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ECO-FRIENDLY MANAGEMENT OF PULSE BEETLE (*CALLOSOBRUCHUS ANALIS*) USING INDIGENOUS PLANT AQUEOUS EXTRACTS

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ABSTRACT

Post-harvest losses caused by insect pests threaten the safe storage of pulses, particularly mung bean (*Vigna radiata* L.). The pulse beetle, *Callosobruchus analis*, is a major storage pest responsible for severe quantitative and qualitative losses. This study evaluated the insecticidal efficacy of aqueous extracts from six indigenous plant species, such as garlic (*Allium sativum*), turmeric (*Curcuma longa*), neem (*Azadirachta indica*), tumha (*Citrullus colocynthis*), ajwain (*Trachyspermum ammi*), and bitter cress (*Caralluma tuberculata*), against *C. analis* under laboratory conditions. A Completely Randomized Design with five replications was used to test six concentrations (0.5–3.0% w/v) of each extract. Adult mortality was recorded up to 7 days, and effects on fecundity, development, adult emergence, grain infestation, and weight loss were evaluated. All plant extracts significantly affected the survival and biological parameters of *C. analis*. Garlic and turmeric extracts were most effective, producing up to 81.1% adult mortality, significantly reducing oviposition, delaying development, suppressing progeny emergence, and minimizing grain infestation and weight loss. Grain damage was reduced from ≈40% in control to 11–15% in treated grains, while weight loss decreased from 27.4% to as low as 7.25%. Neem and tumha showed moderate efficacy, whereas ajwain and bitter cress were comparatively less effective. Sex ratio was not significantly affected. The results demonstrate that aqueous extracts of indigenous plants, particularly garlic and turmeric, provide an effective, eco-friendly alternative to synthetic insecticides and hold strong potential for sustainable management of pulse beetle in stored mung beans.

Keywords: *Callosobruchus analis*; Botanical extracts; Mung bean storage; Indigenous plants; Eco-friendly pest control.

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INTRODUCTION

Pulses are edible seeds of leguminous plants such as mung beans, lentils, and chickpeas, and constitute an important component of human nutrition. They contain 25–40% protein, 50–60% carbohydrates, essential minerals, vitamins, and amino acids, making them an affordable source of dietary protein in developing countries where animal protein is limited. (Bhalla et al., 2008; Khalil & Jan, 2002; Yadav et al., 1994). In addition to their nutritional value, pulses improve soil fertility through biological nitrogen fixation and contribute to sustainable agricultural systems. (Afzal et al., 2004; Kannaiyan, 2003). Due to their

high nutritive value, pulses are often referred to as “vegetarian meat.” (Darmadi-Blackberry et al., 2004).

Among grain legumes, mung bean (*Vigna radiata* L.) is widely cultivated in tropical and subtropical regions and ranks among the major pulse crops in Pakistan. (Ali et al., 2010). However, a substantial portion of the stored mung beans is lost due to insect infestation. Stored grain pests cause both quantitative and qualitative losses by feeding on grains and contaminating them with insect fragments and excreta. The Food and Agriculture Organization estimates post-harvest losses of 10–50% in stored grains in developing countries (FAO, 2012). Pulse beetles of the

genus *Callosobruchus* are among the most destructive storage pests of pulses, causing 40–50% losses under favorable conditions. (Ahad, 2003; Ghosh, 2003). Infestation often begins in the field and continues during storage, where larvae bore into grains and destroy the endosperm and embryo, reducing grain weight, nutritional quality, and germination potential. (Appleby & Credland, 2004; Haines, 1989). *Callosobruchus analis* is a major pest of mung bean and other pulses, with reported storage losses ranging from 32–64% and reaching destruction under severe infestation. (Akinkurolere et al., 2006; Ramzan et al., 1990). The management of stored grain insect pests traditionally relies on fumigation and synthetic insecticides. Although these chemicals provide effective control, their repeated and indiscriminate use has resulted in serious problems such as pest resistance, toxic residues in food grains, environmental contamination, and health hazards to humans and livestock. (Desmarchelier, 1985; Fishwick, 1988). Botanical insecticides have long been used in pest management and are gaining renewed attention due to their biodegradability, safety to non-target organisms, and compatibility with integrated pest management programs. (Nizamani et al., 2020; Saxena & Sayyed, 2018). Plants contain bioactive compounds such as alkaloids, phenolics, flavonoids, terpenoids, and sulfur-containing compounds that exhibit insecticidal, repellent, antifeedant, and growth-regulating effects. (Grainge & Ahmed, 1988; Harborne, 1998). Among botanical formulations, aqueous extracts are particularly suitable for small-scale farmers because they are inexpensive, easy to prepare, and relatively safe. Previous studies have demonstrated the effectiveness of plant extracts against pulse beetles. Aqueous extracts have been reported to reduce oviposition, adult emergence, and grain damage. (Jayakumar, 2010; Srivastava & Gupta, 2007; Zia et al., 2011). However, comparative information on the efficacy of indigenous plant aqueous extracts at different concentrations against *C. analis* remains limited. Therefore, the present study evaluated locally available plant aqueous extracts to identify eco-friendly and farmer-friendly options for managing pulse beetle in stored mung beans. The findings are expected to support the development of sustainable pest management strategies that enhance food safety and storage protection.

MATERIALS AND METHODS

Experimental Site and Environmental Conditions

The experiment was conducted under controlled laboratory conditions in the Post Graduate Laboratory of the Department of Entomology, Faculty of Agriculture, Gomal

University, Dera Ismail Khan, Khyber Pakhtunkhwa (KPK), Pakistan. Throughout the study, temperature was maintained at 27 ± 3 °C, relative humidity at $65 \pm 5\%$, and a 12:12 h (Light: Dark) photoperiod. These conditions were selected to favor the normal development of *Callosobruchus analis* and to ensure uniformity during experimentation.

Insect Culture and Maintenance

A laboratory culture of pulse beetle (*Callosobruchus analis*) was established using infested mung bean grains collected from a local grain market. The species was taxonomically identified before culture initiation. Clean and healthy mung bean grains were used for rearing the insect culture. The culture was maintained in plastic jars covered with muslin cloth to allow ventilation and prevent insects from escaping. The jars were kept in an incubator under the same controlled environmental conditions used for experimentation. Newly emerged adult beetles were periodically transferred to fresh jars containing clean mung bean grains to maintain continuous culture. Adults used in the bioassays were 24 hours old and were starved for 24 hours before release to standardize feeding activity.

Preparation of Mung Bean Grains

Mung bean grains were carefully cleaned to remove broken grains, debris, and foreign materials. To eliminate any pre-existing insect infestation, grains were sterilized in a kiln at 60 °C for 3 hours, following the method described by (Fields, 1992). After sterilization, grains were allowed to cool at room temperature and stored in airtight containers until use. For each treatment, 50 g of sterilized grains were weighed using an analytical balance.

Selection and Processing of Plant Materials

Six indigenous plant species were selected based on their traditional use and previously reported insecticidal properties. These included garlic (*Allium sativum*), turmeric (*Curcuma longa*), neem (*Azadirachta indica*), tumha (*Citrullus colocynthis*), ajwaen (*Trachyspermum ammi*), and bitter cress (*Caralluma tuberculata*). The required plant parts were collected locally, washed thoroughly with tap water followed by distilled water, and shade-dried for 7–10 days. Dried plant materials were ground separately into fine powder using an electric grinder. The powders were passed through a fine mesh sieve to ensure uniform particle size and stored in airtight containers at room temperature until extract preparation.

Preparation of Aqueous Plant Extracts

Aqueous extracts were prepared using a cold extraction method. Known quantities of plant powder were mixed with distilled water to prepare six concentrations (0.5, 1.0, 1.5, 2.0, 2.5, and 3.0% w/v). The mixtures were stirred

thoroughly and allowed to stand for 24 hours at room temperature to facilitate the extraction of bioactive compounds. After extraction, the solutions were filtered

through double-layered muslin cloth to remove solid plant residues. Fresh extracts were prepared prior to each experimental run to avoid degradation of active constituents.

Table 1: Plant Materials assessed for Insecticidal properties against *C. analis*.

S. No.	Common Name	Botanical Name	Plant portion used
1	Neem	<i>Azadirachta indica</i>	Seeds
2	Turmeric	<i>Curcuma longa</i>	Rhizomes
3	Garlic	<i>Allium sativum</i>	Bulbs
4	Ajwain	<i>Trachyspermum ammi</i>	Seeds
5	Tumha	<i>Citrullus colocynthis</i>	Fruits
6	Bitter cress (Chungan)	<i>Caralluma tuberculata</i>	Stem

Experimental Design and Treatment Application

The experiment was laid out in a Completely Randomized Design (CRD) comprising seven treatments (six plant aqueous extracts and one untreated control), six concentrations, and five replications. For each replicate, 50 g of sterilized mung bean grains were treated with the respective plant extract concentration and mixed thoroughly to ensure uniform coating of grains. The treated grains were transferred to clean, translucent plastic jars. Control treatments consisted of untreated mung bean grains.

Insect Infestation

After one hour of treatment, five pairs (10 adults) of freshly emerged and 24-hour starved *C. analis* adults were introduced into each jar. The jars were covered with muslin cloth secured with elastic bands to prevent insect escape while allowing proper aeration. All jars were maintained under controlled laboratory conditions throughout the experiment.

Assessment of Adult Mortality

Adult mortality was recorded at **24, 48, and 72 hours, and 7 days** after insect release. Dead beetles were counted and removed after each observation. Mortality data were corrected for control mortality using Abbott's formula:

$$\text{Corrected \% Mortality} = \frac{\% \text{ mortality in treatment} - \% \text{ mortality in control}}{100 - \% \text{ mortality in control}} \times 100$$

Evaluation of Biological Parameters

After seven days of exposure, all surviving adult beetles were removed from the jars. The treated grains were retained under laboratory conditions to evaluate the following biological parameters:

Fecundity: Number of eggs laid per 20 randomly selected grains using a magnifying lens

Developmental duration: Number of days required for F_1 adult emergence

Adult progeny emergence: Total number of F_1 adults

emerged from each treatment

Percent infestation: Calculated based on the proportion of damaged grains

Grain weight loss: Determined using the difference between initial and final grain weights

Sex ratio: Ratio of male to female adults emerged

Adult longevity: Number of days adult beetles survived after emergence

Statistical Analysis

All data were subjected to analysis of variance (ANOVA) under a Completely Randomized Design (CRD). Treatment means were compared using the Least Significant Difference (LSD) test at the 5% probability level. Percentage data were transformed where necessary to satisfy the assumptions of normality and homogeneity of variance. All statistical analyses were performed using R software version 4.5.0.

RESULTS

Insecticidal properties of six local plant aqueous extracts at six different concentrations were assessed against pulse beetle on different parameters under controlled laboratory conditions. The data obtained were statistically evaluated and explained below:

Mortality after 24, 48, 72 Hours, and 7 Days

Mortality after 24 hours

Twenty-four hours after treatment, all plant aqueous extracts caused low mortality of *Callosobruchus analis*, with values remaining below 10%. However, mortality increased slightly with increasing concentration, and several treatments differed significantly from the untreated control ($P < 0.05$) (Table 2; Figure 1). The lowest mortality (0.20%) was observed in grains treated with ajwain extract at 0.5%, which did not differ significantly from bitter cress, tumha, and neem treatments at the same concentration. The highest mortality (7.50%) was recorded

with garlic extract at 3.0%, which was statistically comparable to turmeric (6.60%). Overall, the highest concentration (3.0%) produced significantly greater mortality than lower concentrations.

Cumulative mortality after 48 hours

After 48 hours, mortality increased slightly but remained moderate across treatments (Table 3; Figure 2). Minimum

mortality ($\approx 2\%$) was recorded in grains treated with lower concentrations of ajwain and bitter cress extracts. Garlic extract at 3.0% caused the highest mortality (11.60%), followed closely by tumha and turmeric treatments. Mortality in the control remained minimal ($\approx 1.40\%$). Higher concentrations (3.0%) consistently produced greater mortality than lower doses.

Table 2: Percent mortality of pulse beetle in grains treated with six plant aqueous extracts after 24 hours of treatment.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	0.90 $\pm$ 0.79 bc	1.70 $\pm$ 0.83 bc	2.60 $\pm$ 0.96 abc	2.70 $\pm$ 0.83 bcd	3.50 $\pm$ 0.79 c	4.30 $\pm$ 0.90 c
Turmeric	1.90 $\pm$ 0.74 ab	2.20 $\pm$ 0.65 ab	3.60 $\pm$ 0.96 ab	4.30 $\pm$ 1.03 ab	5.70 $\pm$ 0.97 ab	6.60 $\pm$ 0.96 ab
Garlic	2.90 $\pm$ 0.74 a	3.70 $\pm$ 1.03 a	4.20 $\pm$ 1.14 a	4.50 $\pm$ 1.06 a	6.50 $\pm$ 0.74 a	7.50 $\pm$ 0.79 a
Ajwaen	0.20 $\pm$ 0.14 c	0.40 $\pm$ 0.25 c	0.80 $\pm$ 0.53 de	1.20 $\pm$ 0.83 de	1.90 $\pm$ 0.74 d	1.60 $\pm$ 0.54 d
Tumha	0.40 $\pm$ 0.15 c	0.60 $\pm$ 0.18 bc	2.00 $\pm$ 0.79 bcd	3.10 $\pm$ 0.89 abc	4.90 $\pm$ 0.65 bc	5.90 $\pm$ 0.65 b
Bitter cress	0.60 $\pm$ 0.13 c	0.90 $\pm$ 0.19 bc	1.80 $\pm$ 0.33 cde	1.90 $\pm$ 0.54 cde	1.80 $\pm$ 0.43 d	3.20 $\pm$ 0.83 c
Control	0.20 $\pm$ 0.16 c	0.40 $\pm$ 0.14 c	0.20 $\pm$ 0.15 e	0.20 $\pm$ 0.15 e	0.40 $\pm$ 0.16 d	0.20 $\pm$ 0.17 d
LSD Value	1.23	1.66	1.76	1.72	1.55	1.52

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

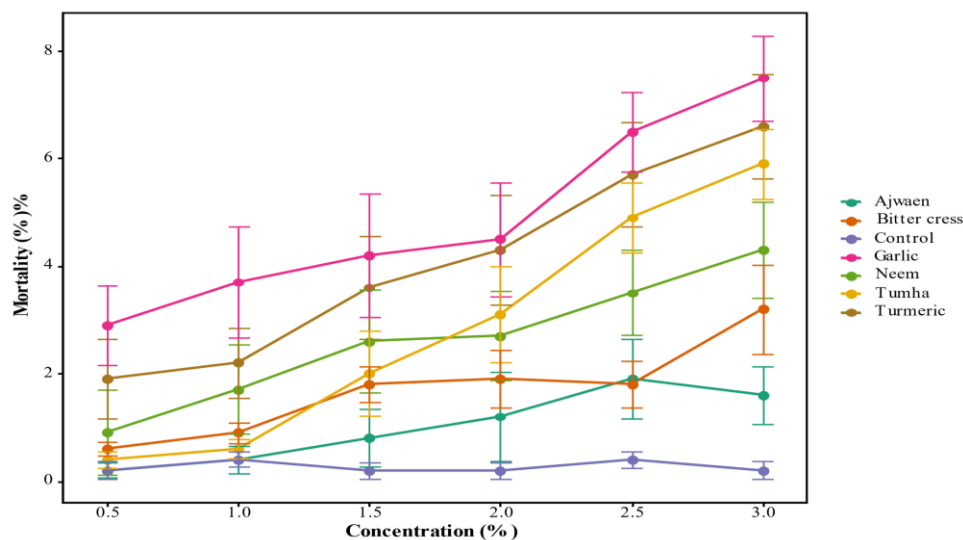


Figure 1: Effect of plant extracts on 24hour mortality.

Table 3: Percent mortality of pulse beetle in grains treated with six plant aqueous extracts after 48 hours of treatment.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	3.10 $\pm$ 1.19 cd	6.50 $\pm$ 0.79 b	8.00 $\pm$ 0.79 b	9.00 $\pm$ 1.12 a	9.30 $\pm$ 1.03 b	9.60 $\pm$ 1.14 b
Turmeric	5.10 $\pm$ 0.96 ab	7.50 $\pm$ 0.79 ab	8.90 $\pm$ 0.96 ab	9.50 $\pm$ 0.93 a	9.90 $\pm$ 0.96 ab	10.50 $\pm$ 0.79 ab
Garlic	6.50 $\pm$ 0.79 a	8.50 $\pm$ 0.79 a	9.90 $\pm$ 0.96 a	10.30 $\pm$ 1.03 a	11.30 $\pm$ 0.90 a	11.60 $\pm$ 0.96 a
Ajwaen	2.00 $\pm$ 0.57 d	2.50 $\pm$ 1.27 c	2.70 $\pm$ 0.90 c	4.40 $\pm$ 1.19 b	4.60 $\pm$ 0.96 c	6.90 $\pm$ 0.96 c
Tumha	3.90 $\pm$ 0.96 bc	7.70 $\pm$ 1.15 ab	9.10 $\pm$ 0.96 ab	9.40 $\pm$ 0.96 a	11.00 $\pm$ 0.79 ab	11.00 $\pm$ 0.79 ab
Bitter cress	2.00 $\pm$ 0.79 d	2.50 $\pm$ 0.79 c	3.70 $\pm$ 1.03 c	4.00 $\pm$ 0.79 b	6.30 $\pm$ 1.03 c	7.00 $\pm$ 0.79 c
Control	1.50 $\pm$ 0.44 d	2.00 $\pm$ 0.79 c	2.60 $\pm$ 0.96 c	1.40 $\pm$ 0.96 c	2.40 $\pm$ 0.65 d	2.00 $\pm$ 0.79 d
LSD Value	1.87	1.86	1.89	2.02	1.84	1.80

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

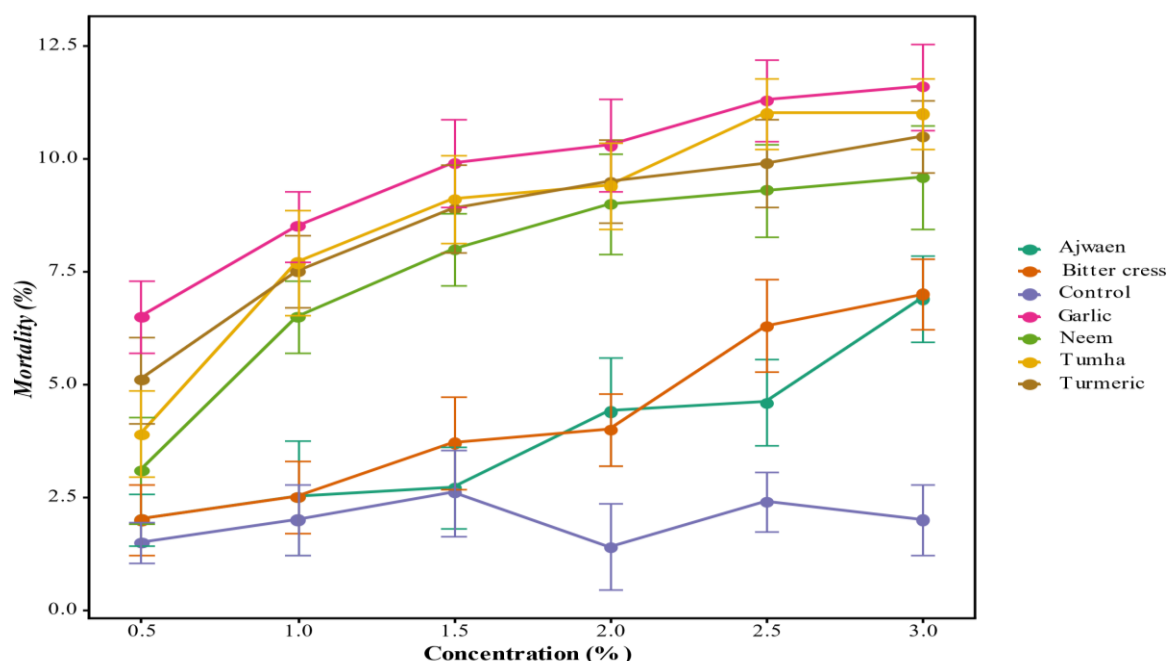


Figure 2: Effect of plant extracts on 48hour mortality.

Cumulative mortality after 72 hours

A clear increase in mortality was observed after 72 hours, indicating enhanced effectiveness with prolonged exposure (Table 4; Figure 3). Garlic and turmeric extracts were the most effective treatments, whereas ajwain and bitter cress were the least effective. The lowest mortality (5.00%) was recorded with ajwain extract at 0.5%, while the highest mortality (22.50%) occurred in grains treated with garlic extract at 3.0%. Mortality increased progressively with concentration, with higher doses (2.0–3.0%) producing significantly greater mortality than lower concentrations. Control mortality remained low (4.50%).

Cumulative mortality after 7 days

After 7 days of exposure, mortality differed significantly among treatments ($P < 0.05$) (Table 5; Figure 4). Four plant extracts caused more than 50% mortality at most

concentrations. At 0.5%, garlic and turmeric treatments recorded the highest mortality (76.30% and 74.20%, respectively), while ajwain and bitter cress produced the lowest mortality (40.80% and 44.30%). Mortality increased consistently with concentration, reaching a maximum of 81.10% in grains treated with garlic extract at 3.0%, followed closely by turmeric and tumha treatments. In contrast, ajwain extract showed the lowest mortality (54.10%) at the same concentration. Control treatments recorded only 11.10% mortality.

Fecundity (Egg Deposition)

Plant aqueous extracts significantly affected the fecundity of *Callosobruchus analis* at all tested concentrations (Table 6; Figure 5). Egg deposition varied significantly among treatments, and oviposition decreased progressively with increasing extract concentration.

Table 4: Percent mortality of pulse beetle in grains treated with six plant aqueous extracts after 72 hours of treatment.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	10.50 ± 0.79 b	11.40 ± 0.96 c	13.10 ± 0.96 b	13.50 ± 1.06 b	16.10 ± 0.96 b	16.50 ± 0.79 c
Turmeric	15.50 ± 0.79 a	16.00 ± 0.79 b	19.50 ± 0.79 a	19.80 ± 1.15 a	20.50 ± 0.79 a	20.00 ± 0.79 b
Garlic	16.90 ± 0.96 a	18.00 ± 0.79 a	20.00 ± 0.79 a	21.10 ± 0.96 a	21.90 ± 0.96 a	22.50 ± 0.79 a
Ajwaen	5.00 ± 0.79 d	7.50 ± 0.79 d	7.50 ± 0.79 d	8.50 ± 0.79 c	8.70 ± 0.57 d	10.50 ± 0.79 d
Tumha	12.40 ± 1.19 b	12.20 ± 1.20 c	14.90 ± 1.19 b	14.20 ± 1.20 b	16.50 ± 0.79 b	19.30 ± 1.15 b
Bitter cress	7.40 ± 1.19 c	8.00 ± 0.79 d	9.60 ± 0.96 c	13.50 ± 0.79 b	14.40 ± 0.96 c	16.10 ± 0.96 c
Control	4.50 ± 0.93 d	6.50 ± 0.79 d	5.80 ± 0.96 d	4.50 ± 0.79 d	7.00 ± 0.79 e	6.00 ± 1.12 e
LSD Value	1.94	1.78	1.93	1.96	1.69	1.86

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

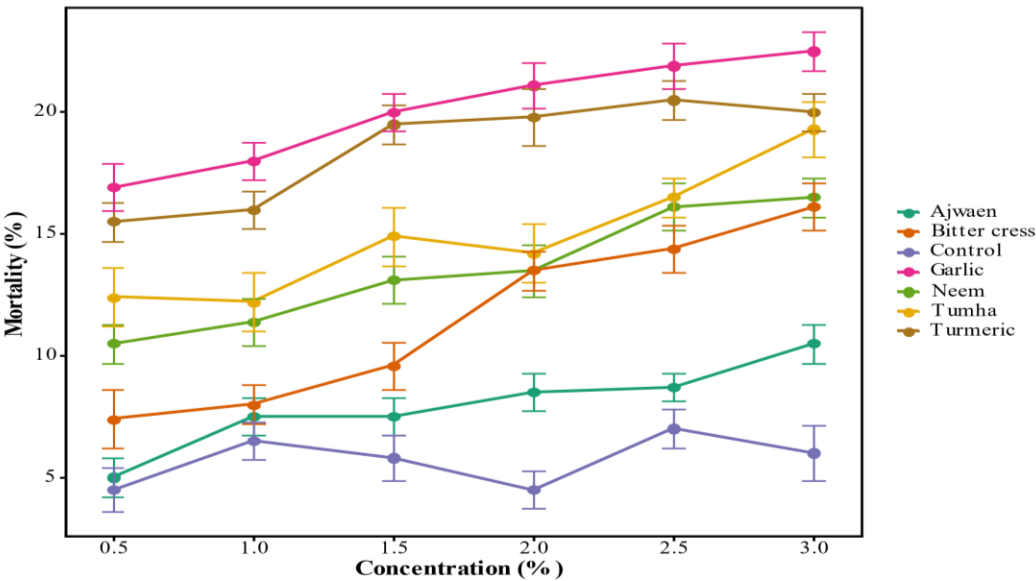


Figure 3: Effect of plant extracts on 72hour mortality.

Table 5: Percent mortality of pulse beetle in grains treated with six plant aqueous extracts after 7 days of treatment.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	50.40 ± 1.59 c	52.70 ± 1.44 d	54.40 ± 1.43 d	61.40 ± 1.43 b	62.10 ± 1.55 d	66.20 ± 1.03 b
Turmeric	74.20 ± 1.20 a	75.10 ± 1.98 b	74.40 ± 2.07 b	78.20 ± 1.20 a	77.40 ± 1.52 b	78.60 ± 1.85 a
Garlic	76.30 ± 1.03 a	78.50 ± 1.06 a	78.80 ± 1.48 a	80.10 ± 1.29 a	80.80 ± 1.82 a	81.10 ± 1.29 a
Ajwaen	40.80 ± 1.48 e	42.50 ± 1.90 f	45.90 ± 2.16 e	48.90 ± 2.27 d	53.60 ± 1.59 f	54.10 ± 1.47 b
Tumha	60.60 ± 1.74 b	62.10 ± 1.71 c	61.70 ± 1.95 c	63.90 ± 1.85 b	71.50 ± 1.69 c	80.00 ± 1.11 a
Bitter cress	44.30 ± 1.35 d	46.30 ± 1.35 e	52.60 ± 1.43 d	56.30 ± 1.60 c	58.70 ± 1.35 e	61.30 ± 2.61 c
Control	11.10 ± 1.19 f	12.30 ± 1.44 g	13.30 ± 1.35 f	15.90 ± 1.85 e	12.60 ± 0.96 g	14.30 ± 1.35 e
LSD Value	2.79	3.18	3.47	3.37	3.05	3.24

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

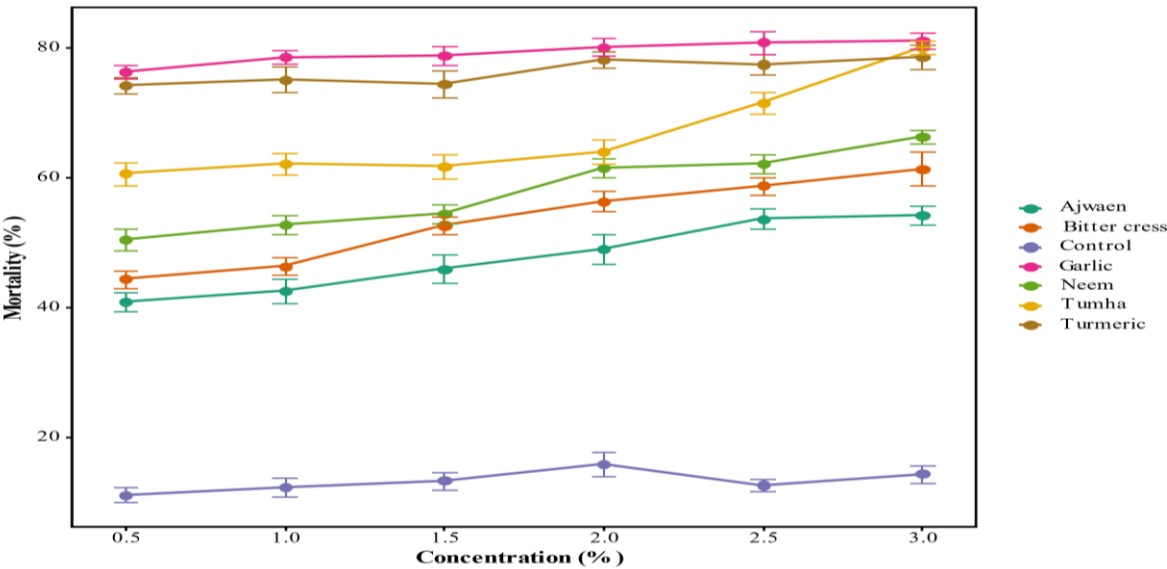


Figure 4: Effect of plant extracts on 7day mortality.

Table 6: Number of pulse beetle eggs per 20 grains in grains treated with six plant aqueous extracts.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	12.00 ± 1.58 bc	10.60 ± 1.14 bc	9.80 ± 0.83 bc	9.20 ± 0.83 bc	7.80 ± 1.48 bc	6.40 ± 1.14 bc
Turmeric	10.20 ± 1.92 bc	7.80 ± 1.64 c	8.40 ± 1.14 bc	7.40 ± 1.48 cd	7.40 ± 1.30 bc	6.20 ± 0.83 bc
Garlic	8.80 ± 1.78 c	7.20 ± 1.30 c	6.20 ± 1.30 c	5.40 ± 1.14 d	4.80 ± 0.83 c	4.40 ± 1.14 c
Ajwaen	13.00 ± 1.58 b	12.00 ± 1.58 b	12.00 ± 1.58 b	11.20 ± 1.92 b	10.00 ± 1.58 b	8.60 ± 2.30 b
Tumha	11.40 ± 1.14 bc	10.20 ± 1.92 bc	10.00 ± 1.58 bc	9.80 ± 1.30 bc	8.00 ± 1.58 bc	6.40 ± 2.70 bc
Bitter cress	12.80 ± 1.92 b	10.80 ± 1.48 bc	10.20 ± 2.58 b	10.00 ± 1.58 bc	9.00 ± 1.58 b	8.00 ± 1.58 bc
Control	17.40 ± 2.40 a	17.00 ± 2.91 a	16.80 ± 2.42 a	16.20 ± 1.92 a	17.00 ± 2.23 a	17.20 ± 2.38 a
LSD Value	3.61	3.60	3.95	3.07	3.28	3.72

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

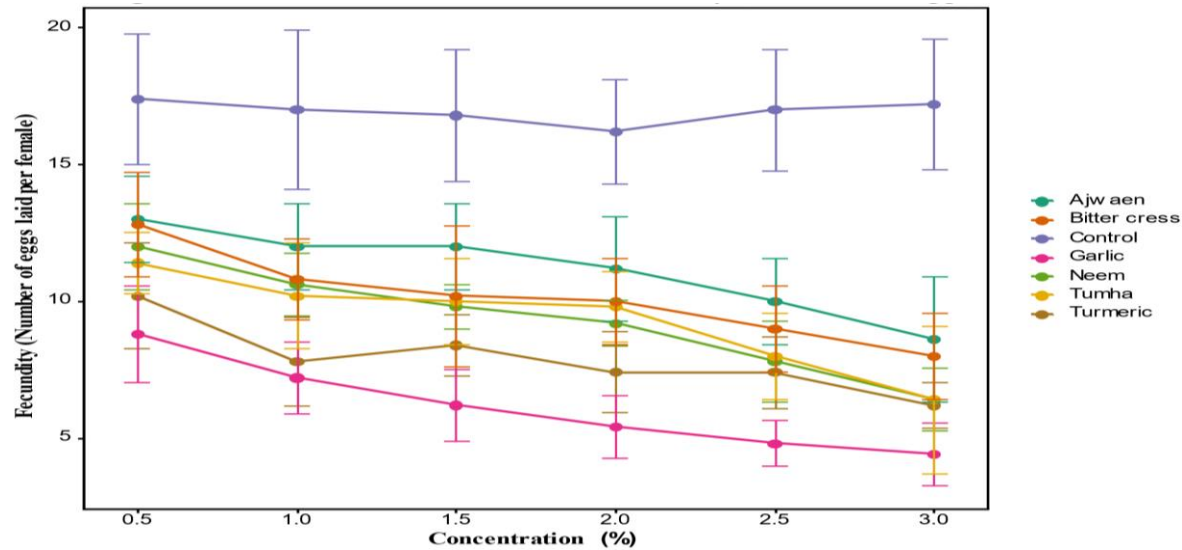


Figure 5: Effect of plant extracts on fecundity (Number of eggs).

Among the treatments, the highest egg deposition (≈13 eggs per 20 grains) was recorded in grains treated with ajwain extract, which did not differ significantly from bitter cress, tumha, turmeric, and neem treatments. In contrast, garlic extract resulted in the lowest oviposition, with approximately 8.8 eggs recorded at lower concentrations and a minimum of 4.4 eggs at the highest concentration (3.0%). Overall, all botanical treatments significantly reduced egg laying compared to the untreated control, which recorded the highest fecundity (17.4 eggs per 20 grains).

Developmental Duration

Developmental duration of *Callosobruchus analis* was significantly influenced by botanical treatments and their concentrations ($P < 0.05$) (Table 7; Figure 6). Lower concentrations (0.5% and 1.0%) did not significantly affect developmental time compared to the control. At 1.5% concentration, garlic, turmeric, and neem extracts significantly prolonged the developmental period, whereas the remaining treatments showed no significant effect. At

2.0%, all treatments except ajwain significantly increased developmental duration. Garlic extract was most effective at this concentration, resulting in the longest developmental period (≈25.0 days), followed by turmeric and neem. Further increases in developmental duration were observed at higher concentrations (2.5% and 3.0%). Garlic extract produced the maximum prolongation (≈25.9–26.3 days), showing comparable effects with turmeric and neem, while ajwain and bitter cress exhibited relatively shorter developmental periods.

Overall, the shortest developmental duration (≈21.1 days) was recorded in the untreated control, indicating that botanical treatments delayed insect development.

Adult Emergence (F_1 Progeny)

Plant aqueous extracts applied at six concentrations significantly affected the progeny production of *Callosobruchus analis* compared with the untreated control ($P < 0.05$) (Table 8; Figure 7). Adult emergence was lowest in grains treated with garlic extract, followed by turmeric,

neem, and tumha, whereas ajwain and bitter cress treatments resulted in comparatively higher emergence and did not differ significantly from each other; the control recorded the highest progeny production. At lower concentrations (0.5–1.0%), garlic extract was most effective in reducing emergence, while ajwain and bitter cress were least effective. A similar trend was observed at medium concentrations (1.5–2.0%), where garlic produced the

greatest suppression of progeny, followed by turmeric and neem. At higher concentrations (2.5–3.0%), adult emergence declined further, with garlic extract producing the minimum emergence and ajwain and bitter cress remaining the least effective among botanical treatments. Overall, all plant extracts significantly reduced progeny emergence relative to untreated grains, and effectiveness increased with concentration.

Table 7: Number of days to F₁ adult pulse beetle emergence in grains treated with six plant aqueous extracts.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	22.50 ± 0.79 ab	23.00 ± 0.79 ab	23.70 ± 1.03 ab	23.90 ± 0.96 ab	24.20 ± 1.20 ab	25.00 ± 1.12 ab
Turmeric	22.90 ± 0.65 ab	23.50 ± 0.79 ab	23.80 ± 1.15 ab	24.50 ± 0.79 ab	25.00 ± 0.79 ab	25.40 ± 0.89 ab
Garlic	23.10 ± 0.96 a	23.90 ± 0.96 a	25.30 ± 0.57 a	25.00 ± 1.11 a	25.90 ± 0.96 a	26.30 ± 1.03 a
Ajwaen	21.70 ± 0.57 ab	22.50 ± 0.79 ab	23.10 ± 0.65 bc	23.00 ± 0.79 bc	23.70 ± 0.75 b	24.50 ± 0.79 ab
Tumha	22.00 ± 0.83 ab	23.00 ± 1.11 ab	23.20 ± 1.15 bc	24.20 ± 1.20 ab	24.50 ± 0.79 ab	25.30 ± 0.75 ab
Bitter cress	22.20 ± 0.83 ab	22.40 ± 0.74 ab	23.20 ± 0.83 bc	23.50 ± 0.79 ab	24.00 ± 0.79 ab	24.10 ± 0.96 b
Control	21.50 ± 0.79 b	21.90 ± 0.82 b	21.50 ± 0.79 c	21.10 ± 0.96 c	21.30 ± 1.44 c	21.50 ± 0.79 c
LSD Value	1.74	1.83	1.92	1.99	2.16	1.84

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

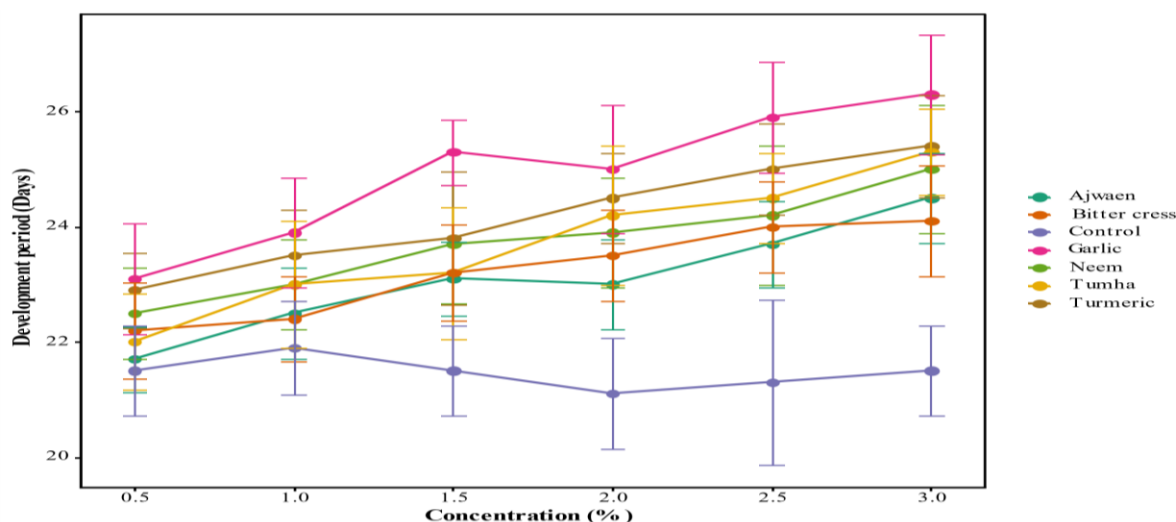


Figure 6: Effect of plant extracts on F₁ development time.

Table 8: F₁ adult pulse beetle emergence in grains treated with six plant aqueous extracts.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	103.00 ± 2.67 c	92.20 ± 2.86 d	81.20 ± 2.87 d	77.00 ± 3.08 c	68.60 ± 2.82 cd	64.40 ± 2.82 cd
Turmeric	71.80 ± 2.71 d	70.20 ± 2.20 e	69.00 ± 2.39 e	63.40 ± 2.36 d	60.40 ± 2.27 d	58.00 ± 2.12 d
Garlic	60.00 ± 2.69 e	58.20 ± 2.14 f	55.80 ± 2.65 f	55.00 ± 1.80 d	48.40 ± 1.71 e	46.40 ± 2.94 e
Ajwaen	125.80 ± 2.54 b	123.40 ± 2.77 b	119.40 ± 2.41 b	110.80 ± 2.97 b	104.00 ± 2.33 b	91.60 ± 2.04 b
Tumha	107.80 ± 2.57 c	103.40 ± 2.18 c	93.80 ± 2.58 c	80.40 ± 2.84 c	75.80 ± 2.32 c	73.20 ± 1.70 c
Bitter cress	122.00 ± 2.16 b	121.00 ± 1.86 b	119.00 ± 2.39 b	110.00 ± 1.79 b	100.80 ± 2.89 b	96.00 ± 2.68 b
Control	143.00 ± 2.67 a	144.80 ± 2.49 a	143.80 ± 2.56 a	143.00 ± 2.91 a	141.60 ± 2.07 a	139.80 ± 2.93 a
LSD Value	10.63	10.29	10.97	10.18	10.26	9.58

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

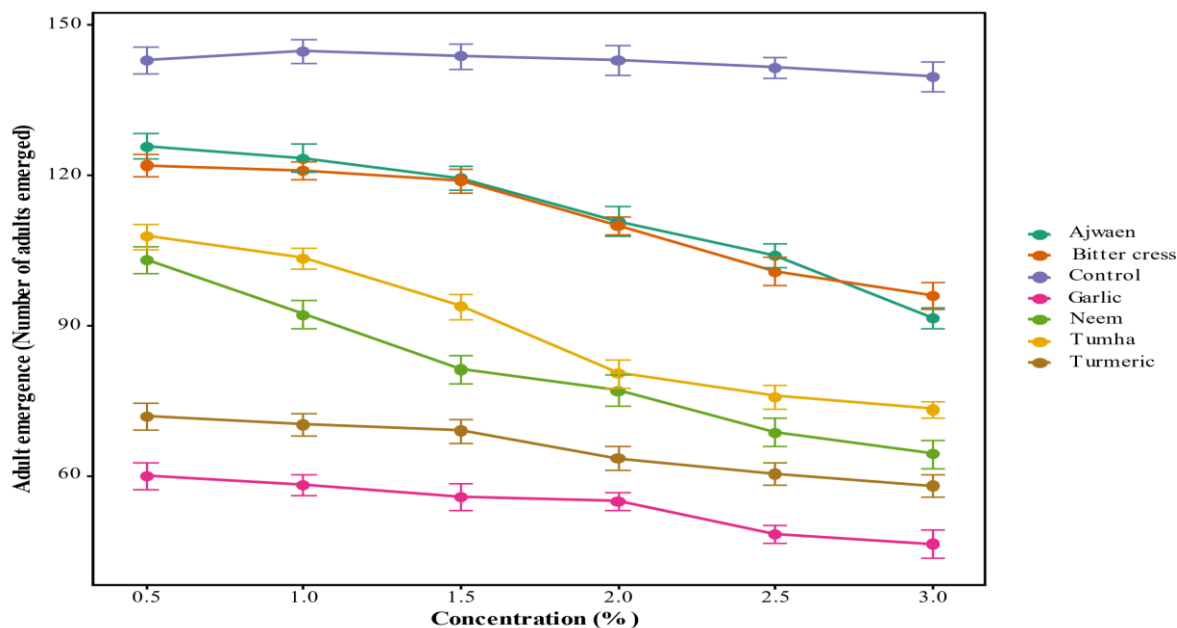


Figure 7: Effect of plant extracts on F1 adult emergence.

Grain Infestation

Aqueous extracts prepared from six plant species significantly reduced mung bean grain damage caused by *Callosobruchus analis* compared with untreated grains (Table 9; Figure 8). Grain damage decreased progressively with increasing extract concentration. Garlic and turmeric extracts were consistently the most effective across all concentrations, producing the lowest levels of damaged grains, whereas ajwain and bitter cress treatments resulted in comparatively more serious damage.

At lower concentrations (0.5–1.0%), garlic extract provided the greatest protection, while ajwain and bitter cress were least effective. A similar trend was observed at medium concentrations (1.5–2.0%), where garlic and turmeric treatments recorded minimal grain damage, and ajwain and bitter cress showed higher infestation levels.

At higher concentrations (2.5–3.0%), grain damage was further reduced, with garlic extract producing the lowest damage levels, while ajwain treatments recorded the most serious damage among botanical treatments. The untreated control exhibited the maximum grain damage ($\approx 40\%$), confirming the protective effect of plant extracts. Overall, all botanical treatments significantly reduced grain damage relative to the control, with greater effectiveness at higher concentrations.

Grain Weight Loss

Plant aqueous extracts significantly reduced the weight loss of mung bean grains caused by *Callosobruchus analis* compared with the untreated control (Table 10; Figure 9). Among the treatments, garlic extract was the most effective, followed by turmeric, while bitter cress and ajwain were comparatively less effective.

Table 9: Percent infestation of pulse beetle in grains treated with six plant aqueous extracts.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	26.82 $\pm$ 1.78 b	25.09 $\pm$ 1.80 c	24.60 $\pm$ 1.33 c	23.30 $\pm$ 1.27 bc	21.82 $\pm$ 1.66 bc	20.14 $\pm$ 1.94 c
Turmeric	22.30 $\pm$ 1.35 c	21.63 $\pm$ 1.89 d	18.15 $\pm$ 1.67 e	16.94 $\pm$ 1.54 d	16.10 $\pm$ 1.75 d	15.28 $\pm$ 1.10 d
Garlic	18.39 $\pm$ 1.58 d	17.70 $\pm$ 1.57 e	16.58 $\pm$ 1.50 e	14.69 $\pm$ 1.41 d	12.62 $\pm$ 1.62 e	11.46 $\pm$ 1.27 e
Ajwaen	29.64 $\pm$ 1.47 b	28.68 $\pm$ 1.46 b	26.56 $\pm$ 1.23 bc	25.57 $\pm$ 1.29 b	24.46 $\pm$ 1.31 b	23.65 $\pm$ 1.34 b
Tumha	27.19 $\pm$ 1.37 b	24.77 $\pm$ 1.43 cd	21.23 $\pm$ 1.59 d	20.98 $\pm$ 1.50 c	20.69 $\pm$ 1.33 c	18.67 $\pm$ 1.54 c
Bitter cress	30.55 $\pm$ 1.76 b	29.74 $\pm$ 1.74 b	28.09 $\pm$ 1.85 b	25.76 $\pm$ 1.36 b	24.50 $\pm$ 1.73 b	19.50 $\pm$ 1.86 c
Control	40.44 $\pm$ 2.93 a	39.09 $\pm$ 1.96 a	39.36 $\pm$ 1.84 a	39.80 $\pm$ 1.86 a	40.44 $\pm$ 1.54 a	40.55 $\pm$ 1.86 a
LSD Value	3.79	3.43	3.19	3.37	3.17	3.20

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

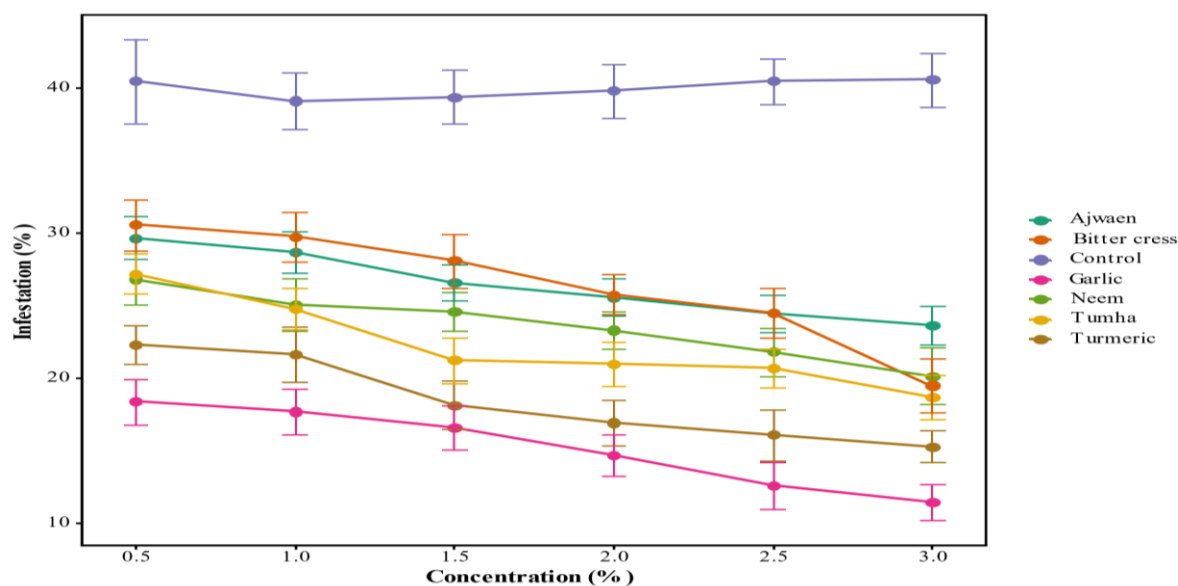


Figure 8: Effect of plant extracts on percent infestation.

Table 10: Percent weight loss of mung bean grains treated with six plant aqueous extracts.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	13.76 ± 1.13 d	13.33 ± 0.87 c	12.49 ± 0.77 cd	11.83 ± 0.87 c	11.58 ± 0.97 c	10.03 ± 1.06 c
Turmeric	11.19 ± 1.01 e	11.17 ± 0.68 d	10.98 ± 0.81 d	10.79 ± 0.83 c	9.34 ± 0.70 d	8.59 ± 1.06 cd
Garlic	9.99 ± 0.86 e	9.11 ± 0.71 e	9.06 ± 0.87 e	8.73 ± 0.56 d	7.78 ± 0.49 d	7.25 ± 0.72 d
Ajwaen	17.84 ± 1.10 bc	17.52 ± 0.94 b	16.85 ± 0.91 b	16.08 ± 0.92 b	16.09 ± 0.97 b	14.04 ± 0.83 b
Tumha	15.94 ± 0.84 c	14.67 ± 0.76 c	13.65 ± 0.69 c	12.42 ± 0.78 c	11.69 ± 1.01 c	9.90 ± 0.87 c
Bitter cress	18.88 ± 0.88 b	18.35 ± 0.74 b	16.33 ± 0.49 b	15.84 ± 0.67 b	14.66 ± 0.79 b	12.55 ± 0.69 b
Control	26.67 ± 1.43 a	27.40 ± 1.54 a	26.63 ± 1.59 a	26.65 ± 1.43 a	26.81 ± 1.55 a	26.41 ± 1.32 a
LSD Value	2.12	1.88	1.87	1.82	1.96	1.93

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

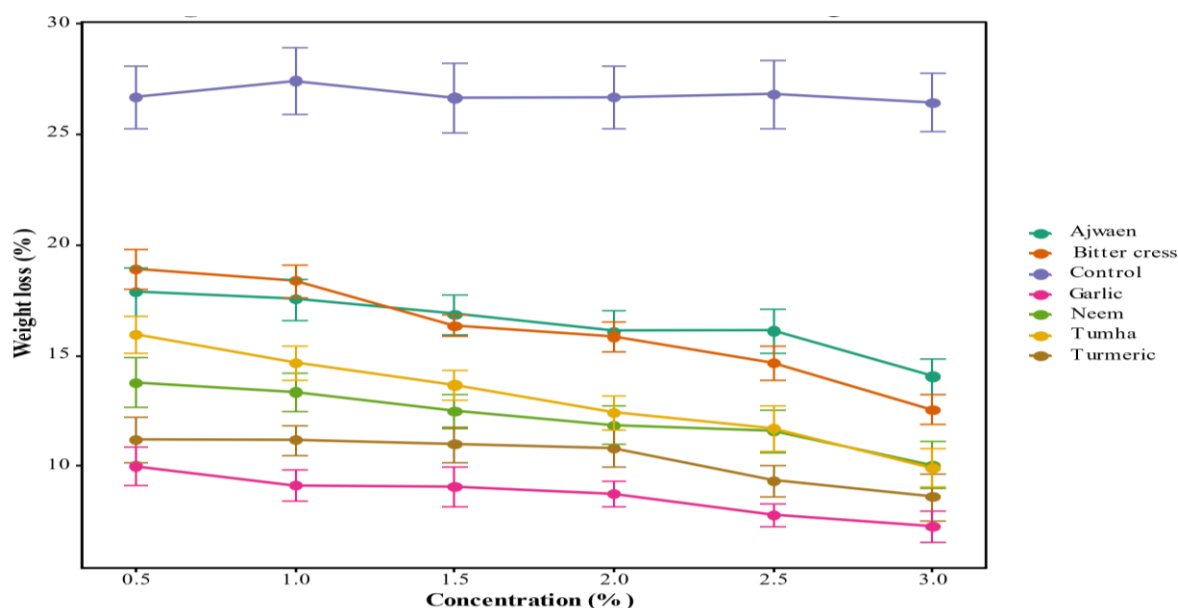


Figure 9: Effect of plant extracts on percent weight loss.

Minimum weight loss was recorded in grains treated with garlic and turmeric extracts, which did not differ significantly from each other, whereas tumha and neem provided moderate protection and were statistically similar. In contrast, ajwain and bitter cress treatments resulted in higher weight loss among botanical treatments, while the untreated control recorded the maximum loss ($\approx 27\%$). Weight loss decreased progressively with increasing extract concentration; higher concentrations (2.0–3.0%) were most effective in minimizing losses, whereas lower concentrations (0.5–1.5%) were comparatively less effective. Overall, all botanical treatments significantly reduced grain weight loss relative to untreated grains.

Sex ratio

Sex ratio of adult pulse beetles emerged from all the treatments, including control, did not differ significantly ($P < 0.05$). The mean number of male and female (sex ratio) adult beetles emerged indicated that in all the treatments, the number of males was found to be less than that of females.

However, no significant variations were recorded among all the treatments and concentrations of plant aqueous extracts and control (Table 11; Figure 10).

Adult Longevity

Plant aqueous extracts significantly affected the adult longevity of *Callosobruchus analis* emerging from treated mung bean grains compared with the control (Table 12; Figure 11). Adult lifespan decreased with increasing extract concentration. Among treatments, garlic, turmeric, and tumha extracts produced the shortest adult longevity and did not differ significantly from each other, whereas the untreated control recorded the longest lifespan (≈ 12.7 days). Most botanical treatments reduced adult longevity relative to the control. Higher concentrations (2.5–3.0%) were most effective, resulting in the minimum adult lifespan, while lower concentrations (0.5–1.5%) showed little effect. However, even at lower concentrations, garlic extract reduced adult longevity significantly compared with untreated grains.

Table 11: Sex ratio of pulse beetle in grains treated with six plant aqueous extracts.

Treatments	Concentrations (%)					
	0.5 ^{NS}	1.0 ^{NS}	1.5 ^{NS}	2.0 ^{NS}	2.5 ^{NS}	3.0 ^{NS}
Neem	44.64 $\pm$ 1.77	44.20 $\pm$ 1.86	45.38 $\pm$ 1.82	44.62 $\pm$ 1.35	44.71 $\pm$ 1.32	44.60 $\pm$ 1.38
Turmeric	44.79 $\pm$ 1.26	44.35 $\pm$ 1.59	45.24 $\pm$ 0.88	44.78 $\pm$ 1.29	45.15 $\pm$ 0.85	44.39 $\pm$ 1.05
Garlic	44.44 $\pm$ 1.66	44.50 $\pm$ 1.38	44.92 $\pm$ 1.31	45.37 $\pm$ 1.04	44.77 $\pm$ 1.64	45.38 $\pm$ 1.11
Ajwaen	44.81 $\pm$ 1.26	44.41 $\pm$ 1.77	44.73 $\pm$ 1.42	44.98 $\pm$ 1.29	44.26 $\pm$ 1.48	44.31 $\pm$ 1.51
Tumha	44.36 $\pm$ 1.64	44.56 $\pm$ 1.33	44.57 $\pm$ 1.29	44.43 $\pm$ 1.64	44.46 $\pm$ 1.29	44.73 $\pm$ 1.33
Bitter cress	45.44 $\pm$ 1.33	44.94 $\pm$ 1.29	44.72 $\pm$ 1.63	44.56 $\pm$ 1.47	45.12 $\pm$ 1.59	45.38 $\pm$ 1.11
Control	44.71 $\pm$ 1.36	44.73 $\pm$ 1.46	45.28 $\pm$ 1.03	44.57 $\pm$ 1.23	44.50 $\pm$ 1.36	44.65 $\pm$ 1.50
LSD Value	2.98	3.10	2.76	2.71	2.78	2.61

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

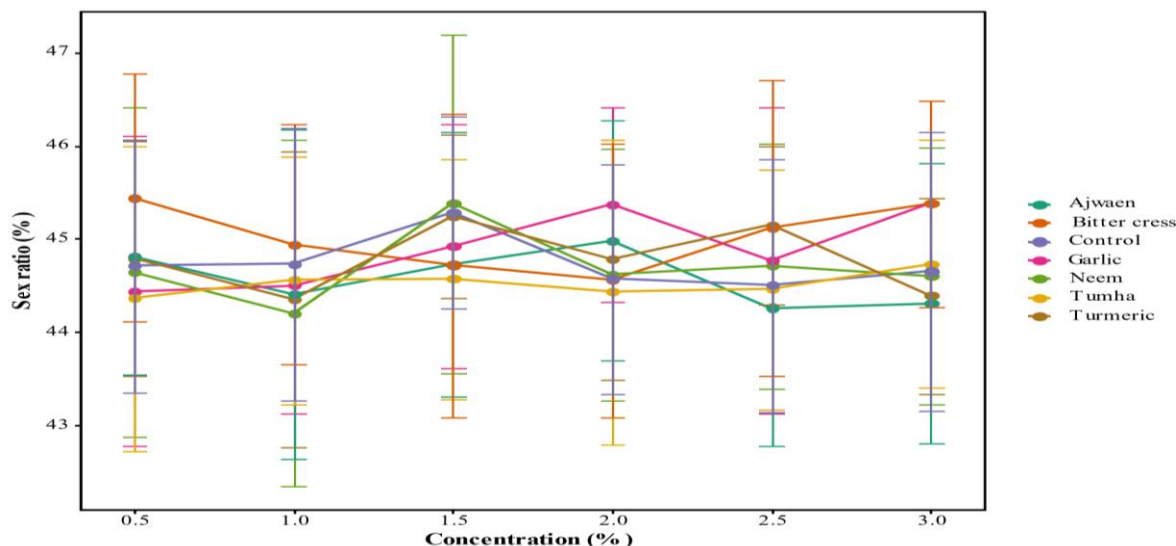


Figure 11: Effect of plant extracts on sex ratio.

Table 12: Life span of adult pulse beetles after emergence in grains treated with six plant aqueous extracts.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	11.10 ± 0.82 bc	11.00 ± 0.79 bc	11.00 ± 0.79 ab	11.70 ± 0.90 ab	10.30 ± 1.03 bc	10.60 ± 0.74 ab
Turmeric	11.20 ± 0.83 bc	10.80 ± 0.57 bc	10.40 ± 0.50 b	10.20 ± 0.84 b	10.00 ± 0.79 bc	9.80 ± 0.97 b
Garlic	10.50 ± 0.79 c	10.31 ± 0.57 c	10.30 ± 0.50 b	10.10 ± 0.65 b	09.70 ± 0.57 c	9.40 ± 0.74 b
Ajwaen	12.10 ± 0.65 ab	11.90 ± 0.96 ab	11.70 ± 0.57 ab	11.60 ± 0.74 ab	11.30 ± 0.75 ab	10.60 ± 0.74 ab
Tumha	11.30 ± 0.83 abc	11.00 ± 0.79 bc	11.30 ± 0.57 ab	10.80 ± 0.83 ab	10.00 ± 0.50 bc	10.10 ± 0.82 b
Bitter cress	12.20 ± 0.67 ab	12.00 ± 0.50 ab	11.50 ± 0.79 ab	11.40 ± 0.74 ab	11.00 ± 0.79 abc	10.50 ± 0.79 ab
Control	12.70 ± 0.44 a	12.50 ± 0.79 a	11.90 ± 0.96 a	12.00 ± 1.12 a	11.90 ± 0.96 a	12.20 ± 1.20 a
LSD Value	1.47	1.46	1.45	1.70	1.59	1.75

Mean values in corresponding groups having dissimilar letter(s) are significant using the LSD Test.

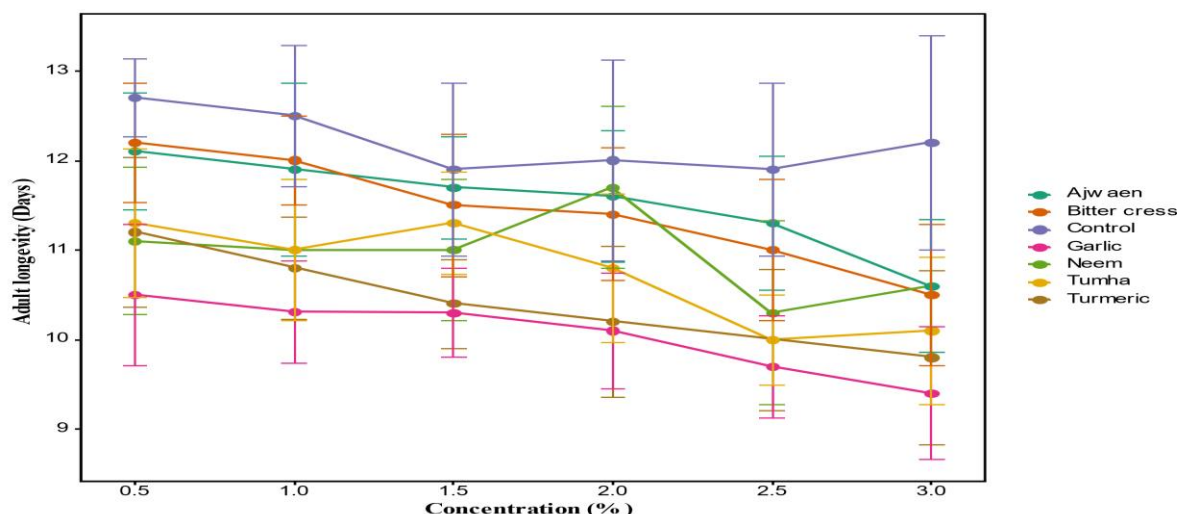


Figure 11: Effect of plant extracts on adult life span.

DISCUSSION

The use of botanical powders and their extracts in various solvents against insect pests of field crops and stored grains is an old practice and dates back more than 3000 years. In our experiment, aqueous extracts of six native plants were used to find out their efficacy against *C. analis* in stored mung beans. During the investigations, it was observed that among the tested plant extracts, the aqueous extracts of garlic, turmeric, neem, and tumha at higher concentrations exhibited significant effects on the survival and biology of the pulse beetle. The superior efficacy of garlic and turmeric extracts may be attributed to their bioactive constituents. Garlic contains sulfur-containing compounds such as allicin, which exhibit strong insecticidal and repellent properties, while turmeric contains curcumin and turmerones, known for their toxic, antifeedant, and growth-inhibitory effects on insects. These compounds likely contributed to the increased mortality, reduced oviposition, delayed development, and suppression of progeny observed in the present study. It was noted that the mortality of pulse beetle

increased with increasing concentrations and exposure period after treatment of plant extracts. Similar results were also reported by some researchers in previous years. (Murasing et al., 2017) Conducted a laboratory trial to assess the efficacy of petroleum ether, methanol, ethanol, and water extracts of *Ocimum sanctum* against *C. chinensis* in stored green gram. They reported that the petroleum ether extract of *Ocimum sanctum* showed maximum mortality (84.0%) of pulse beetle at 5% concentration after 96 hours of exposure time, followed by methanol (82.0%), ethanol (80.0%), and water (76.0%). Similarly, maximum oviposition deterrence was recorded in grains treated with petroleum ether extract of *Ocimum sanctum* (60.75%). Moreover, maximum inhibition of F₁ adult emergence (77.29%) was recorded in petroleum ether extract at 5% concentration. Ai Lawati et al., (2002) tested water and solvent (methanol and ethanol) extracts of 8 diverse plants for their repellent and insecticidal properties against *C. chinensis*. Both the extracts of the *A. squamosa* plant caused 100% mortality of pulse beetle adults within 24 hours.

Similar results were also reported by Mamoon-ur-Rashid et al. (2018). They reported that water extracts of *N. tabacum* at a higher concentration of 3% caused maximum adult mortality of 93.66% after 6 days of treatment, followed by *A. indica* extract, which resulted in 88% of adult mortality. Similar results were also reported by Zia et al. (2011), who tested the insecticidal potential of water extracts of 10 local botanicals against *C. chinensis* on stored chickpea. They reported that aqueous extracts of black pepper exhibited higher mortality of adult beetles, followed by cloves, bhang, neem, and garlic extracts. The above-mentioned extracts also significantly reduced egg laying, infestation, and weight loss of grains caused by the pulse beetle. More or less similar to our findings (Mostafa et al., 2012), the insecticidal efficacy of hexane, methanol, and water extracts of 6 indigenous plants at different concentrations against *T. castaneum*. The results revealed that the hexane extract of *Cucumis sativus* at higher concentrations resulted in the highest mortality (80%) within 72 hours exposure period, followed by the hexane extract of *A. indica*, having 75.0% mortality of *T. castaneum*. Water extracts of *A. indica* also showed satisfactory results with 66.66% adult mortality at the highest concentration within 72 hours.

Makanjuola., (1989) reported that water and methylated spirit extracts of neem (leaves and seeds) actively suppressed the *C. maculatus*, significantly reduced egg laying, and F₁ adult emergence. Similarly, Rajopadhye et al., (2016) tested the efficacy of *Glossocardia bosvallia* extracted with hexane, ethanol, and water against three major pests of stored grains, including *C. chinensis*. Hexane extracts resulted in higher mortality of all the tested insects; however, water extracts were effective at higher concentrations.

It was noted that the application of aqueous extracts significantly reduced the fecundity of adult beetles, which eventually resulted in the reduction of F₁ adult emergence. It may be due to higher mortality of adult beetles and antifeedant effects of plant extracts. Our results also indicate that garlic, turmeric, neem, and tumha extracts significantly reduced % infestation and weight loss of mung bean grains caused by *C. analis*. Reduction in % grain damage and weight loss may be due to the mortality and less oviposition of the pulse beetle. Our findings are consistent with Rajopadhye et al. (2016), who reported that hexane, ethanol, and water extracts of *G. bosvallia* significantly reduced the adult emergence of three stored grain insect pests at 30-60mg/ml dose in wheat grains. However, hexane extract exhibited 100% F₁ progeny inhibition. Jayakumar (2010) tested aqueous extracts of six botanicals at four different

concentrations to check their effects on the biology of *C. maculatus* on cowpea seeds. Maximum oviposition deterrence (84.66% and 82.11%) was noted in *C. siamea* and *C. aurantium* extracts at 10% concentration. Similarly, maximum reduction in F₁ adult emergence was recorded in grains treated with *P. daemia* (91.25%). Moreover, Jayakumar also reported that weight loss in most of the treatments was (0.6 to 3.9%) remarkably reduced compared to the control (4.88%).

CONCLUSION

The present study demonstrated that aqueous extracts of indigenous plants significantly affect the survival and biology of *Callosobruchus analis* in stored mung beans. Garlic (*Allium sativum*) and turmeric (*Curcuma longa*) extracts were the most effective, particularly at higher concentrations (2.5–3.0%), causing high adult mortality, reduced oviposition, delayed development, suppressed progeny emergence, and minimized grain damage and weight loss. Neem (*Azadirachta indica*) and tumha (*Citrullus colocynthis*) showed moderate efficacy, whereas ajwain (*Trachyspermum ammi*) and bitter cress (*Caralluma tuberculata*) were comparatively less effective. These findings highlight the potential of plant-based aqueous extracts as safe, eco-friendly alternatives to synthetic insecticides for protecting stored mung beans.

RECOMMENDATIONS

According to the research conducted in this study, it is advised that the higher concentrations of aqueous extracts of both garlic and turmeric can be encouraged in the eco-friendly management of *Callosobruchus analis* in mung beans. They should be tested in field and farmer-storage conditions in further studies in order to confirm their effectiveness and economic viability. Also, recognition and profiling of effective plant extracts of active bio-compounds, and their combination in integrated pest management (IPM) programs, are proposed to enhance sustainability in the protection of stored pulses.

AUTHOR'S CONTRIBUTION

All authors contributed significantly to the conception, design, data collection, analysis, and preparation of the manuscript. All authors reviewed and approved the final version.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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