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Research Article

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Impact of Insecticide Applications on Yield and Residual Effects on Biochemical Properties of Brinjal (*Solanum melongena* L.)

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Abstract

Pesticides are recognized for disrupting the biochemical processes of plants, consequently reducing their food quality. An experiment was carried out at the main agriculture research field of Lovely Professional University in Punjab, India, to examine the effects of various insecticides on brinjal yield and the evaluation of the residual levels of different pesticides in brinjal, along with their influence on the biochemical properties of brinjal. The experiment comprises nine treatments arranged in a completely randomized block design with three replications. The quantification of pesticide residues in brinjal was evaluated using high-performance liquid chromatography (HPLC). The data analysis showed that T_7 (Cartap-hydrochloride 50% SP) exhibited the highest yield parameters, including the number of fruits per plant (7.00), fruit length (14.20 cm), fruit width (7.96 cm), fruit yield per plant (0.98 kg), fruit yield per plot (29.44 kg) and fruit yield (36.35 t ha^{-1}) as compared to T_0 (control). The residual analysis results indicated that insecticide residues decreased below the detection limit (BDL) on the following days: the seventh day for acetamiprid, deltamethrin, and cartap hydrochloride; the tenth day for triazophos and chlorpyrifos; and the fifteenth day for carbofuran, with residual levels ranging from 0.034 - 1.391 mg/kg for various insecticides. No residues were detected in botanical insecticides and the control treatment. The biochemical parameters of brinjal fruit exhibited negligible and insignificant variation among different treatments when compared to the control. The results concluded that the influence of pesticide residues on biochemical properties was negligible when applied at recommended dosages.

Keywords

Brinjal, HPLC, Biochemical parameters, Insecticides, Yield, Cartap hydrochloride

Introduction

Brinjal, scientifically known as *Solanum melongena* L., is a highly demanded vegetable in South Asia and is utilized worldwide. It is closely related to potatoes and tomatoes and is a member of the Solanaceae family. Eggplant originates from India. It is often referred to as eggplant or aubergine in various parts of the world [1]. According to NHB (2019 - 2020), in India area under brinjal cultivation is estimated to be 736 thousand hectares with total production of 12777 thousand metric tons [2]. A 100 gm portion of brinjal contains 1.4 gm of protein, 18 mg of calcium, and provides 24 kilocalories of dietary energy [3]. Nevertheless, insect infestation poses a significant obstacle to the large-scale production of brinjal. Insect pests and diseases may lead to decreased agricultural output and, in rare cases, result in a total crop failure. It has been reported that vegetable crops have an annual yield loss of 30 - 40% only owing to insect pests [4]. Infestations by pests like jassids, fruit and shoot borers, red spider mites, beetles, aphids, and

mealybugs significantly affect the brinjal crop during its fruiting period. The fruit borer is responsible for 70% of the crop's damage, making it unsuitable for human consumption [5]. The brinjal shoot and fruit borer is a major pest that can destroy an established brinjal crop, with a 10 - 50% infestation being disastrous for the production [6]. The shoot and fruit borer severely damages brinjal from the seedling stage to fruiting, resulting in reduced yield and fruit quality [7]. One of the most important inputs in contemporary horticulture and agriculture for ensuring food security is pesticides.

Vegetable production extensively needs pesticides for managing insect pest infestations. These substances infiltrate vegetables, become their components due to their direct application, and persist within them at harvest time. To ensure consumer safety, various developed nations have established maximum residue limits (MRL) based on the acceptable daily intake (ADI) and potential DI (PDI) for the majority of pesticides, which are not allowed to be exceeded for a food product to be considered safe for intake [8]. The application of hazardous pesticides on vegetables has been assumed to have increased the danger of consumer poisoning and associated problems. Farmers assume that pesticide application is an essential component for enhancing yield of the crop; hence, they extensively apply pesticides to crops, even during the fruiting stage. Pesticide residues accumulate in vegetables due to their frequent and repeated use, particularly during the fruiting stage, and the non-adoption of safe waiting periods [9]. Due to the water solubility of certain pesticides and the fat solubility of others, ingestion of even minute quantities can lead to the accumulation of these substances within the body tissues, resulting in adverse impacts on the consumer. Pesticide residues induce both acute and chronic toxic effects that pose health hazards, particularly at higher concentrations that may result in toxicity. Headaches, nausea, irritability, vomiting, diarrhea, stomach pain, and hypersensitivity are frequently documented effects of acute pesticide exposure. Long-term exposure to pesticides also increases the risk of reproductive problems, neurological diseases, organ damage (renal and hepatic), mutagenic and carcinogenic changes, and endocrine disruption [10].

The environmental and health issues, along with the risks associated with chemical usage, particularly pesticides, in agriculture, are serious. This results in the accumulation of pesticide residues in crops and disturbs the plant's biochemical parameters [11]. The application of these insecticides on brinjal plants may impact their quality and nutritional characteristics. When plants are exposed to pesticides, their biochemical, physiological, enzymatic and mineral processes can be altered, ultimately affecting yield and leading to residue deposition in brinjal fruits. Foliar application of these pesticides may promote plant growth if used at dosages and concentrations recommended by regulatory agencies. However, their persistence can influence the quality parameters of both the plants and fruits. Pesticide-induced abiotic stress causes the plants to fail in absorbing important micronutrients, leading to fluctuations in total phenolics, total ortho-dihydroxy phenols, and ascorbic acid, all of which function as non-enzymatic antioxidants in potatoes and other crops [12].

The current investigation aimed to determine the influence of various insecticides on yield attributes, quantify the residual concentrations of insecticidal treatments and evaluate their effects on the biochemical characteristics of brinjal.

Materials and Methods

An experiment was performed on the main agricultural research field of Lovely Professional University in Phagwara, Punjab in the year 2023 - 2024. The location is at a latitude of 31°15' N, a longitude of 75°41' E, and an elevation of 245 m above mean sea level. The field trials used a randomized complete block design with three replications. The seeds of the brinjal cultivar Navkiran were used as planting material. The experiment comprised nine treatments, including T_0: Control (water spray), T_1: Chlorpyrifos 20% EC at 200 a.i. g ha^{-1}; T_2: Triazophos 40% EC at 500 a.i. g ha^{-1}; T_3: Karanja oil 1% at 20 a.i. g ha^{-1}; T_4: Neem oil 1% at 20 a.i. g ha^{-1}; T_5: Acetamiprid 20% SP at 20 a.i. g ha^{-1}; T_6: Deltamethrin 2.8% EC at 15 a.i. g ha^{-1}; T_7: Cartap-hydrochloride 50% SP at 500 a.i. g ha^{-1}; and T_8: Carbofuran 3% CG at 2000 a.i. g ha^{-1}. Five plants were randomly chosen from each unit plot to evaluate and quantify yield and quality-related characteristics. The pesticides were introduced after the insect population reached the economic threshold level. Two applications of each insecticide were administered individually at 15 days intervals, commencing the first application at the fruiting stage. The yield characteristics of the control and treated samples were examined by comparing various parameters, including the number of fruits per plant, fruit length, fruit width, fruit yield per plant, fruit yield per plot, and fruit yield per hectare. The brinjal seedlings were transplanted in July 2023 during the Kharif season, with a plant spacing of 60 × 45 cm, in an area of 349.8 m^2. During field preparation, prior to the final ploughing, well-rotted farmyard manure was thoroughly incorporated into the soil at a rate of 25 tons per hectare. The recommended doses of fertilizer included urea (271.81 kg ha^{-1}), single super phosphate (383.01 kg ha^{-1}) and muriate of potash (49.42 kg ha^{-1}), supplying 122.5 kg ha^{-1} of N, 61.8 kg ha^{-1} of P_2O_5, and 29.65 kg ha^{-1} of K_2O.

Residual analysis of brinjal fruit

Sampling

Brinjal fruit samples were randomly collected from each replicate of the treated and control plots at regular intervals of 0 (2 h post-spraying), 1, 3, 5, 7, 10, and 15 days following the second spray. The collected brinjal samples were taken to the laboratory in polyethylene bags and processed without delay.

Extraction and clean-up

The procedure for extraction and cleanup of brinjal fruit samples for residual analysis is depicted in figure 1. In 25 g of fruit samples, 100 mL of acetonitrile was added and mixed in an electric blender for 2 - 3 min. The mixture was subsequently filtered using coarse filter paper in a Buchner funnel. The extraction was repeated using 50 mL of acetonitrile and subsequently filtered. 500 mg of activated charcoal were added to the filtrate, combined, and shaken for 30 min on a rotary shaker. The solution was subsequently filtered using What-

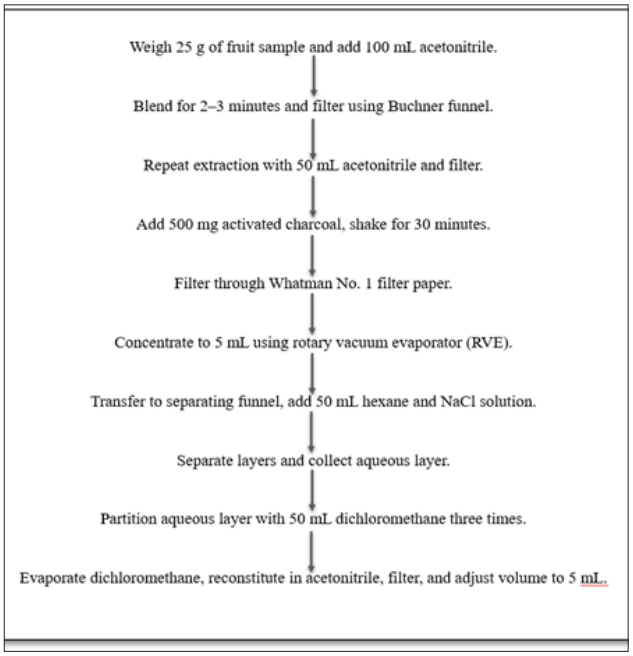


Figure 1: Flowchart of extraction and cleanup for residual analysis of brinjal fruit samples.

man No. 1 filter paper and concentrated in a rotary vacuum evaporator (RVE) to approximately 5 mL. After the transfer to a separating funnel, 50 mL of hexane and 50 mL of saturated aqueous NaCl solution were added, the layers were partitioned, and the aqueous layer was collected. The aqueous layer was subsequently partitioned three times with 50 mL of dichloromethane and collected on a bed of anhydrous Na_2SO_4. The dichloromethane extract was evaporated to dryness using RVE, reconstituted in HPLC-grade acetonitrile, filtered through a 0.22 µm membrane, and the volume was adjusted to 5 mL.

Recovery study

Recovery experiments conducted in the laboratory confirmed the dependability of the selected analytical method and the efficacy of the extraction and purification procedures. To 25 g of finely chopped brinjal fruits, 10 mL of analytical insecticide solutions at concentrations of 2.0, 1.0, 0.5, 0.1, 0.05, and 0.01 mg kg^{-1} were added, mixed completely, and kept for 15 min. The pesticide residues in the fortified samples were subsequently extracted, purified, and quantified using the aforementioned procedure. The average recovery rates for brinjal fruits treated with various insecticides ranged from 75.17% - 88.33%. The limit of detection was determined by identifying the lowest standard concentration level. The detection limit was determined to be 0.02 mg kg^{-1}.

Residual determination by HPLC

The acetamiprid residues were quantified using HPLC with a UV detector. The detector was calibrated to a wavelength of 246 nm. A C_{18} column was employed with a mobile phase consisting of Acetonitrile and Water in a 40:60 v/v ratio, an injection volume of 20 µL, and an isocratic solvent system of acetonitrile at a flow rate of 1.0 mL min^{-1}. The retention times of chlorpyrifos, triazophos, karanja oil, neem oil, acetamiprid, deltamethrin, cartap hydrochloride, and carbofuran under the specified circumstances were 8.10, 15.25, 2.85, 8.60, 10.46, and 8.50 min, respectively.

Fruit biochemical parameters

The brinjal fruit samples obtained from both insecticide-treated and control fields were rigorously cleaned in tap water to eliminate adherent soil particles, rinsed in distilled water, drained, and subsequently dried in a hot air oven at 50 °C. The desiccated fruits were properly powdered. The desiccated powder was extracted in 100 ml of a 80:20 methanol-distilled water solution using a shaker for 8 h. The extract was decanted, and the extraction was repeated using fresh 80:20 methanol-water until the extract became colorless. The extracts were combined and evaporated in a rotary evaporator at temperatures below 40 °C until the solvent was completely removed.

Total polyphenol content

The total polyphenol content of brinjal fruit extract was measured using a modified method described in Matthaus [13]. The concentration was estimated to be using gallic acid as a standard, and the results were reported as gallic acid equivalents (mg GAE) per gram of extract.

Total flavonoid content

The total flavonoid content was determined utilizing the method of Lamien et al. [14] with specific adjustments. The total flavonoid level was quantified in milligrams of quercetin equivalents per gram of extract (QAE) g^{-1}.

Total antioxidant activity

Diphenyl-β-α-α-picryl-hydrazyl (DPPH) assay

The free radical scavenging activity (RSA) of brinjal methanol extracts was evaluated using DPPH according to the method outlined by Oktay et al. [15]. A 0.1 mmol L-1 solution of DPPH in methanol was prepared, and 1 ml of this solution was combined with 3 ml of brinjal fruit extract at a concentration of 50 µg. Absorbance was measured at 517 nm after 30 min. The reaction mixture had a lower absorbance, indicating increased free RSA. RSA was quantified as a percentage of inhibition, determined using the specified formula.

$$RSA(\%) = \frac{(Absorbance\ of\ control\ - Absorbance\ of\ sample)}{Absorbance\ of\ control} \times 100$$

Statistical Analysis

Analysis of variance was performed with post-hoc testing Duncan's multiple range test utilized to determine the homogeneity or variances among the treatments utilizing SPSS (Version 25.0) statistical software. A probability level of $p < 0.05$ was designated as the standard for statistical significance [16]. All data are expressed as mean ± standard deviation. The residual analysis results are expressed as mg kg^{-1}.

Results and Discussion

Yield parameters

The data presented in table 1 and figure 2 revealed significant variation in all the observed yield parameters of brinjal

Table 1: Effect of insecticides on number of fruits per plant, fruit length (cm), fruit width (cm), yield per plant (kg), yield per plot (kg), yield tons per hectare (tons).

Treatments	Number of fruits per plant	Fruit length (cm)	Fruit width (cm)	Yield per plant (kg)	Yield per plot (kg)	Yield per hectare (tons)
T_0 (Control)	$4.13^{i} \pm 0.23$	$8.59^{i} \pm 0.62$	$4.48^{i} \pm 0.14$	$0.57^{i} \pm 0.03$	$17.01^{i} \pm 0.98$	$21.00^{i} \pm 1.20$
T_1 (Chlorpyrifos 20% EC)	$6.00^{d} \pm 0.20$	$11.90^{d} \pm 0.56$	$6.71^{d} \pm 0.37$	$0.83^{d} \pm 0.03$	$25.04^{d} \pm 0.82$	$30.92^{d} \pm 1.01$
T_2 (Triazophos 40% EC)	$5.67^{e} \pm 0.12$	$11.34^{e} \pm 0.21$	$6.22^{e} \pm 0.15$	$0.79^{e} \pm 0.02$	$23.60^{e} \pm 0.51$	$29.13^{e} \pm 0.63$
T_3 (Karanja oil 1%)	$5.33^{f} \pm 0.31$	$10.79^{f} \pm 0.22$	$5.83^{f} \pm 0.25$	$0.74^{f} \pm 0.05$	$22.15^{f} \pm 1.30$	$27.34^{f} \pm 1.61$
T_4 (Neem oil 1%)	$5.00^{g} \pm 0.35$	$9.95^{g} \pm 0.28$	$5.42^{g} \pm 0.70$	$0.69^{g} \pm 0.05$	$20.71^{g} \pm 1.45$	$25.57^{g} \pm 1.78$
T_5 (Acetamiprid 20% SP)	$6.33^{c} \pm 0.31$	$12.58^{c} \pm 0.55$	$7.10^{c} \pm 0.20$	$0.88^{c} \pm 0.04$	$26.50^{c} \pm 1.30$	$32.72^{c} \pm 1.60$
T_6 (Deltamethrin 2.8% EC)	$6.67^{b} \pm 0.23$	$13.17^{b} \pm 0.18$	$7.49^{b} \pm 0.17$	$0.93^{b} \pm 0.03$	$27.97^{b} \pm 0.98$	$34.54^{b} \pm 1.20$
T_7 (Cartap-hydrochloride 50% SP)	$7.00^{a} \pm 0.20$	$14.20^{a} \pm 0.60$	$7.96^{a} \pm 0.31$	$0.98^{a} \pm 0.03$	$29.44^{a} \pm 0.82$	$36.35^{a} \pm 1.02$
T_8 (Carbofuran 3% CG)	$4.53^{h} \pm 0.12$	$9.19^{h} \pm 0.34$	$4.92^{h} \pm 0.11$	$0.62^{h} \pm 0.01$	$18.71^{h} \pm 0.45$	$23.10^{h} \pm 0.56$
CD (p = 0.05)	0.33	0.54	0.37	0.05	1.35	1.67
SEM (±)	0.11	0.18	0.12	0.02	0.45	0.55

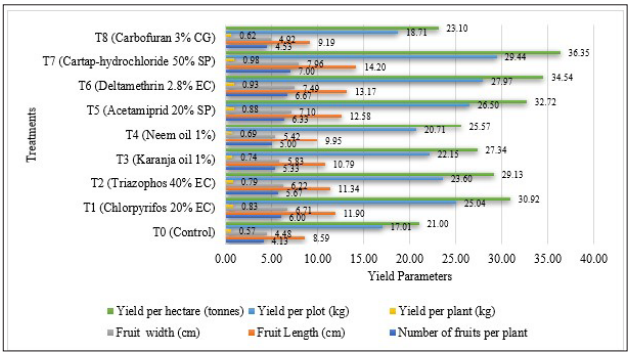


Figure 2: Effect of insecticides on number of fruits per plant, fruit length (cm), fruit width (cm), yield per plant (kg), yield per plot (kg), and yield tons per hectare (tons).

across different treatments. The T_7 treatment, which involved the application of Cartap-hydrochloride 50% SP, consistently showed the highest values in the following yield parameters: maximum number of fruits per plant (7.00), fruit length (14.20 cm), fruit width (7.96 cm), fruit yield per plant (0.98 kg), fruit yield per plot (29.44 kg), and fruit yield per hectare (36.35 t ha^{-1}). In contrast, the T_0 treatment (Control) consistently recorded the lowest mean values for following yield characteristics, including the minimum number of fruits per plant (4.13), fruit length (8.59 cm), fruit width (4.48 cm), fruit yield per plant (0.57 kg), fruit yield per plot (17.01 kg), and fruit yield per hectare (21.00 t ha^{-1}). The researcher found similar reports, indicating that cartap hydrochloride was the most effective application for increasing brinjal yield [17]. The aforementioned findings are closely supported by the findings suggested by Latif et al. [18]. The early worker also found that applying cartap hydrochloride increased the yield attributes in tomato [19]. Senapati [20] also observed a higher fruit yield in brinjal when cartap hydrochloride was applied at optimal dosage. A pesticide belonging to the nereis toxin analogue group, cartap hydrochloride effectively controls insects through contact and systemic action [21] while ensuring long-lasting plant protection, which further leads to an indirect impact on crop growth. Insect infestation causes fruit deformation and internal deterioration, making them unfit for consumption [22]. According to Gautam et al. [23], the application of synthetic insecticides effectively reduced the infestation of shoot and fruit borer in brinjal, which eventually led to an increase in the yield attributes of brinjal.

Residual levels of different insecticides in brinjal fruit

The persistence and dissipation of different insecticides in brinjal fruit at different day intervals are shown in table 2 and table 3 and illustrated in figure 3 and figure 4. The initial deposits (2 h after spraying) of different insecticides, viz., chlorpyrifos, triazophos, acetamiprid, deltamethrin, cartap-hydrochloride and carbofuran in brinjal fruit were 0.691, 1.391, 1.139, 0.482, 1.238, and 0.332 mg kg^{-1}, respectively. Residual analysis revealed no detectable insecticide residues in fruit samples treated with the untreated control (water spray), neem oil and karanja oil. The treatments dissipated approximately 38.12, 18.68, 34.53, 29.70, 26.03, and 33.50% of the initial residue one day after application. After three days, the residue levels varied, ranging from 62.93 - 80.20% dissipation for various insecticide treatments. After seventh day, the levels of acetamiprid, deltamethrin, and cartap hydrochloride residues dropped BDL. In other treatments, residues declined BDL by the tenth day for triazophos and chlorpyrifos; and the fifteenth day for carbofuran. According to the European Union, the MRL values for different insecticide treatments applied in brinjal were chlorpyrifos (0.01 mg kg^{-1}), Triazophos (0.01 mg kg^{-1}), neem oil (1.0 mg kg^{-1}), karanja oil (1.0 mg kg^{-1}), Acetamiprid (0.20 mg kg^{-1}), deltamethrin (0.40 mg kg^{-1}), Cartap-hydrochloride (0.02 mg kg^{-1}) and carbofuran (0.002 mg kg^{-1}). According to Hunter and Helmy [24], various physical and chemical parameters, such as ambient conditions, application method, plant species and growth rate, dosage, application intervals, and harvest timing, influence the dissipation of pesticides. According to Ahmed et al. [25], chlorpyrifos residues were not detected on the 8th day after application. Rao et al. [26] reported that cartap hydrochloride residues were BDL

Table 2: Residues (mg kg^{-1}) of different insecticides present in brinjal fruit at different days interval.

Treatments	Residues (mg kg^{-1}) after treatment application						
	0 days (2 h)	1 day	3 days	5 days	7 days	10 days	15 days
T_0 (Control)	ND	ND	ND	ND	ND	ND	ND
T_1 (Chlorpyrifos 20% EC)	0.691 ± 0.008	0.427 ± 0.011	0.256 ± 0.011	0.109 ± 0.012	0.034 ± 0.010	BDL	BDL
T_2 (Triazophos 40% EC)	1.391 ± 0.092	1.129 ± 0.028	0.554 ± 0.012	0.248 ± 0.032	0.080 ± 0.012	BDL	BDL
T_3 (Karanja oil 1%)	ND	ND	ND	ND	ND	ND	ND
T_4 (Neem oil 1%)	ND	ND	ND	ND	ND	ND	ND
T_5 (Acetamiprid 20% SP)	1.139 ± 0.163	0.736 ± 0.035	0.348 ± 0.073	0.096 ± 0.027	BDL	BDL	BDL
T_6 (Deltamethrin 2.8% EC)	0.482 ± 0.078	0.334 ± 0.017	0.163 ± 0.021	0.034 ± 0.014	BDL	BDL	BDL
T_7 (Cartap-hydrochloride 50% SP)	1.238 ± 0.138	0.902 ± 0.102	0.243 ± 0.002	0.152 ± 0.022	BDL	BDL	BDL
T_8 (Carbofuran 3% CG)	0.332 ± 0.028	0.219 ± 0.023	0.124 ± 0.023	0.076 ± 0.015	0.060 ± 0.017	0.036 ± 0.003	BDL

Note: ND = Not detected.

on the 7th day after application. Patil et al. [27] observed that effect of insecticidal residues on the nutritional and antioxi-

Table 3: Percent dissipation (%) of different insecticides in brinjal fruit at different intervals.

Treatments	Per cent dissipation (%) after treatment application					
	1 day	3 days	5 days	7 days	10 days	15 days
T_1 (Chlorpyrifos 20% EC)	38.12 ± 2.12	62.93 ± 1.44	84.22 ± 1.60	95.01 ± 1.42	BDL	BDL
T_2 (Triazophos 40% EC)	18.68 ± 5.05	60.02 ± 3.27	82.21 ± 1.13	94.19 ± 1.21	BDL	BDL
T_3 (Karanja oil 1%)	ND	ND	ND	ND	ND	ND
T_4 (Neem oil 1%)	ND	ND	ND	ND	ND	ND
T_5 (Acetamiprid 20% SP)	34.53 ± 9.32	69.60 ± 2.29	91.64 ± 1.24	BDL	BDL	BDL
T_6 (Deltamethrin 2.8% EC)	29.70 ± 8.98	65.14 ± 10.19	92.48 ± 4.08	BDL	BDL	BDL
T_7 (Cartap-hydrochloride 50% SP)	26.03 ± 14.97	80.20 ± 2.08	87.46 ± 3.19	BDL	BDL	BDL
T_8 (Carbofuran 3% CG)	33.50 ± 11.22	62.34 ± 8.12	77.21 ± 3.81	81.42 ± 6.67	89.18 ± 1.64	BDL

Note: ND = Not detected.

triazophos residues were below the quantification limit on the 10th day after application at the optimal dosage. Patel et al. [28] reported that deltamethrin residues fell BDL by the 7th day after application. Romeh and Hendawi [29] noted that acetamiprid residues were BDL on the 7th day after application. Kamala [30] reported that carbofuran residues reached BDL by the 14th day after application in brinjal.

Phytochemical compounds

Table 4 and figure 5 presents the data demonstrating the dant characteristics of brinjal fruit. The findings indicated that the nutritional and antioxidant parameters of the brinjal fruit samples were statistically insignificant compared to the control at a 5% significance level. The highest polyphenol content (3.60) was observed in T_4 (Neem oil 1%), whereas the lowest (3.39) was recorded in T_2 (Triazophos 40% EC). Both the total flavonoid content and the DPPH test percentage of RSA showed identical trends, whether in enhancement or reduction. The maximal total flavonoid content (0.35) and DPPH

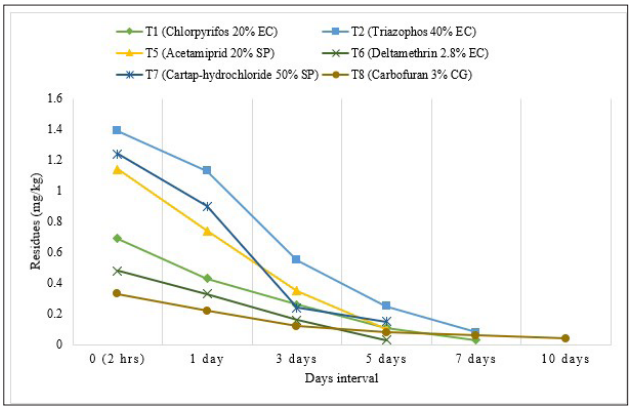


Figure 3: Residues (mg kg^{-1}) of different insecticides present in brinjal fruit at different intervals.

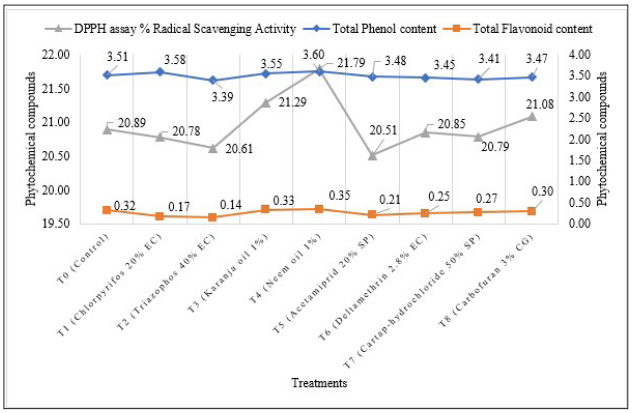


Figure 5: Effect of different insecticides residues on total phenol content, total flavonoid content, DPPH assay % RSA in brinjal fruit.

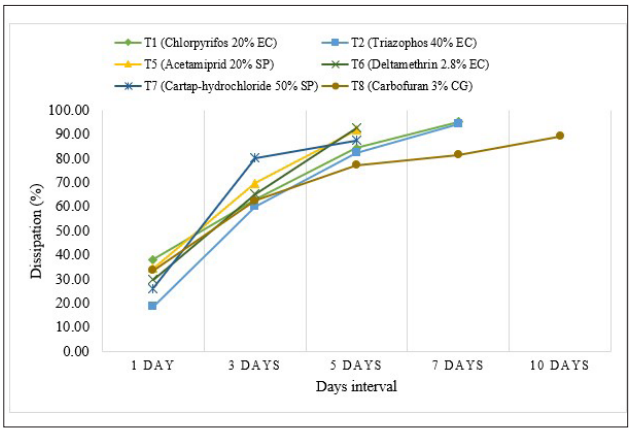


Figure 4: Percent dissipation (%) of different insecticides in brinjal fruit at different days intervals.

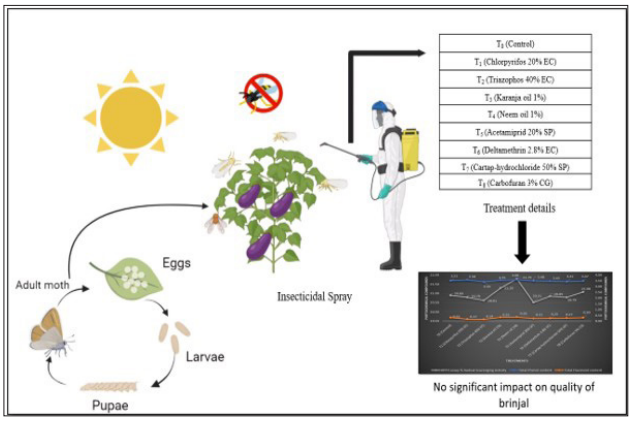


Figure 6: Graphical abstract on impact of insecticidal treatment on quality of brinjal.

Table 4: Effect of different insecticides residues on total phenol content (mg GAE g^{-1} extract), total flavonoid content (mg QAE g^{-1} extract), DPPH assay % RSA in brinjal fruit.

Treatments	Total phenol content (mg GAEg^{-1} extract)	Total flavonoid content (mg QAE g^{-1} extract)	DPPH assay % RSA
T_0 (Control)	3.58^a ± 0.10	0.32^a ± 0.10	20.89^a ± 0.68
T_1 (Chlorpyrifos 20% EC)	3.51^a ± 0.06	0.17^a ± 0.06	20.78^a ± 0.17
T_2 (Triazophos 40% EC)	3.39^a ± 0.10	0.14^a ± 0.09	20.61^a ± 0.40
T_3 (Karanja oil 1%)	3.55^a ± 0.21	0.33^a ± 0.12	21.29^a ± 0.72
T_4 (Neem oil 1%)	3.60^a ± 0.02	0.35^a ± 0.12	21.79^a ± 0.58
T_5 (Acetamiprid 20% SP)	3.48^a ± 0.17	0.21^a ± 0.02	20.51^a ± 0.32
T_6 (Deltamethrin 2.8% EC)	3.45^a ± 0.06	0.25^a ± 0.01	20.85^a ± 0.15
T_7 (Cartap-hydrochloride 50% SP)	3.41^a ± 0.06	0.26^a ± 0.02	20.79^a ± 0.19
T_8 (Carbofuran 3% CG)	3.47^a ± 0.10	0.30^a ± 0.14	21.08^a ± 0.14
CD (p = 0.05)	0.18	0.14	0.73
SEM (±)	0.060	0.05	0.24

assay % RSA (21.79) were observed in T_4 (Neem oil 1%), while the minimum values (0.14) and (20.61) were recorded in T_2 (Triazophos 40% EC), respectively. Research findings indicated a strong association between phenolic content and antioxidant activity among many vegetables. Plant materials' flavanols, including quercetin and flavones, significantly contribute to their antioxidant function. This is primarily due to their redox properties, which operate through various mechanisms like free-radical scavenging, transition-metal chelation, and singlet oxygen quenching capacity [11]. The researcher reported a strong correlation (r = 0.88) between polyphenol content and hydroxyl radical scavenging ability [31]. Brinjal contains key antioxidants that are stable secondary metabolites, such as flavonoids, polyphenols, and ascorbic acid (vitamin C).

These compounds are generally resistant to alteration by external applications like pesticides when used at recommended doses [11]. The present results align closely with the findings reported by Goswami et al. [11], who observed that insecticidal treatments have no significant effect on the phytochemical compounds of brinjal. According to Dumra et al. [32], the maximum phenol content was recorded with the minimal application of synthetic insecticide, showing no statistically significant difference compared to the untreated control.

Conclusion

The study concludes that the judicious application of pesticides on brinjal leads to increased yields and persistence of lower levels of pesticide residues (MRL values) in the crops at harvest. From a quality perspective, the study showed that insecticidal residues on brinjal caused minor alterations in fruit quality, which were not statistically significant when applied at the recommended dosages. Yield characteristics indicated that treatment T_7 (Cartap-hydrochloride 50% SP) at the recommended dosage, significantly increased the yield attributes of brinjal. From a residue perspective, no residues were detected in the control and botanical insecticide treatments. A waiting period of 7 - 10 days is recommended for all synthetic insecticides, except for treatment T_8 (Carbofuran 3% CG), which requires 15 days waiting period before harvesting brinjal. Farmers are encouraged to avoid the indiscriminate application of insecticides and to utilize them judiciously to enhance crop yields while maintaining a healthy environment free of hazardous chemicals.

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Conflict of Interest

None.

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