate 5SG @ 0.004 (1.99) > emamectin benzoate 5SG @ 0.002 (0.92). Overall spinosad 45SC@ 0.007 per cent had maximum LT_{50} against *A. himensis.*

Table 9: Residual toxicity in terms of LT_{50} value of different insecticides against *P. striolata* on cabbage during 2019-20

Insecticide	y = a + bx	LT_{50}	LT_{50}	95% of Confidential limit	R	R^2	x^2
	Regression equation	(in hours)	(in days)	(Lower-upper limit)	(Correlation coefficient)	(Coefficient of determination)	Chi-square
Emamectin benzoate 5 SG 0.002 %	y = 265-71.5x	52.31	2.17	39.41-59.75	-0.962	0.925	2.72
Emamectin benzoate 5 SG 0.004 %	y = 251-45.2x	45.21	1.88	35.21-52.3	-0.922	0.972	3.12
Spinosad 45 SC 0.0035 %	y = 296-71.3x	54.36	2..26	46.58-67.28	-0.922	0.886	2.56
Spinosad 45 SC 0.007 %	y = 238-42.6x	99.2	4.13	75.26-109.38	-0.961	0.971	2.99

*Significant at $p \leq 0.004$

Table 10: Residual toxicity in terms of LT_{50} value of different insecticides against *P. striolata* on cabbage during 2020-21

Insecticide	y = a + bx	LT_{50}	LT_{50}	95% of Confidential limit	R	R^2	x^2
	Regression equation	(in hours)	(in days)	(Lower-upper limit)	(Correlation coefficient)	(Coefficient of determination)	Chi-square
Emamectin benzoate 5 SG 0.002 %	y = 280-70.5x	50.61	2.10	39.26-62.76	-0.971	0.92	2.76
Emamectin benzoate 5 SG 0.004 %	y = 232-64.7x	47.98	1.99	40.12-58.36	-0.924	0.918	3.03
Spinosad 45 SC 0.0035 %	y = 298-73.6	57.68	2.40	45.23-69.27	-0.923	0.899	2.63
Spinosad 45 SC 0.0007 %	y = 286-73.2x	81.32	3.38	70.11-90.20	-0.992	0.926	2.83

*Significant at $p \leq 0.004$

Table 11: Residual toxicity in terms of LT_{50} value of different insecticides against *A. himensis* on cabbage during 2019-20

Insecticide	y = a + bx	LT_{50}	LT_{50}	95% of Confidential limit	R	R^2	x^2
	Regression equation	(in hours)	(in days)	(Lower-upper limit)	(Correlation coefficient)	(Coefficient of determination)	Chi-square
Emamectin benzoate 5 SG 0.002 %	y = 299-86x	22.16	0.92	16.46-33.26	-0.912	0.992	3.12*
Emamectin benzoate 5 SG 0.004 %	y = 246-94x	45.29	1.88	36.22-52.11	-0.991	0.926	2.93*
Spinosad 45 SC 0.0035 %	y = 301-76x	47.29	1.97	39.26-57.88	-0.988	0.992	3.03*
Spinosad 45 SC 0.007 %	y = 265-74.6x	74.12	3.08	60.22-86.99	-0.972	0.899	2.78*

*Significant at $p \leq 0.004$

Table 12: Residual toxicity in terms of LT_{50} value of different insecticides against *A. himensis* on cabbage during 2020-21

Insecticide	y = a + bx	LT_{50}	LT_{50}	95% of Confidential limit	R	R^2	x^2
	Regression equation	(in hours)	(in days)	(Lower-upper limit	(Correlation coefficent)	(Coefficent of determination)	Chi-square
Emamectin benzoate 5 SG 0.002 %	y = 269-70.2x	22.29	0.92	15.96-37.29	-0.932	0.901	3.00*
Emamectin benzoate 5 SG 0.004 %	y = 282-81x	47.99	1.99	33.26-56.76	-0.906	0.902	2.89
Spinosad 45 SC 0.0035 %	y = 301-85.29x	73.20	3.05	60.52-86.29	-0.907	0.932	3.12
Spinosad 45 SC 0.007 %	y = 236-41.3x	92.29	3.84	81.16-98.11	-0.988	0.977	2.97

*Significant at $p \leq 0.004$

4 DISCUSSION

In the present study, the greener insecticides employed for the control of flea beetles, *viz*., spinosad 45 SC and emamectin benzoate 5 SG were the promising treatments compared to control. Although greener insecticides have been used elsewhere for the control of flea beetles, nevertheless no work has been done for evaluation of these newer insecticides against *Phyllotreta striolata* and *Altica himensis* on cabbage crop in Kashmir. In the present investigation, it was found that spinosad 45SC @ 0.007 per cent caused the highest per cent mortalities of 78.20 and 78.16 per cent against *Phyllotreta striolata* and 77.30 and 75.11 per cent against *Altica himensis* during 2019-2020 & 2020-21 respectively. Spinosad 45SC @ 0.0035, emamectin benzoate 5SC @ 0.004 and emamectin benzoate 5SC @ 0.002 per cent were next effective treatments. This promising activity of spinosad 45 SC @ 0.007 per cent was supported by findings of Brickle et al. (2001), Ahmed et al. (2004) and Jat et al. (2017) who evaluated same insecticide at different concentrations against different insect pests and found that spinosad was an effective pest control agent. Earlier studies are in line with the present study as Meena & Raju (2014) investigated the efficacy of spinosad 45 SC, profenophos 5 EC, fipronil 5 SC and indoxacarb 14.5 SC against *H. armigera* in India and found that spinosad 45 SC was significantly superior to all used treatments and was best and most effective treatment. These results are in agreement with the findings of Kumar et al., (2008) who reported that spinosad was most toxic to *Erias vitelli* when compared with emamectin benzoate.

Persistent residual toxicity of spinosad 45SC @ 0.007 & 0.0035 per cent and emamectin benzoate @ 0.002 & 0.004 per cent was studied against *Phyllotreta striolata* and *Altica himensis*. The study revealed that the highest persistent toxicity of 346.11 & 321.43 and 299.57 & 322.38 was observed for spinosad 45SC @ 0.007 per cent against *P. striolata* and *A. himensis* during 2019-2020 and 2020-21, followed by spinosad 45SC @ 0.0035, emamectin benzoate 5SG @ 0.004 and emamectin benzoate 5SG @ 0.002 percent. However, the results are more or less in conformity with studies of Dake et al. (2017) and Deole et al. (2018) who reported similar results. Our findings showed that spinosad 45 SC @ 0.007 per cent persisted in cabbage crop from 8- 9 days at low and high doses and has the highest PT and LT_{50} values. Sharma et al., (2007) also reported that spinosad persisted in cabbage and cauliflower up to 7 and 10 days, respectively following spinosad application at lower and higher doses. Present studies are in conformity with Shinde et al. (2010) who concluded that on the basis of PT values, spinosad 0.005 % (1026.2) was effective. During the present investigation, spinosad 0.007 per cent was having the highest LT_{50} values of (4.13 & 3.38) against *P. striolata* and (3.08 & 3.84) against *A. himensis* during two years of study. Studies are in line with McLeod et al. (2002) who found that LT_{50} values for thiamethoxam, chlorfenapyr and spinosad against eggplant flea beetle were 1.8, 3.0 and 3.6 respectively. Our study revealed that spinosad 45SC @ 0.007 per cent resulted in maximum mortalities of 79.32, 80.60 against *Phyllotreta striolata* and 82.46, 80.11 against *Altica himensis* after one day of spray and persisted up to 9 days. This is in conformity with McLeod et al., (2011) who found that spinosad is toxic to eggplant flea beetle and found significant mortality of flea beetles after one day of spray. Mortality of beetles on treated foliage declined to 65 % one day after treatment and continued to drop to 63 % after 6 days indicating that activity of chemical had degraded within one week. These results suggested that spinosad 0.007 per cent has great potential for the management of *Phyllotreta striolata* and *Altica himensis* on cabbage crop and could be used as eco-friendly alternative to chemical control.

5 CONCLUSIONS

The use of chemical insecticides against insect pests is the main cause of environmental pollution and the death of natural enemies. The present study was thus aimed to evaluate the use of newer greener insecticides against predominant flea beetles on cabbage crops. There was a shift from chemical to greener insecticides. Control through spinosad 45 SC @ 0.007 per cent proved to be an effective approach against *P. striolata* and *A. himensis* on cabbage crop. The persistence and residual toxicity of greener insecticides was also studied, indicating an effective period over which greener insecticide could persist in the field. The present study would provide insight to make future investigations and also reduces the practice of using toxic chemicals for insect pest control of major crops.

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