Journal of
Food Chemistry & Nanotechnology

https://doi.org/10.17756/jfcn.2025-200

Research Article

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Dissipation Dynamics of Various Insecticides and Their Impact on the Quality Attributes of Brinjal

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Received: March 01, 2025
Accepted: March 27, 2025
Published: March 31, 2025

Citation: Thakur V, Mal D, Bhatta S, Gharde SK, Soga K, et al. 2025. Dissipation Dynamics of Various Insecticides and Their Impact on the Quality Attributes of Brinjal. *J Food Chem Nanotechnol* 11(1): 36-41.

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Abstract

A field investigation was carried out in the main research farm at department of vegetable science, Lovely Professional University Phagwara, Punjab in the year of 2024 to 2025 to determine the dissipation pattern of synthetic insecticides on leaves using reversed-phase high-performance liquid chromatography (RP-HPLC) (Shimadzu), fully equipped with a refractive index (RI) and photodiode array (PDA) detector and their impact on the quality characteristics of brinjal. The study included different insecticidal treatments applied at recommended dosages: T_0 (Control), T_1 (Cartap hydrochloride 50% SP at 500 grams (g) a.i./hectare (ha)), T_2 (Chlorpyrifos 20% EC at 200 g a.i./ha), T_3 (Deltamethrin 2.8% EC at 15 g a.i./ha). The experiment was performed using a randomized block design with three replications. The highest initial deposits (1.91 mg/kg) were found in treatment T_2, followed by treatment T_1 and T_3 (1.62 mg/kg and 1.17 mg/kg), respectively. The treatment T_3 degraded rapidly within 7 days as compared to other treatments. The dissipation rates for different pesticides were observed as T_1 was 33.66% after one day which was increased to 96.58% on tenth day, similarly for T_2 and T_3 the initial dissipation was 31.70% and 42.35% which increased to 97.04% and 93.11% on 12th and 7th day of application. Analysis of data revealed that the application of different treatments found a non-significant effect on quality characteristics of brinjal fruit. The maximum total soluble solids (TSS) (3.79 °Brix), titratable acidity (0.58%), crude protein (1.76%), and chlorophyll content (44.27%) was found in T_0, compared to other treatments. The findings concluded that insecticides applied at recommended dosages degraded within 7 - 15 days intervals from leaves of brinjal and found negligible impact on quality characteristics of brinjal.

Keywords

Reversed-phase high-performance liquid chromatography, Eggplant, Brinjal, Crude protein

Introduction

Brinjal, or eggplant (*Solanum melongena* L.), is a significant solanaceous vegetable that is commercially grown in India and is often referred to as the 'king of vegetables'. India ranks as the world's second-largest producer of vegetables, after China, largely due to brinjal. In India, about 12.99 million metric tons of brinjal are produced from 0.683 million ha of land [1]. Eggplant is cultivated at 168.37 thousand ha in West Bengal, and as the leading producing state, it contributes a total production of 3097.93 thousand metric tons [1]. Eggplant contains potassium, a vital element that is necessary for ensuring electrolyte balance in humans. As a result, it helps mitigate the effects of sodium and supports blood pressure

regulation. Meanwhile, biotic stress, particularly from insect pests, poses severe challenges for brinjal cultivation, contributing to large yield losses and quality deterioration. Various insects and pests, such as shoot and fruit borers, aphids, whiteflies, mites, stem borers and Epilachna beetles, are responsible for severe crop damage and yield losses of 70 - 80% globally [2]. Among them, the shoot and fruit borer, scientifically known as *Leucinodes orbonalis*, is an important insect pest that contributes to yield losses of about 3 - 6 tons/ha [3]. The main strategy for reducing the infestation of these insect pests has been the adoption of various chemical-based pesticides [3]. Eggplant was protected by spraying approximately 4.6 kg a.i./ha per season [4]. After chili, which used almost 5.13 kg of pesticides, it was the most sprayed quantity among vegetable crops [5].

In recent years, agricultural pesticides have become one of the most effective tools for protecting crops [6]. Farmers, however, frequently spray chemical pesticides in order to combat the attacks of various insect pests in brinjal without adopting recommended waiting period for brinjal [7]. Enviro-news Forum reported an estimate of 1 million deaths every year because of widespread pesticide spraying [8]. Pesticides have severe adverse impacts on human health, particularly for those working in the agricultural industry. Genetic toxicity associated with the chronic effects of pesticides is a major contributing factor to long-term health issues like cancer, whereas acute pesticide exposure leads to symptoms such as convulsions, rashes, and gastrointestinal disorders. A broad spectrum of mental health problems, such as dizziness, headaches, tiredness, nausea, weakness, chest tightness, breathing difficulties, lack of sleep, and confusion, has been associated with pesticide poisoning [9]. Insecticides containing carbamates and organophosphorus compounds are still considered significant pesticides, as they can be used to control insect-borne illnesses in addition to reducing insect infestations. Since carbamates are highly soluble, their widespread application contaminates not only food but also water bodies, as they leach out from the soil, harming both aquatic and human life [8].

The biochemical attributes of eggplant may be influenced by the frequent application of these insecticides. It has been previously documented that pesticides affect the levels of sugars, acids, and potentially other components that may impact flavor [10]. Another study reported that the fruits of eggplant had lower levels of total soluble sugars, percent acidity, and TSS, but higher levels of ascorbic acid due to insecticide residues [10]. The proper assessment and estimation of insecticide residues in vegetables play an important role in protecting consumer health [11]. Nonetheless, there is a lack of knowledge regarding the residues of several pesticides in brinjal grown in India, particularly in Punjab, which is crucial for protecting the ecosystem and consumers. To ensure the safety of the environment and humans, the recent study was conducted to assess the dissipation pattern of insecticides from different groups and their influence on brinjal quality characteristics.

Materials and Method

The field investigation was carried out in the main agricultural farm at Department of Vegetable Science, Lovely Professional University, Phagwara, during the kharif season of 2024 - 2025. Using the navkiran variety, the study was conducted in a randomized complete block design with three replications. The experiment included three insecticidal treatments along with an untreated control: T_0 (Control), T_1 (Cartap hydrochloride at 500 g a.i./ha), T_2 (Chlorpyrifos at 200 g a.i./ha), T_3 (Deltamethrin at 15 g a.i./ha). In July 2024, brinjal seedlings were transplanted using a randomized block design with a plant spacing of 60 × 45 cm over an area of 349.8 m^2. The seedlings were acclimated by gradually reducing irrigation and shade before being moved to the main field. The crop was cultivated using optimal NPK dosage and recommended agronomic practices. The prescribed fertilizer treatments included urea (271.81 kg/ha), single super phosphate (SSP) (383.01 kg/ha), and muriate of potash (49.42 kg/ha), providing 122.5 kg/ha of N, 61.8 kg/ha of P_2O_5, and 29.65 kg/ha of K_2O. The following fertilization rates are generally recommended for cultivating brinjal under Punjab conditions. Insecticidal treatments were applied when the insect population reached the economic threshold level. Five healthy plants were selected randomly to determine the quality characteristics of brinjal fruit. The first spray was applied after the appearance of insect pests, followed by the second spray and third spray at a 15-day interval. Leaf samples from different brinjal plants were collected from each plot at 0 (after 2 h), 1st, 3rd, 5th, 7th, 10th, and 15th day after the third spray.

Residual analysis of brinjal leaves

Recovery study

Laboratory recovery studies validated the efficiency of the extraction and purification processes, as well as the accuracy of the analytical technique used. 10 mL of analytical pesticide solution containing concentrations of 0.01, 0.10, and 0.20 mg/kg were added to 25 g of properly chopped eggplant leaves, thoroughly mixed, and left for 15 min. The method described by Pandit et al. [12] was used to extract, purify, and quantify pesticide residues in the fortified samples. The limit of detection was estimated by determining the lowest concentration of the insecticide standard. The recovery percentage was determined using the equation below

$$Recovery\ percentage = \frac{Extracted\ amount\ (mg/kg)}{Added\ amount\ (mg/kg)} \times 100$$

Extraction, clean up and estimation

A 25 g representative brinjal field sample was extracted with 100 mL of acetonitrile and homogenized for 2 - 3 min. After preliminary filtration, an additional 50 mL of acetonitrile was added and filtered. The filtrate was mixed with 500 mg of activated charcoal, shaken for 30 min, then filtered using grade 1 filter paper and concentrated to 5 mL via rotary vacuum evaporation. It was partitioned in a separating funnel with 50 mL hexane and 50 mL saturated NaCl solution. The aqueous layer was collected, extracted 3 times with 50 mL dichloromethane, and collected over a bed of anhydrous Na_2SO_4. The sample was then evaporated using a rotary vacuum evaporator, reconstituted in HPLC-grade acetonitrile, filtered through a 0.22 µm membrane and adjusted to 5 mL. Residual analysis was performed on RP-HPLC (Shimadzu) with an RI and PDA detector, a C_{18} column and an acetonitrile-water

(70:30) mobile phase at an isocratic flow rate. Retention times for cartap hydrochloride, chlorpyrifos, and deltamethrin were 10.46, 8.10, and 8.60 min, respectively.

Insecticide residues were determined by the method suggested by Ahmed et al. [13] using the following equation:

$$Residues\left(mg/kg\right)=\frac{C-V}{W}$$

Where: C = concentration of volume injected (mg/kg); V = final volume obtained (ml); and W = weight of sample taken (kg).

The rates of dissipation were estimated using the following equation:

$$Rate\ of\ Dissipation=1-\frac{Initial\ Deposit-Concentration\ at\ Different\ Days}{Initial\ Deposit}\times 100$$

Quality characteristics

Fruit samples were collected for juice extraction, and TSS was measured using a digital refractometer and expressed as °Brix. The titratable acidity was determined using titration with a standard solution of NaOH as given by Kandoliya et al. [14]. The crude protein was estimated to be using micro Kjeldahl approach [15] and calculated by multiplying the nitrogen content by 6.25 factor. The chlorophyll content of leaves was determined using a soil plant analysis development (SPAD 502) chlorophyll meter.

Statistical analysis

Using SPSS (Version 25.0) and OPSTAT statistical software, an analysis of variance was conducted with post-hoc testing using Duncan's multiple range test. The criteria for statistical significance were set at a probability level of $p < 0.05$ [16]. The residual data are presented as mean ± standard deviation (SD). The results of the residual analysis are given in mg/kg.

Results and Discussion

Recovery study

The residues of different pesticides were quantified using HPLC method. The method's validation was established by fortifying leaf samples at various concentration levels. The percentage recoveries in the T_1 ranged from 75.33 - 88.17%. Similarly, in T_2, recoveries varied between 75.33 - 88.17%. Additionally, the T_3 showed percentage recoveries ranging from 75.33 - 88.17% across various substrates, which was considered valid for further analysis (Table 1). The linearity of different pesticidal treatments was determined, and it was observed that treatments T_1, T_2 and T_3 exhibited linearity at concentrations ranging from 0.02 to 2.56 ppm, as shown in figure 1, figure 2, and figure 3. The limit of quantification was determined to be 0.05 mg/kg, while the detection limit was 0.01 mg/kg.

Table 1: Recovery percentage of different pesticides residues from brinjal leaves.

Pesticide	Amount fortified (mg/kg)	Percent recovery (Mean ± SD)
T_1 (Cartap hydrochloride 50% SP)	0.01	83.67 ± 2.52
	0.10	88.80 ± 1.59
	0.20	95.17 ± 2.36
T_2 (Chlorpyrifos 20% EC)	0.01	86.40 ± 1.71
	0.10	85.93 ± 6.71
	0.20	94.68 ± 0.74
T_3 (Deltamethrin 2.8% EC)	0.01	88.00 ± 1.00
	0.10	89.87 ± 1.55
	0.20	96.33 ± 1.04

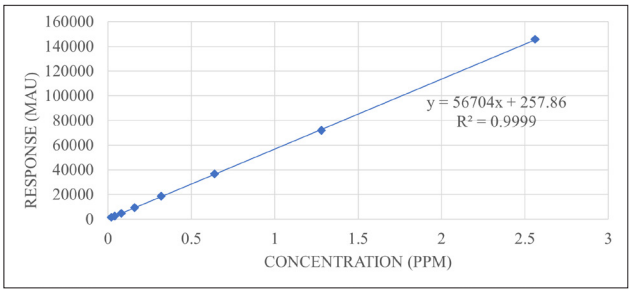

Figure 1: Linearity curve of chlorpyrifos at different concentrations.

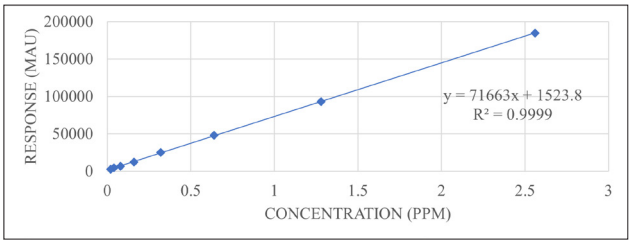

Figure 2: Linearity curve of deltamethrin at different concentrations.

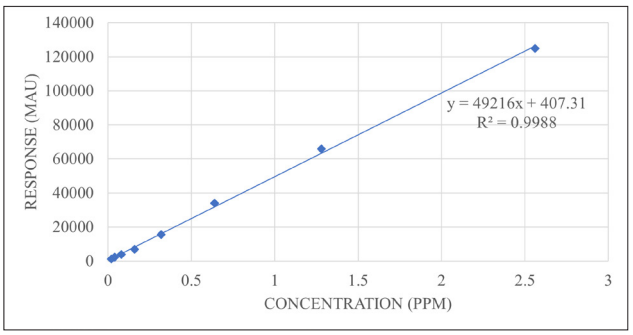

Figure 3: Linearity curve of cartap hydrochloride at different concentrations.

Dissipation rates of insecticides in brinjal leaves

Cartap hydrochloride

The results of the HPLC residual analysis of cartap hydrochloride are presented in table 2 and figure 4. Data on cartap hydrochloride residues in brinjal field leaves recorded over different days indicated that the initial deposit of 1.62 mg/kg was observed on 0 day (2 h after application) as declined to 1.07, 0.73, 0.36 and 0.06 mg/kg on the 3rd, 5th, 7th and 10th day after treatments, respectively, during 2024. The dissipation rates were 33.66%, 54.76%, 77.58%, and 96.58% on the 3rd, 5th, 7th and 10th day, respectively (Table 2 and figure 5). Furthermore, the data indicated that cartap hydrochloride, when applied at the optimum dosage, decreased below determination limit (BDL) by the 12th day post-application. The maximum residue limit (MRL) for cartap hydrochloride

Table 2: Dissipation rate and residues of different pesticides from brinjal leaves.

Treatment dose	Days after application	Residue (mg/kg)	Dissipation (%)
T_1 (Cartap hydrochloride 50% SP)	0 (2 h)	1.62 ± 0.04	-
	3	1.07 ± 0.06	33.66 ± 5.41
	5	0.73 ± 0.05	54.76 ± 1.91
	7	0.36 ± 0.02	77.58 ± 0.42
	10	0.06 ± 0.02	96.58 ± 1.40
	12	BDL	-
T_2 (Chlorpyrifos 20% EC)	0 (2 h)	1.91 ± 0.04	-
	3	1.31 ± 0.03	31.70 ± 0.89
	5	0.84 ± 0.09	56.13 ± 3.91
	7	0.54 ± 0.05	71.96 ± 2.50
	10	0.20 ± 0.06	89.70 ± 3.08
	12	0.06 ± 0.01	97.04 ± 0.29
	15	BDL	-
T_3 (Deltamethrin 2.8% EC)	0 (2 h)	1.17 ± 0.04	-
	3	0.67 ± 0.07	42.35 ± 4.65
	5	0.28 ± 0.03	75.93 ± 3.31
	7	0.08 ± 0.02	93.11 ± 1.93
	10	BDL	-

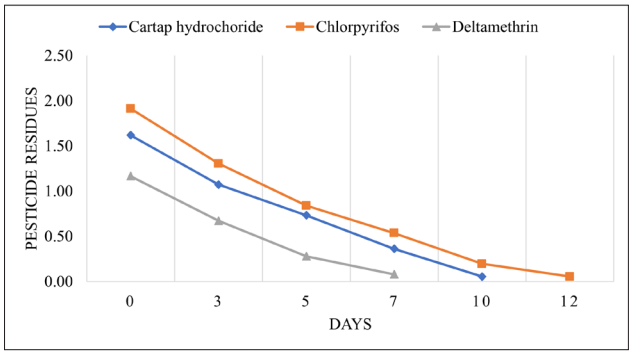

Figure 4: Residues of different pesticides at different days interval.

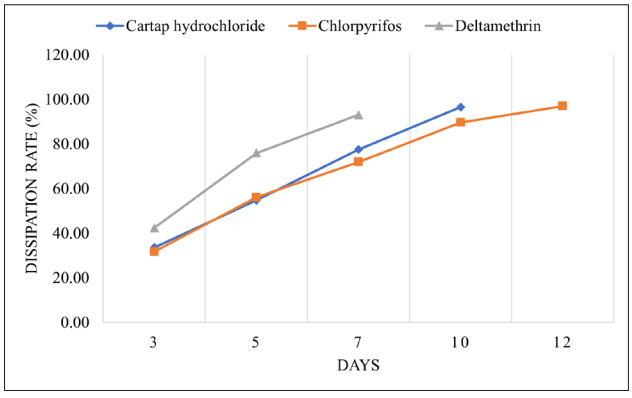

Figure 5: Dissipation rate of different pesticide residues at different days intervals.

is recommended as 0.02 mg/kg, as suggested by the United Kingdom and other European Union nations. Due to its translaminar action and rapid penetration into leaf tissue, cartap hydrochloride retains residual activity in the field despite its quick photodegradation after application. In addition to its high effectiveness, it is a bio-rational substance derived from a biological source, making it suitable for use in environmentally friendly integrated pest management systems. However, Rao et al. [17] reported that no residues of cartap hydrochloride were traced in brinjal after 5 days of application and found BDL on seventh day after application. The variation in results might be due to the variations in the agroclimatic condition, method of application and quantity applied.

Chlorpyrifos

The results of the HPLC residual analysis of chlorpyrifos are presented in table 2 and figure 4. Data on chlorpyrifos residues in soil of brinjal field recorded at different time intervals revealed that initial deposit of 1.91 mg/kg was recorded at 0 day (2 h after application), which was reduced to 1.31, 0.84, 0.54, 0.20 and 0.06 mg/kg at 3rd, 5th, 7th, 10th and 12th day after treatments, respectively. The dissipation rates were 31.71%, 56.12%, 71.96%, 89.70% and 97.04% on the 3rd, 5th, 7th and 10th and 12th day, respectively (Table 2 and figure 5). Further, the data also revealed that chlorpyrifos applied at optimum dosage reached BDL 15 days after application. However, an MRL value of 0.01 mg/kg has been proposed by the European commission. The results were in close conformity with the results of Ahmed et al. [13] who observed that the chlorpyrifos residue was not detectable on the 8th day in brinjal fruit after application, whereas below detection limit on the 10th day after application. Chandra et al. [18] reported that the dissipation of chlorpyrifos residues reached below the detection limit on the 11th, 13th, and 15th day after application at different concentrations in brinjal. The physical and chemical characteristics of pesticides, such as their absorption by plants and metabolic rate, may be related to plant behavior. The degradation of insecticides depends on the different factors such as environmental factors, including wind, rain, sunlight, humidity, and temperature, along with chemical and physical characteristics like plant growth and volatilization, causes residue dissipation from plants.

Deltamethrin

Data on deltamethrin residues in soil of brinjal field recorded at different time intervals revealed that initial deposit

Table 3: Influence of pesticides on quality attributes of brinjal.

Treatments	TSS (°Brix)	Titratable acidity (%)	Crude protein (%)	Chlorophyll content of leaves
T_0 (Control)	3.79	0.58	1.76	44.27
T_1 (Cartap hydrochloride 50% SP)	3.58	0.36	1.50	43.63
T_2 (Chlorpyrifos 20% EC)	3.49	0.31	1.34	43.02
T_3 (Deltamethrin 2.8% EC)	3.62	0.38	1.43	43.00
CD (p = 0.05)	0.29	0.31	0.33	2.23
SEM (±)	0.08	0.09	0.10	0.64
CV (%)	4.04	37.32	11.11	2.56

of 1.17 mg/kg was recorded at 0 day (2 h after application), which was reduced to 0.67, 0.28 and 0.08 mg/kg on 3rd, 5th and 7th day after treatments, respectively (Table 2 and figure 4). The dissipation rate of insecticidal residues was 42.43%, 75.93% and 93.11% on 3rd, 5th and 7th day, respectively (Table 2 and figure 5). Further, the data also revealed that deltamethrin applied at recommended dose reached BDL at 10th day after application. However, an MRL value of 0.40 mg/kg has been proposed by the European commission. The rate at which residue decreases over time is directly proportional to the amount of residue present at that time, indicating first-order kinetics. Deltamethrin has stable chemical properties, and degradation occurs slowly in natural environment. It can be degraded by multiple pathways, depending on experimental conditions [19]. The results were in close conformity with the results of Majumder et al. [20] who observed that the deltamethrin residue was not detectable 12th day after application in tomato.

Quality characteristics of brinjal fruit

TSS

The data presented in table 3 indicates the influence of various insecticides on the qualitative characteristics of brinjal. The results showed no statistically significant ($p < 0.05$) differences in the overall change in TSS content between the T_0 and the insecticide-treated samples. The T_2 (3.49 °Brix), followed by the T_1 (3.58 °Brix), had the lowest TSS, while the T_0 had the highest TSS content (3.79 °Brix). These results are aligned with those of Abdelfatah et al. [21], who found that TSS content and other fruit quality parameters were minimally affected when pesticides were applied to brinjal at the optimal dosage. Additionally, they suggested that the systemic effects of insecticides, which penetrate deeper into the fruit and impact the biochemical system, could be responsible for the biochemical changes observed in eggplant fruits treated with these pesticides.

Titratable acidity

The data presented in table 3 indicate the influence of various insecticides on the percentage of titratable acidity in brinjal. The results showed no statistically significant ($p < 0.05$) differences in titratable acidity between the T_0 and the insecticide-treated samples. The T_0 had the highest titratable acidity (0.58%), followed by the T_3 (0.38%), while the T_1 had the lowest (0.36%). Insecticides control pests on plants and animals but may disrupt their biochemical processes. Pesticides can hinder photosynthesis, mitosis, cell division, protein and chlorophyll production, root development, enzyme activity, and cell membrane integrity [22]. These findings are consistent with those of Abdelfatah et al. [21], who reported that when pesticides were applied to brinjal at an appropriate dosage, the percentage of titratable acidity was only minimally influenced.

Crude protein

The data presented in table 3 indicates the influence of various insecticides on the crude protein content of brinjal. The results showed no statistically significant ($p < 0.05$) differences in crude protein content between the T_0 and the insecticide-treated samples. The highest crude protein content (1.76%) was observed in the T_0, followed by T_1 (1.50%), while the lowest (1.34%) was found in the T_2. Crude protein levels may vary only slightly due to the insecticide's weak effects on the plant's nitrogen metabolism and protein synthesis pathways [23]. These findings are consistent with the results reported by Thakur et al. [24], who stated that pesticide application at an optimum dosage had a non-significant impact on the quality of brinjal.

Chlorophyll content of leaves

The data presented in table 3 indicate the influence of various insecticides on the chlorophyll content of leaves. The results showed no statistically significant ($p < 0.05$) differences in chlorophyll content of leaves between the T_0 and the insecticide-treated samples. The maximum amount of chlorophyll content of leaves (44.27) was found in T_0 followed by T_1 (43.63), while minimum (43.00) was found in case of T_3. Some insecticides may not significantly affect the pathways involved in chlorophyll biosynthesis or degradation. If an insecticide does not directly impact nitrogen metabolism or photosynthetic pigments, changes in chlorophyll content will likely be minimal [25]. The findings agreed with the results revealed by Nikam and Barwant [26], who reported that insecticides applied at recommended doses had a non-significant impact on the chlorophyll content in comparison to control treatment. Reduced photosynthetic efficiency in plants might occur due to insecticides affecting photosynthetic pigments [27].

Conclusion

The study concluded that brinjal leaves treated with synthetic insecticides at optimal dosages exhibited variable dissipation rates, with complete degradation occurring within 7 - 15 days. Chlorpyrifos had the highest initial residue levels,

while deltamethrin showed the fastest dissipation. Additionally, the results indicated that insecticide sprays did not significantly affect the qualitative attributes of brinjal fruit, such as TSS, titratable acidity, crude protein, and chlorophyll content remained largely unchanged. These findings highlight that the recommended insecticide dosages ensure effective pest management while minimizing residue persistence, making them a viable option for safe brinjal cultivation.

Acknowledgements

The authors would like to extend their sincere gratitude to the Department of Vegetable Science and the Department of Entomology at Lovely Professional University for their assistance in providing the facilities, lab instruments, and planting materials required for this investigation.

Conflict of Interest

None.

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