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Biopesticidal Potential of Extracts of Nicotiana tabacum, Nicotiana rustica A. galanga, Azadirachta indica and Curcuma longa against Tribolium Castanelum

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Abstract

Red flour beetle, *Tribolium castaneum* (Fabricius) (Coleoptera: Tenebrionidae) is one of the most devastating pests of stored grains. In current study, the pesticidal effect of deltamethrin and five plant extracts *Nicotiana tabacum, Nicotiana rustica A. galangal Azadirachta indica* and *Curcuma longa* was evaluated. Deltamethrin was applied at the rate of 0.001, 0.002, 0.003, 0.004, 0.005 and 0.006% while five different concentrations 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 % were used for each of the plant extracts, for 24, 48, 72 and 96 h. Four replications for each treatment were carried out adapting Completely Randomized Design (CRD). Probit analysis was used to determine the LC50 and LC90 values. In contact toxicity test, deltamethrin demonstrated the highest toxicity with 0.88 v/v and 4.74 v/v, LC_{50} and LC_{90} respectively. The plant extracts however, demonstrated the highest mortality rate after 96 h of exposure. Lowest LC50 of 1.00 g/L and LC90,5.38 g/L, was recorded for *N. rustica*. Next in order was *N. tabacum* with LC_{50} 1.09 g/L and LC_{90} 6.50 g/L, followed by *C. longa* LC_{50} 1.33 g/L and LC_{90} 6.89 g/L and *A. indica* LC_{50} 1.46 g/L and LC_{90} 7.43 g/L against the pest species. In residual toxicity on the other hand, deltamethrin exhibited an LC50 of 0.93v/v and LC_{90} 3.83 v/v. Whereas, in case of plant extracts the order of toxicity in terms of lowest LC50 0.79 g/L and LC_{90} 10.37 g/L was observed with *N. rustica*, followed by LC_{50} 1.18 g/L and LC_{90} 9.02 g/L *N. tabacum* and LC_{50} 1.82 g/L and LC_{90} 22.36 g/L, *A. indica* against the red flour beetle. Various groups of phytochemicals such as phenols, saponins, alkaloids, di-terpenes, flavonoids and phytol-steroids were identified in the plants species aqueous extracts. Findings in the present study suggest that *N. rustica, N. tabacum, C. longa,* and *A. indica* can be effectively utilized to control *T. castaneum* as well as these plant species may be useful in the development of novel bio-pesticides.

Summary

In this study, the researchers evaluated the pesticidal effects of deltamethrin (a chemical pesticide) and five plant extracts (*Nicotiana tabacum, Nicotiana rustica*, *A. galangal, Azadirachta indica,* and *Curcuma longa*) against *Tribolium castaneum*, a destructive pest of stored grains. They conducted tests over different time periods and concentrations for each substance. The results showed that deltamethrin was highly toxic to the beetles, with the lowest LC_{50} and LC_{90} values among all treatments in the contact toxicity test. However, the plant extracts demonstrated significant mortality rates after 96 hours of exposure. *N. rustica* was the most effective, with the lowest LC_{50} and LC_{90} values, followed by *N. tabacum*, *C. longa,* and *A. indica*. The researchers also identified various phytochemicals in the plant extracts, including phenols, saponins, alkaloids, di-terpenes, flavonoids, and phytol-steroids. In conclusion, the study suggests that *N. rustica, N. tabacum, C. longa*, and *A. indica* could be used effectively to control the red flour beetle. These plant extracts have potential for the development of novel bio-pesticides, providing more environmentally friendly alternatives to chemical pesticides for managing this pest in stored grains.

1. INTRODUCTION

Because stored grains, cereals, and their products are significant sources of food on a worldwide scale, it is crucial for human survival to effectively conserve this precious resource [1]. Wheat, rice and maize are among the most commonly consumed grains, while chickpeas serve a significant source of animal feed and therefore important to help to meet global food demands [2]. These crops make a significant proportion of Pakistan agricultural yield. Post-harvest, these commodities are kept in storage for up to a year in order to maximize market prices for the yield [3]. During this extended storage, these valuable resources are susceptible to numerous losses, particularly those brought on by insect pest infestation [4].

An estimated 10 to 40% qualitative and quantitative loss to agricultural stored goods occur globally due to these disastrous insect pests of grains. One such devastating grain pests which is capable of reducing the grain weight by up to 40% is *Tribolium castaneum* (Herbst) [5]. It attacks the endosperm of the seeds, leaving the seeds with decaying smell and coagulating texture [6]. To prevent these grains from rotting, an efficient control method is necessary. At the moment, synthetic grain protectants are the mainstay of the stored grain industry. These substances not only negatively affect the environment but also pose a major health risk to the consumers [7]. Furthermore, these insects have grown significantly more resistance to these synthetic chemicals as a result of their widespread and indiscriminate use against pests of stored grains. Because of the harmful effects of chemical pest control, natural yet equally efficient compounds that can be considered for usage to combat these pests without seriously compromising human health or affecting grain quality [8].

Chemicals derived from plants that are organic and natural may be a source of such discoveries. Regarding this, new research has identified several promising plant extracts that naturally ward off insects in grain storage systems [9]. In order to aid in pest control, these botanical extracts may do a variety of wonders, by not only deterring pests or keeping them from feeding and egg laying, but concurrently act as insecticides [10]. One well-known example is azadirachtin, a plant product extracted from *Azadirachta indica*. Recent research has demonstrated its tremendous efficacy against *Callosobruchus maculatus*, a notorious pest of stored items [11]. It functions as an insect growth regulator, repellant, sterilant, and feeding inhibitor. In addition, it may also prevent oviposition [13]. Likewise, Nicotine, another plant derivative (from *N. tabacum*), acts as acetylcholine inhibitor and has been effective in controlling insects' pests' infestation with LD_{50} reported in the range of 50 to 60 mg/kg. Similarly, turmeric, is also well known for possessing insecticidal properties and makes it beneficial against several agricultural and household insect pests. It also shows some insect repellent properties. Research shows that turmeric products are a safe and affordable alternative to synthetic insecticides. Consequently, it is important to compare their effectiveness to that of other species of plants that are readily available. Consequently, it is crucial to compare their effectiveness to that of other readily available plant species [12]. Plant based products can serve as effective substitute for synthetic chemicals. As a result, the negative effects of synthetic pesticides will be greatly reduced. The current study set out to find out if the leaf extracts of *A. indica, C. longa, N. tabacum, A. galangal*, and *N. rustica* when used to treat *T. castaneum* had any negative side effects.

2. MATERIALS AND METHODS

The current investigation was carried out in a lab setting in Entomological Laboratory, The University of Haripur Khyber Pakhtunkhwa, Pakistan, in 2022. *T. castaneum* was collected from various godowns in district of Swabi, the Khyber Pakhtunkhwa and were raised on wheat flour. The culture was maintained under laboratory conditions at a relative humidity of 65% ± 5% and average temperature of 27 ± 2^{o}C [13]

2.1: Collection of plant species:

Plant materials, such as leaves, roots and fruit were collected from various plants in different areas of District Swabi, Khyber Pakhtunkhwa, Pakistan

The following Plant materials were tested against T. castaneum:

Common Name	Botanical Name	Family	Parts used
Neem	*Azadirachta indica*	Meliaceae	Seed
Turmeric	*Curcuma longa*	Zingiberacae	Roots
Virginia tobacco	*Nicotiana tabacum*	Solanacaae	Leaves
Ginger	*Alpinia galanga*	Zingiberaceae	Rhizome
White patta	*Nicotiana rustica*	Solanacaae	Leaves

2.2: Preparation of Powder from Plant species:

A total of five commonly occurring plant species were tested. The plant parts underwent a 15-day air drying process after initial cleaning with distilled water. After drying, the plant material was ground in an electric grinder to prepare a fine powder. The powder was sieved through sieves with a mesh size of 60. Afterwards powder was stored in airtight jars at room temperature to avoid quality loss [14].

2.3: Preparation of Crude Extract for Insecticidal Activity

For crude extracts, shade-dried powdered plant matter weighing 20 g each was added to 200 ml of distilled water and placed on the orbit shaker for one hour at 180 rpm (revolutions per minute). After that the mixture was allowed to rest at room temperature for a period of 48h. This was followed by filtration of the plant extract with Whatman No.1. The stock solution (10%) obtained, was later on diluted for the designed experiments.

2.4: Detection of phenols, alkaloid, terpenes, phyto-sterols and flavonoids in plant extracts

Few drops of potassium iodide and iodine were dissolved separately in diluted hydrochloric acid (1.5%). The plant extracts were mixed with 1 mL of this reagent for 5 minutes. The formation of dark red precipitates in the samples, indicate the occurrence of alkaloids in plants extracts [15]. To detect phenol, 3

to 4 drops of ferric chloride solution were mixed with the plant aqueous extracts. The presence of phenols in the extract is indicated by the extract's appearance as bluish black [15]. Similar to this, chloroform-cured extracts of the chosen plants were filtered to look for phyto-sterol. To the filtrate, a few drops of concentrated sulfuric acid was added and allowed to stand for a short while. The development of a golden yellow hue suggested the presence of phyto-sterol [16]. Diterpenes were detected by adding 3 to 4 drops of copper acetate solution to the plant aqueous solution. Appearance of emerald green color indicate diterpenes [17]. Likewise, flavonoids were investigated in plant extracts by adding 2–3 drops of lead acetate solution to the plant aqueous extracts. Emergence of vivid yellow color confirms that flavonoids are present. When a few drops of weak acid were applied, the color vanished [17].

2.5: Direct effect of plant aqueous extracts on T. castaneum

The designed experiment was conducted in a 6x6 factorial treatment arrangement, with five plant species extracts, one synthetic insecticides and 6 concentrations as factors making a total of 36 treatments. To study the residual effect of plant extracts, sterilized flour was treated with five concentrations, i.e., 0.5, 1, 1.5, 2, 2.5, and 3% of the mentioned materials whereas treatment with distilled water served as control. Flours were tested at each concentration. In order to achieve full blending with botanical elements and leaves, the mixture was shaken vigorously for half hour. Treated flour were placed in plastic Petri dishes (12 cm). Adult beetles were released into each Petri dish with treated flour. Mortality of the beetle was recorded after 24, 48, 72, and 96 hours of exposure. The dead beetles from these Petri dishes were discarded every 24 hours [14].

2.6: Contact effect of plant aqueous extracts against T. castaneum

To determine the action of various plants, materials on adult beetles we sprayed 16 cm Petri dishes from all sides with hand operated and disclosed the dishes for half an hour to make it dry. Twenty adult beetles were released in every petri dish. The number of dead beetles were converted to percentage mortality in each treatment after 24, 48, 72, and 96 hours.

2.7: Data analysis

The data was subjected to Analysis of Variance (ANOVA) and Highest Significant Difference (HSD) test was applied at the 5% confidence level, to evaluate the difference within the means of various bioassays. For this purpose, STATISTIX8.1 was used [13]. For estimation of LC_{50} and LC_{90} of various treatments on adult *T. castaneum*, Log-Probit analysis was used on the percentage mortality [18]. All statistical analysis was carried out with SPSS, version 20.

3. Results

3.1 Phytochemical screening:

A variety of phytochemicals such as phenols, alkaloid, diterpenes, phyto-sterols and flavonoids were identified in *N. rustica* and *N. tabacum* plant extracts, however, *A. indica* contained only a few of them. of these, Phyto-sterol was found in highest concentration. Moreover, the plant aqueous extracts also contained saponins (Table 2).

Table 2. Composition of phytochemicals in aqueous extracts of plant species.

	Phytochemical constituents of five plant species					
Plant species	Phenols	Alkaloids	Diterpenes	Phyto-sterol	Flavonoids	Saponins
A. indica	Low	highly	Low	Low	Low	Low
C. longa	Moderately	Moderately	Low	Moderately	Moderately	Low
N. tabacum	Low	highly	highly	Low	Low	Low
A. galanga	Low	Low	Moderately present	Low	Low	Low
N. rustica	highly	Moderately	highly	Moderately	Moderately	Low
- = not present, + = Low present; ++= moderately present; +++= highly present						

From **Table-3**, the results showed that deltamethrin exhibited the highest toxicity against *T. castaneum* in terms of lowest LC_{50} 13.93 and LC_{90} 185.26 with slope 1.14 after 24 h of exposure. Of the 5 plant extracts, the lowest LC_{50} 27.25 g/L and LC_{90} 356.20 g/L (slope = 1.14, P value = 0.99), was found with *C. longa*, followed by *N. rustica* with LC_{50} 29.02 g/L and LC_{90} 792.32 g/L (slope = 0.89, P value = 0.99). *N. tabacum* showed an LC_{50} value of 31.88 g/L and LC_{90} 944.79 g/L (slope 0.87, P values = 0.98). *A. galangal* on the other hand, with LC_{50} 43.19 g/L and LC_{90} 851.23 g/L (slope = 0.99, P value = 0.99) was observed as the least toxic. In general, the highest mean percentage mortality of the pest insect was brought about by deltamethrin 23.33%. among the 5 plant extracts however, it was highest with *N. rustica* 19.58% followed by *N. tabacum* 19.17%, whereas, *A. galangal* caused the lowest mean percentage mortality i. e. 13.33% (Fig. 2**)**.

Likewise, the mortality rate of *T. castaneum* was highest with deltamethrin in terms of low LC_{50} 4.60 g/L and LC_{90} 54.28 g/L (slope = 1.19, P value = 0.58) after exposure to five plants extracts and deltamethrin for 48 h (**Table-3).** Among the 5 plants extracts however,the lowest LC_{50} 5.75 g/L and LC_{90} 94.80 g/L having (slope = 1.05 and P = 0.98) were found for *N. rustica*. This was followed by *N. tabacum* exhibiting an LC_{50} value of 9.62 g/L and LC_{90} value of 235.80 g/L (slope = 0.92 and P = 0.93) and *A. indica* with LC_{50} 12.08 g/L and LC_{90} 160.15 g/L (slope = 1.02 and P = 0.86) and *C. longa* with LC_{50} 12.62 g/L and LC_{90} 460.16 g/L (slope = 0.92 and P = 0.89). The least effective against the pest species was *A. galangal* with an LC_{50} value of 14.08 g/L and LC_{90} of 443.32 g/L. Figure 2 (b) shows the overall mean percentage mortality of *T. castaneum* where deltamethrin exhibited maximum mortalities of 41.67%, whereas among

the plant species extracts maximum mortalities were recorded for *N. rustica* 38.75% and *N. tabacum* 32.50%.

With increase in exposure time of *T. castaneum* to plant species extracts, the mortalities increased after 72 h. In plant species extracts, the highest toxicity was observed with *N. rustica* with an LC_{50} = 1.92 g/L and LC_{90} = 12.36 g/L (slope = 1.58 and P value = 0.20). The second most effective plant species extract was *N. tabacum* followed by *C. longa* and *A. indica* having LC_{50} (2.31, 2.65 and 2.85 g/L) and LC_{90} (24.55, 31.14 and 23.78 g/L) slope (1.24, 1.19 and 1.39) and P values (0.88, 0.87 and 0.66). On the other hand, deltamethrin showed the highest toxicity effect with least LC_{50} 1.77 g/L and LC_{90} 11.75 g/L against *T. castaneum* as shown in **Table-3.** Among the plant species extracts overall means mortalities to *T. castaneum, N. rustica* recorded maximum mortalities i.e. 61.25% and minimum was seen with *A. galangal* i.e. 45.00%. on other hand deltamethrin showed highest mortalities i.e. 62.92% to *T. castaneum* as shown in Fig. 2 after 72 hours' exposure.

Likewise, after 96 h of exposure, the mortality rate of *T. castaneum* increased as the time exposure to deltamethrin and plant species increased, and vice versa. Deltamethrin showed the highest toxicity effect with least LC_{50} 0.88 g/L and LC_{90} 4.74 g/L having slope 1.75 and P value 0.05. Among the plant species, the highest toxicities were observed with *N. rustica* having minimum LC_{50} 1.00 g/L and LC_{90} 5.38 g/L with slope 1.76 and P = 0.24 values. The second most effective plant species extract was *N. tabacum* followed by *C. longa* and *A. indica* having LC_{50} (1.09, 1.33, and 1.46 g/L) and LC_{90} (6.50, 6.89 and 7.43 g/L) with slope (1.65, 1.79 and 1.81) and P values (0.01, 0.04 and 0.19) against *T. castaneum.* After 96 hours' exposure period deltamethrin showed maximum mortalities to *T. castaneum* i.e. 80.00%. On other hand, among the plant species extracts, *N. rustica* exhibited highest mortalities 77.50% followed by *N. tabacum* 74.58%, *C. longa* 71.67% and *A. indica* 69.58% whereas, the lowermost was seen with *A. galanga* i.e. 65.00% against *T. castaneum* as shown in Fig. 2.

Table-3 Contact toxicity of deltamethrin and five plant extracts on *T. castaneum* after 24, 48, 72 and 96 hours' exposure time.

	Plant species	LC_{50} (95% CLs)	LC_{90} (95% CLs)	χ^2	P	Slope ± SE
24	*A. indica*	40.86 (16.18-956.61)	997.60 (128.62-934.98)	0.25	0.99	0.86 ± 0.26
	C. longa	27.25 (13.60-181.13)	356.20 (79.09-237.97)	0.13	0.99	1.14 ± 0.27
	N. tabacum	31.88 (13.74–515.70)	944.79 (125. 67-897.29)	0.36	0.98	0.87 ± 0.24
	A. galanga	43.19 (16.98-1014.72)	851.23 (117.92-776.29)	0.08	0.99	0.99 ± 0.27
	N. rustica	29.02 (13.11-360.48)	792.32 (116.03-417.39)	0.17	0.99	0.89 ± 0.24
	Deltamethrin	13.93 (8.80-39.39)	185.26 (56.63–309.40)	0.86	0.93	1.14 ± 0.23
48	*A. indica*	12.08 (7.97–29.82)	160.15 (52.23–210.30)	1.28	0.86	1.02 ± 0.23
	C. longa	12.62 (7.44–56.63)	460.16 (84.12- 829.88)	1.10	0.89	0.92 ± 0.21
	N. tabacum	9.62 (6.37–25.75)	235.80 (60.50- 843.74)	0.84	0.93	0.92 ± 0.21
	A. galanga	14.08 (8.13–65.35)	443.32 (84.33- 612.91)	0.62	0.96	0.85 ± 0.21
	N. rustica	5.75 (4.42–9.26)	94.80 (35.89-834.23)	0.38	0.98	1.05 ± 0.20
	Deltamethrin	4.60 (3.73–6.26)	54.28 (25.79-240.52)	2.84	0.58	1.19 ± 0.20
72	*A. indica*	2.85 (2.37–3.39)	23.78 (14.64–56.08)	2.37	0.66	1.39 ± 0.20

	Plant species	LC_{50} (95% CLs)	LC_{90} (95% CLs)	χ^2	P	Slope ± SE
	C. longa	2.65 (2.11–3.23)	31.14 (17.02–100.70)	1.25	0.87	1.19 ± 0.20
	N. tabacum	2.31 (1.80–2.79)	24.55 (14.40–66.90)	1.17	0.88	1.24 ± 0.20
	A. galanga	3.89 (3.18–5.05)	47.78 (23.30-201.21)	2.73	0.60	1.77 ± 0.20
	N. rustica	1.92 (1.53–2.26)	12.36 (8.92–20.97)	5.96	0.20	1.58 ± 0.20
	Deltamethrin	1.77 (0.92–2.44)	11.75 (6.83–55.67)	7.84	0.09	1.56 ± 0.20
96	*A. indica*	1.46 (1.14–1.74)	7.43 (5.92–10.44)	6.05	0.19	1.81 ± 0.21
	C. longa	1.33 (0.54–1.91)	6.89 (4.52–21.43)	9.88	0.04	1.79 ± 0.21
	N. tabacum	1.09 (0.16–1.78)	6.50 (3.98–44.25)	13.36	0.01	1.65 ± 0.21
	A. galanga	1.72 (0.92–2.34)	9.31 (5.85–31.63)	8.67	0.07	1.74 ± 0.21
	N. rustica	1.00 (0.70–1.27)	5.38 (4.39–7.25)	5.49	0.24	1.76 ± 0.22
	Deltamethrin	0.88 (0.22–1.41)	4.74 (3.27–11.93)	9.27	0.05	1.75 ± 0.22

*** 95% confidence intervals surround lethal concentrations (LC) (CLs). plant extracts with LC50 or LC90 values.*

Table 4 shows the residual toxicity of five plant extracts and deltamethrin insecticide. Of all the treatments, deltamethrin demonstrated the highest toxicity against *T. castaneum*, with an LC_{50} 13.93 and LC_{90} 185.26 (slope = 1.14) after 24 hours' exposure period. Among the examined plant species, *N. tabacum* had the highest level of toxicity, with LC50 values of 19.96 g/L and LC90 values of 322.17 g/L

and slopes of 1.06 and P values of 0.91, respectively, killing 50% and 90% of the insects. *A. galanga*, which had LC_{50} values of 26.34 g/L and LC_{90} values of 584.61 g/L (slopes of 0.95, P-value = 0.96,) was the second-most toxic plant species, followed by *A. indica* and *N. rustica*, which had identical LC_{50} values of 29.02 g/L and LC_{90} values of 792.32 g/L (slopes = 0.89 and P values = 0.99). *C. longa* with an LC_{50} value = 47.95 g/L and LC_{90} value = 1531.88 g/L (slope = 0.85, P value = 0.91) was found to be the least toxic plant extract. Identically, maximum percentage mortality 23.33% was exhibited by deltamethrin in *T. castaneum*. Among plants, it was highest for *N. tabacum* extract (20.00%) followed by *N. rustica* 19.58%, whereas, the lowest number of *T. castaneum* 15.83% were killed by *C. longa* (Fig. 3**).**

After 48 hours of exposure period of five plant species and deltamethrin, the highest mortality of *T. castaneum* was observed with deltamethrin with LC_{50} 11.52 g/L and LC_{90} 394.06 g/L having slope 0.83 with P = 0.98 values as shown in **Table-4.** Among the plant species, N. rustica exhibited the highest toxicity with the lowest LC_{50} 13.93 g/L and LC_{90} 658.48 g/L having slope values 0.76 and P = 0.99. After *N. rustica*, the next most toxic plant species was *A. indica* with LC_{50} 22.12 g/L and LC_{90} 1367.58 g/L having slope values 0.71 and P = 0.99 followed by *N. tabacum* having LC_{50} 22.74 g/L and LC_{90} 1980.62 g/L having slope values 0.66 and P = 0.95 respectively. The least toxic plant species was *A. galangal and C. longa* having the same LC_{50} 29.78 g/L and LC_{90} 1574.98 g/L with *T. castaneum.* From Fig. 3 it was cleared that over all mean deltamethrin showed 31.67% maximum mortalities to *T. castaneum*, whereas among the plant species extracts *N. rustica* observed highest mortalities 30.83% followed by *N. tabacum* 28.33%.

As the time exposure period of plant species increases, the mortalities of *T. castaneum* were also increased and vice versa. Among the plant species, the highest toxicities were observed with *N. rustica* having minimum LC_{50} 2.30 g/L and LC_{90} 24.46 g/L with slope 1.25 and P = 0.32 values. The second most effective plant species extract was *N. tabacum* followed by *A. indica* and *C. longa* having LC_{50} (3.51, 6.13 and 9.84 g/L) and LC_{90} (78.16, 359.22 and 475.09 g/L) with slope (0.95, 0.72 and 0.76) and P values (0.85, 0.94 and 0.81). on the other hand, deltamethrin showed the highest toxicity effect with least LC_{50} 1.64 g/L and LC_{90} 36.11 g/L against *T. castaneum* as shown in **Table-4.** Among the plant species extracts overall means mortalities to *T. castaneum, N. rustica* recorded maximum mortalities i.e. 55.42% and minimum was seen with *C. longa* i.e. 35.00%. on other hand deltamethrin showed highest mortalities i.e. 59.58% to *T. castaneum* as shown in Fig. 3 after 72 hours' exposure period.

From **Table-4**, it was cleared that as the time exposure period of deltamethrin and plant species increases, the mortalities of *T. castaneum* were also increased and vice versa. Deltamethrin showed the highest toxicity effect with least LC_{50} 0.93 g/L and LC_{90} 3.83 g/L having slope 2.08 and P value 0.00. Among the plant species, the highest toxicities were observed with *N. rustica* having minimum LC_{50} 0.79 g/L and LC_{90} 10.37 g/L with slope 1.04 and P = 0.99 values. The second most effective plant species extract was *N. tabacum* followed by *A. indica* and *A. galanga* having LC_{50} (1.18, 1.82, and 1.88 g/L) and LC_{90} (9.02, 22.36 and 15.78 g/L) with slope (1.45, 1.17 and 1.38) and P values (0.06, 0.43 and 0.30) against *T.*

castaneum. After 96 hours' exposure period deltamethrin showed maximum mortalities to *T. castaneum* i.e. 80.83%, while on other hand among the plant species extracts *N. rustica* exhibited higher mortalities 73.75% followed by *N. tabacum* 70.83%, *A. indica* 65.58% and *A. galanga* 60.42% and lower was seen with *C. longa* i.e. 54.58% against *T. castaneum* as shown in Fig. 3.

Table-4 Residual toxicity of deltamethrin and five plant extracts on *T. castaneum* after 24, 48, 72 and 96 hours' exposure.

	Plant species	LC_{50} (95% CLs)	LC_{90} (95% CLs)	χ^2	P	Slope ± SE
24	*A. indica*	29.02 (13.11-360.48)	792.32 (116.03- 4170.39)	0.17	0.99	0.89 ± 0.24
	C. longa	47.95 (17.17- 240.61)	1531.88 (154.06- 1164.55)	0.05	1.00	0.85 ± 0.25
	N. tabacum	19.96 (11.00-91.48)	322.17 (76.27- 1453.46)	0.97	0.91	1.06 ± 0.24
	A. galanga	26.34 (12.65- 227.18)	584.61 (101.44- 1170.44)	0.55	0.96	0.95 ± 0.24
	N. rustica	29.02 (13.11-360.48)	792.32 (116.03- 4173.39)	0.17	0.99	0.89 ± 0.24
	Deltamethrin	13.93 (8.80-39.39)	185.26 (56.63-3093.40)	0.86	0.93	1.14 ± 0.23
48	*A. indica*	22.12 (10.15-418.38)	1367.58 (138.90-1142.21)	0.22	0.99	0.71 ± 0.21
	C. longa	29.78 (12.38-845.56)	1574.98 (152.81-1546.66)	0.64	0.95	0.74 ± 0.22
	N. tabacum	22.74 (9.96-771.31)	1980.62 (158.61-1615.04)	0.64	0.95	0.66 ± 0.21
	A. galanga	29.78 (12.38-845.75)	1574.98 (152.81-1546.66)	0.64	0.95	0.74 ± 0.22
	N. rustica	13.93 (7.58–88.02)	658.48 (98.27-4025.07)	0.27	0.99	0.76 ± 0.21
	Deltamethrin	11.52 (7.03–44.64)	394.06 (77.62-4913.54)	0.41	0.98	0.83 ± 0.21
72	*A. indica*	6.13 (4.24–15.89)	359.22 (65.67-1082.52)	0.73	0.94	0.72 ± 0.20

	Plant species	LC_{50} (95% CLs)	LC_{90} (95% CLs)	χ^2	P	Slope ± SE
	C. longa	9.84 (6.10-39.51)	475.09 (81.25-1482.63)	1.59	0.81	0.76 ± 0.20
	N. tabacum	3.51 (2.73–4.78)	78.16 (29.59-783.37)	1.35	0.85	0.95 ± 0.20
	A. galanga	8.02 (4.95–46.43)	895.92 (97.71-1479.40)	0.91	0.92	0.62 ± 0.20
	N. rustica	2.30 (1.80–2.79)	24.46 (14.35–66.35)	4.69	0.32	1.25 ± 0.20
	Deltamethrin	1.64 (0.98–2.16)	36.11 (16.91-211.28)	5.00	0.98	0.95 ± 0.19
96	*A. indica*	1.82 (1.30–2.27)	22.36 (13.04–63.98)	3.81	0.43	1.17 ± 0.20
	C. longa	2.24 (1.55–2.88)	51.89 (21.87-402.85)	3.12	0.53	0.94 ± 0.19
	N. tabacum	1.18 (0.29–1.83)	9.02 (5.27–59.36)	8.96	0.06	1.45 ± 0.21
	A. galanga	1.88 (1.45–2.27)	15.78 (10.50-32.14)	4.86	0.30	1.38 ± 0.20
	N. rustica	0.79 (0.37–1.16)	10.37 (6.97–22.71)	0.19	0.99	1.04 ± 0.21
	Deltamethrin	0.93 (0.28–1.33)	3.83 (2.53–13.31)	7.58	0.00	2.08 ± 0.24

*** 95% confidence intervals surround lethal concentrations (LC) (CLs). Plant extracts with LC_{50} or LC90 values.*

4. DISCUSSION

Tables 3 and 4 show the percentage mortality of *T. castaneum* adults in contact and residual toxicity tests after exposure to different concentrations of plants extracts for 24, 48, 72, and 96 h. Of the five plant

species extracts, *N. tabacum*, *N. rustica, C. longa*, and *A. indica* demonstrated the most encouraging results in terms of high mortality. This may be due to the neurotoxicity and gastro toxicity of *Nicotiana tabacum* [19] [20]. These variations are thought to be the result of both the chemical composition of plant extracts from distinct plant species and the physiological makeup of insects. Additionally, the effectiveness of plant extracts varied depending on the exposure time.

This can be explained by duration of exposure or thought to be linked to the penetration ability of the active chemical compound. The efficacy of plant extracts has been reported by in recent literature. [21] [22], which are in line with the findings of the current study. Percentage mortality of red flour beetle was directly related to the increase in concentration of *C. longa* extracts. These results are in line with [23] who also reported an increase in mortality rate of *T. castaneum* with increased concentration and exposure time. Similarly, [24] in their study showed the repellency effect of turmeric (*Curcuma longa*) extracts on *Oryzaephilus surinamensis, T. castaneum, Sitophilus oryzae, Corcyra cephalonica* and *Cryptolestes ferrugineus.* [25] investigated the toxicity of essential oil in turmeric leaf extracts in contact bioassay and as fumigant on *Sitophilus oryzae*, *T. castaneum and Rhyzopertha dominica's*, eggs, juvinilles and rate of adult oviposition. Adult R. dominica were found significantly susceptible to contact activity. Moreover, in *T. castaneum* the exposure to the essential oils caused a significant decline of 72 and 80% in oviposition and egg hatching respectively. The various chemicals isolated from turmeric powder also demonstrated the repellent effect on *T. castaneum* [26].

Neem seed extracts demonstrated a diverse effect *T. castaneum.* Mortality rate of red flour beetle increased with the increase in concentration of neem seed extract as well as exposure time and experimental concentrations exhibited a high insecticidal effect as compared to the control. Maximum mortality was reported when the pest was exposed to the treatments for 96 hours. Many recent researches confirm the effectiveness of plant derivatives against stored grains pests. For instance [27] reported that azadirachtin found in Neem extracts was noxious for *T. castaneum* than control. As per their findings, the number of F1 adults declined significantly with all the test doses. Likewise, [28] tested neem extracts at 50, 100, and 200 ppm against *T. confusum*, *Sito, philus oryzae* (L.) and *Rhyzopertha dominica* (F.). Their findings showed an increase in mortality of the pests with an increase in dose and duration of exposure.

The contact toxicity of plant extracts against adults was [14] investigated the contact toxicity of various plant extracts on *T. castaneum*. Of these, *A. galangal* plant extract exhibited a significantly high insecticidal effect on *T. castenum*. This may be attributed to the occurrence of 1,8-cineol in high percentage which also has a strong antifeeding action. The presence of 1,8-cineol was also confirmed by [29] *A. calcarata.* The chemical 1,8-cineol is recognized as the marker of Alpinia spp. Insecticidal properties ginger extract, *Z. officinale*, has also been demonstrated by [30].

In current study, deltamethrin exhibited high efficacy against *T. castaneum* (LC_{50} (0.88, 0.93) and LC_{90} (4.74, 3.83)) in contact as well as residual toxicity tests, after 96 hours of exposure. The neurotoxic action of deltamethrin on insects is caused by the disruption of nerve impulse axonal transmission by altering

the ion permeability of nerve membranes [31]. The knockdown effect of deltamethrin is well known against a variety of insect pests, including coleopterans [32]. A similar effect of higher concentrations of deltamethrin in terms of high mortality in *T. castaneum* adults was observed in our investigation. Consumers still perceive any infestation of packaged food as unacceptable. The current study revealed that although the insect infestation of stored gains treated with plant extracts has significantly decreased, the question of whether using plant extracts will completely prevent infestation needs to be addressed. In general, the efficacy of plant extract against *T. castaneum* depend on a variety of factors, such as treatment doses of the plant extract, application methods, and the insect's life cycle stage etc. More research is required to establish the ideal formulation, dosage, method of administration, impact of environmental conditions, and content of plant extracts to use them effectively to prevent *T. castaneum* infection in stored items.

5. CONCLUSION

Using plant species extracts as mitigation and biocontrol tool against *T. castaneum* is a financially viable, socially acceptable, and eco-friendly tactic. According to our findings, *N. rustica, N. tabacum*, and *C. longa* may be used as an alternative to pesticides in rural tropics and subtropical environments due to their high contact toxicity, while in case of residual toxicity *N. rustica, N. tabacum* and *A. indica* exhibited maximum mortalities to *T. castaneum*. The effective and promising toxicity of these botanicals make them as prospective candidate against *T. castaneum*, and their integration with other control measures is advised to lessen environmental pollution and associated health risks. Additionally, the utilization of these plant extracts may create new opportunities for the control of *T. castaneum*.

DECLARATIONS

Author Contribution

Rasheed Akbar conducted experiments and wrote first draft of the manuscript Ashraf Ali wrote part of the manuscript and revised the draft Wajid Ali Khattak carried out statistical analysis Brekhna Faheem Draw the graphs Sikandar Zaman Data curation Abid Farid supervised the work Imtiaz Ali Khan provided lab facility Jianfan Sun provided financial support, Mohsin Nawaz helped in collecting plants

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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Figures

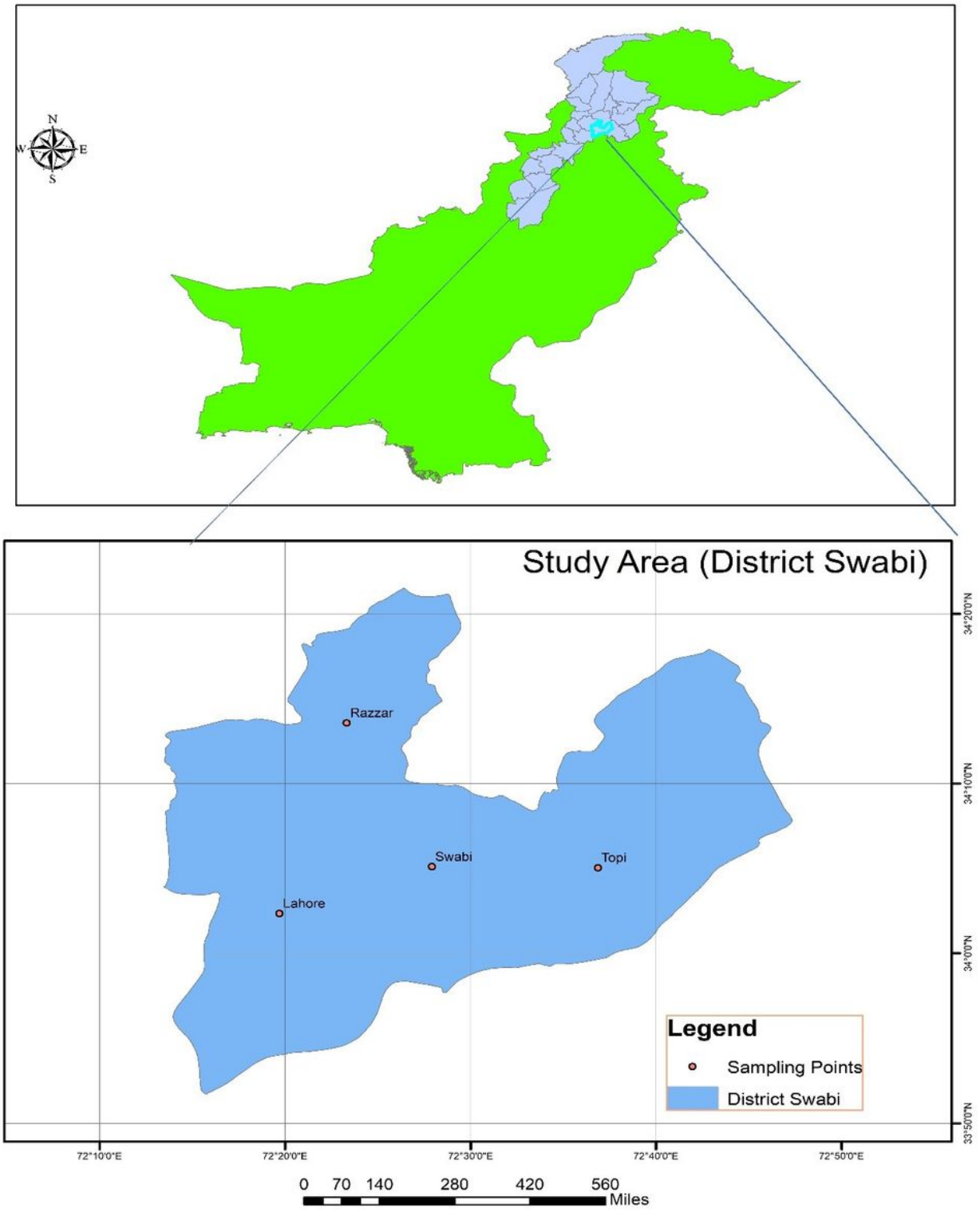


Figure 1

Geographic location of the area where the five plant species were collected during 2022.

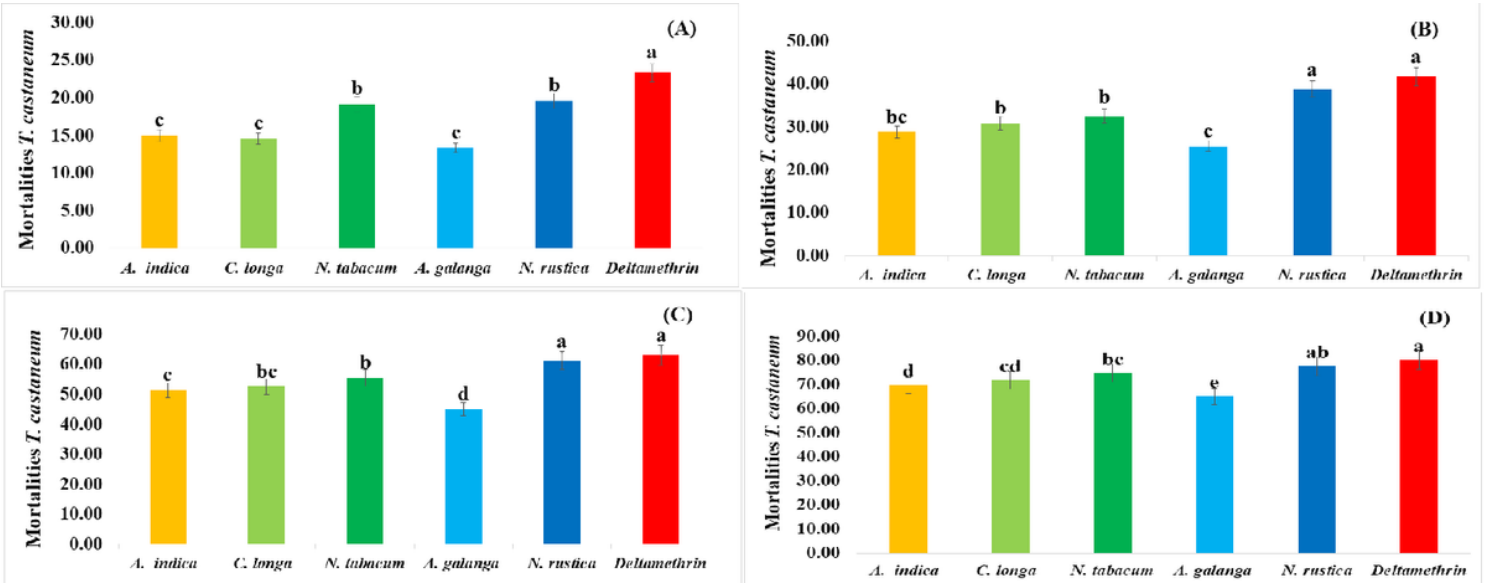


Figure 2

Mean percentage mortality of *T. castaneum* treated with plant extracts and deltamethrin in contact toxicity test (A) after 24 h, (B) after 48 h, (C) after 72 h (D) after 96 h. (The bars with different lowercase letters indicate that the means are significantly different from each other at p = 0.05.

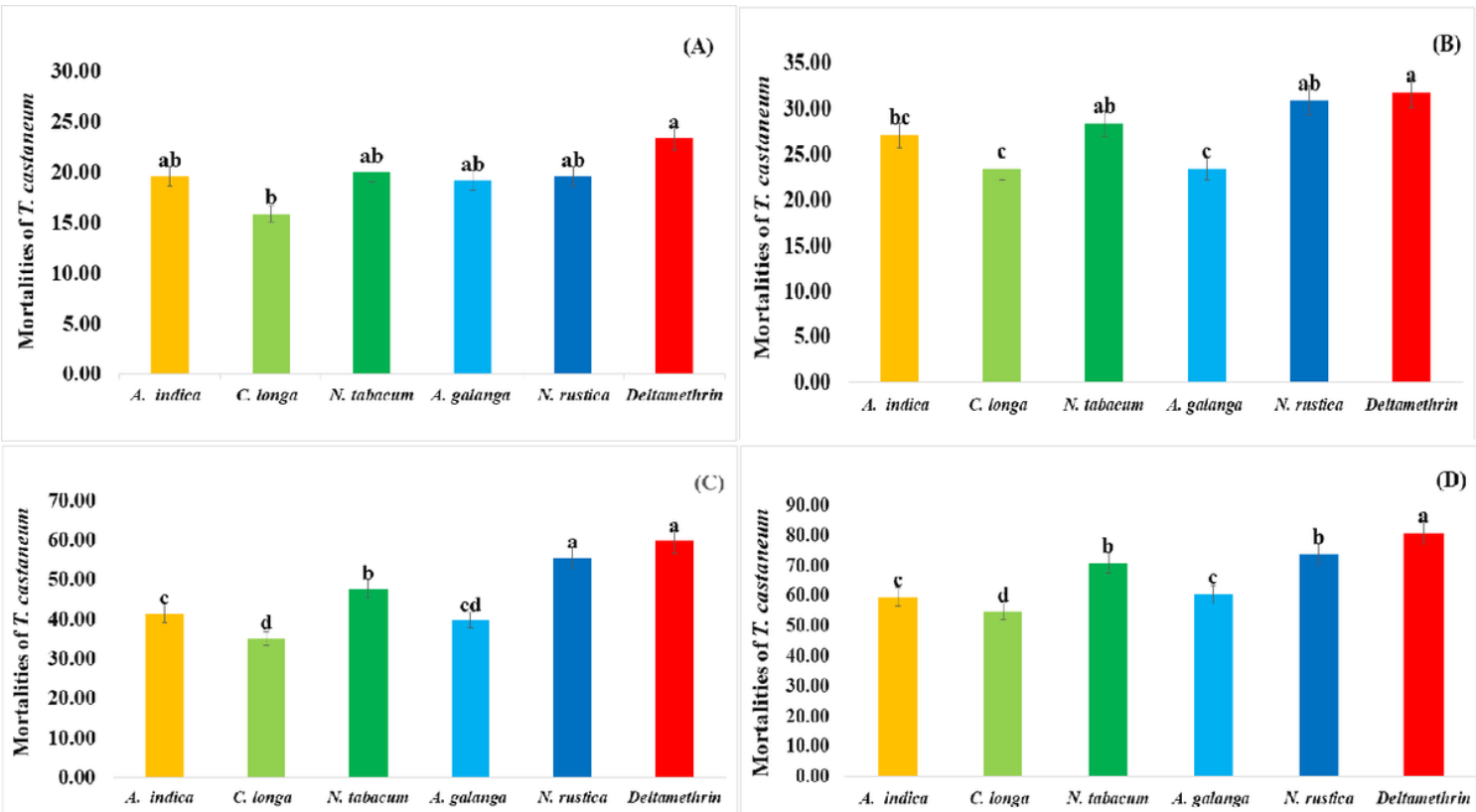


Figure 3

Mean percent mortality of *T. castaneum* treated with plant extracts and deltamethrin after (A) 24h, (B) 48h, (C), 72h and (D), 96 h exposure (residual effect). (The bars with different lowercase letters indicate

that the means are significantly different from each other at p = 0.05.

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