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Research Article

Efficacy of Indigenous Plant Powders against Pulse Beetle *Callosobruchus analis* (Fabricius) in Stored Mung Bean under Laboratory Conditions

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ABSTRACT

Pulse beetle *Callosobruchus analis* (Fabricius) is a serious pest responsible for substantial quantitative and qualitative losses in stored mung bean (*Vigna radiata* L.). The present study evaluated the efficacy of six indigenous plant powders such as neem (*Azadirachta indica*), turmeric (*Curcuma longa*), garlic (*Allium sativum*), ajwaen (*Trachyspermum ammi*), tumha (*Citrullus colocynthis*), and bitter cress (*Caralluma tuberculata*) against *C. analis* under laboratory conditions. The experiment was conducted using a Completely Randomized Design (CRD) with five replications. Plant powders were tested at six concentrations (0.5, 1.0, 1.5, 2.0, 2.5, and 3.0% w/w). Adult mortality was recorded after 24, 48, 72 hours and 7 days, and corrected mortality was calculated using Abbott's formula. Results indicated that mortality increased with increasing concentration and exposure time. Garlic and turmeric powders were the most effective treatments, producing the highest adult mortality of 76.6% and 74.6%, respectively, after seven days at 3% concentration. These treatments also significantly reduced oviposition, adult emergence, grain infestation, and weight loss compared with the untreated control. Neem and tumha showed moderate efficacy, whereas ajwaen and bitter cress were comparatively less effective. The findings suggest that garlic and turmeric powders have strong insecticidal potential and could serve as environmentally friendly alternatives to synthetic insecticides for the management of *C. analis* in stored mung bean.

Keywords: Botanical powders; *Callosobruchus analis*; Eco-friendly Pest Management; Mung Bean; Plant-based Insecticides; Stored Grain Protection.

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INTRODUCTION

Pulses are a very vital part of human diet, especially in the developing nations where they are a main source of plant protein. One of them, mung bean (*Vigna radiata* L.), is a highly popular crop grown in tropical and subtropical areas and is being used due to its high protein content, ease of digestion and the capacity to serve as a biological fixative of nitrogen in the soil (Afzal et al., 2004; Ali et al., 2010).

Though economically significant, the mung bean is very vulnerable to mauling of the storage insect pests. The genus *Callosobruchus* is the pulse beetle known to be the most devastating of all stored legume pests in the world (Haines, 1989). The grains infested by *Callosobruchus analis* (Fabricius) are usually infested in the field and during storage with the larva living inside the seeds, causing severe quantitative and qualitative losses (Appleby & Credland, 2004).

When the temperature and humidity are favorable, grain loss may reach 40-60 percent and in extreme cases, the stored products are destroyed (Akinkurolere et al., 2006; Ramzan et al., 1990).

Fumigants and synthetic insecticides continue to be the main tools of management of stored grain pests. Nevertheless, their constant application has caused various issues which include insect resistance, food residues of toxicity, environmental pollution and health risks (Desmarchelier, 1985; Fields, 1992). The growing limitations on chemical insecticides have made finding the safe, biodegradable and environment-friendly alternatives more intense.

Plant-derived insecticides, especially, plant powders and extracts have been re-examined as environmentally friendly agents of pest control. Plant powders have several modes of action such as by contact toxicity, repellency, feeding deterrent, oviposition inhibitor, obstruction of spiracles (Makanjuola, 1989). Plant powders are biodegradable in comparison with synthetic chemicals, locally available, cost effective and less toxic to non target organisms (Grainge & Ahmed, 1988).

Plant-derived insecticides, particularly plant powders and extracts, have gained increasing attention as eco-friendly pest management tools. Botanical products act through several mechanisms including contact toxicity, repellency, feeding deterrence, oviposition inhibition, and obstruction of insect spiracles (Makanjuola, 1989). Compared with synthetic chemicals, botanical insecticides are biodegradable, locally available, relatively inexpensive, and generally safer for non-target organisms and the environment (Grainge & Ahmed, 1988). Recent research has highlighted the growing importance of plant-based insecticides in stored grain protection because many plants contain bioactive compounds such as alkaloids, terpenoids, phenolics, and sulfur-containing compounds that can effectively suppress insect pests (Rajashekar et al., 2025; Trivedi, 2018; Vijayan et al., 2023).

A number of experiments explicated the effectiveness of plant powders in pulse beetles. Adult survival and progeny emergence of *Callosobruchus* spp has been reported to be greatly reduced by the seed and leaf powders of Neem (*Azadirachta indica*) (Akinkurolere et al., 2006; Makanjuola, 1989). Other sources of indigenous plant materials such as Garlic (*Allium sativum*), turmeric (*Curcuma longa*), and others have also demonstrated potentially promising insecticidal effects against stored-product beetles (Jayakumar, 2010; Zia et al., 2011). Few studies have, however, comparatively assessed the local purposive plant powders available in the area compared to *C. analis* in controlled laboratory environments.

Hence, the current research was done to assess the effectiveness of the chosen indigenous plant extracts of various concentrations against *C. analis* in stored mung bean and determine their impact on adult mortality and biological indices.

Objectives of the Study

The following objectives were followed in the present study:

To evaluate the insecticidal efficacy of selected indigenous plant powders against *Callosobruchus analis* in stored mung bean under laboratory conditions.

To determine the effect of different concentrations (0.5–3.0% w/w) of plant powders on adult mortality of *C. analis*.

To assess the impact of plant powders on important biological parameters of *C. analis*, including oviposition, adult emergence, developmental duration, grain infestation, weight loss, sex ratio, and adult longevity.

MATERIALS AND METHODS

Experimental site and conditions

The experiment was conducted in the Postgraduate Laboratory, Department of Entomology, Faculty of Agriculture, Gomal University, Dera Ismail Khan, Pakistan. The study was carried out under controlled laboratory conditions at 27 ± 3°C, 65 ± 5% relative humidity, and a 12:12 (L:D) photoperiod, which are optimal for the development of *Callosobruchus* spp. (Haines, 1989).

Insect culture

A laboratory culture of *Callosobruchus analis* (Fabricius) was established from infested mung bean grains collected from a local grain market. The species was identified prior to culture initiation. Clean mung bean grains were used to maintain the culture in glass jars covered with muslin cloth to allow aeration and prevent insect escape.

Freshly emerged adults were transferred periodically to fresh grains to maintain continuous culture. Adults used in bioassays were 24-hour-old and were starved for one hour before release to standardize feeding activity.

Insect identification

The collected pulse beetles were identified as *Callosobruchus analis* (Fabricius) based on standard taxonomic keys and morphological characteristics described for stored-product bruchids (Haines, 1989). Identification was confirmed in the Department of Entomology, Gomal University, Dera Ismail Khan, Pakistan.

Preparation of mung bean grains

Mung bean grains were cleaned to remove debris and broken seeds. To eliminate any pre-existing infestation, grains were heat-sterilized at 60°C for 3 hours following standard procedures for stored-product research (Fields, 1992). Sterilized grains were cooled to room temperature and stored in airtight containers until use. Fifty grams of grains were used per treatment replicate.

Plant materials and powder preparation

Six indigenous plant materials were selected based on their traditional insecticidal uses (table 1).

Table 1. Indigenous plant materials used in the study.

S. No.	Common Name	Botanical Name	Plant Part Used
1	Neem	*Azadirachta indica*	Seeds
2	Turmeric	*Curcuma longa*	Rhizomes
3	Garlic	*Allium sativum*	Bulbs
4	Ajwaen	*Trachyspermum ammi*	Seeds
5	Tumha	*Citrullus colocynthis*	Fruits
6	Bitter cress	*Caralluma tuberculata*	Stem

Fresh plant materials were collected locally and washed with distilled water to remove dust and contaminants. The plant materials were shade-dried at room temperature (25–30°C) for 7–10 days until constant weight was achieved (moisture content approximately 8–10%). Dried materials were ground using an electric grinder to obtain fine powders and sieved through a 60-mesh sieve to ensure uniform particle size. The powders were stored in airtight glass containers at room temperature (approximately 25°C) in a dark environment until use to prevent degradation of active compounds.

Experimental design and treatment application

The experiment was laid out in a Completely Randomized Design (CRD) with seven treatments (six plant powders and one untreated control) and five replications.

Each plant powder was tested at six concentrations:

0.5%, 1.0%, 1.5%, 2.0%, 2.5%, and 3.0% (w/w)

For each replicate, 50 g of sterilized mung bean grains were thoroughly mixed with the respective plant powder to ensure uniform coating. Treated grains were transferred into transparent glass jars. Untreated grains served as the control.

Insect infestation

Five pairs (10 adults) of freshly emerged *C. analis* were introduced into each jar. The jars were covered with muslin cloth and secured with rubber bands to prevent escape while allowing aeration.

Mortality assessment

Adult mortality was recorded after 24, 48, 72 hours, and 7 days of exposure. Dead beetles were counted and removed daily.

Corrected mortality percentage was calculated using Abbott's formula (Abbott, 1925):

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

Statistical analysis

The experimental data were analyzed using Analysis of Variance (ANOVA) under a Completely Randomized Design (CRD). Percentage data were arcsine square-root transformed prior to analysis to satisfy the assumptions of normality and homogeneity of variance. Treatment means were separated using the Least Significant Difference (LSD) test at the 5% probability level. Statistical analyses were performed using Statistix 8.1 software (Analytical Software, Tallahassee, USA).

RESULTS

Efficacy of six local plant powders at various concentrations was assessed against pulse beetle on different parameters under controlled laboratory conditions. The data obtained were statistically evaluated and explained below:

Mortality after 24 hours

Mortality of pulse beetle adults recorded after 24 hours of application of plant powders showed significant differences among treatments compared with the untreated control (Table 2). Among the tested botanicals, garlic powder (*Allium sativum*) showed the highest adult mortality, reaching 15.20% at 3% concentration, followed by turmeric (*Curcuma* *longa*) with 8.80% and neem (*Azadirachta indica*) with 7.20% mortality. Ajwaen (*Trachyspermum ammi*) and bitter cress (*Caralluma tuberculata*) showed comparatively lower effectiveness, while the control treatment recorded negligible mortality (0.20%).

The results further indicated a concentration-dependent response. The highest dose (3%) resulted in the maximum mortality of pulse beetles, whereas the lowest concentration (0.5%) produced minimal mortality (0.40%). These results demonstrate that the insecticidal activity of plant powders increased with increasing concentration.

Table 2. Percent mortality of pulse beetle in grains treated with six different plant powders after 24 hours of treatment.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	2.40 ± 0.54 a	2.60 ± 0.54 ab	4.80 ± 0.84 b	4.80 ± 0.84 bc	5.80 ± 0.84 c	7.20 ± 1.14 c
Turmeric	3.20 ± 0.84 a	3.80 ± 0.84 a	5.20 ± 0.84 ab	6.00 ± 0.71 b	7.20 ± 1.14 b	8.80 ± 1.48 b
Garlic	2.40 ± 0.54 a	2.60 ± 0.71 ab	6.60 ± 0.54 a	9.60 ± 1.09 a	12.20± 1.14 a	15.20 ± 1.14 a
Ajwaen	0.40 ± 0.54 b	0.80 ± 0.83 c	2.60 ± 0.84 c	4.00 ± 0.84 cd	6.20 ± 0.84 bc	7.60 ± 1.58 bc
Tumha	0.40 ± 0.54 b	0.80 ± 1.14 c	2.00 ± 1.14 c	3.00 ± 1.00 d	3.00 ± 0.83 d	3.60 ± 1.34 d
Bitter cress	0.40 ± 0.84 b	1.20 ± 1.14 bc	1.40 ± 0.71 cd	3.40 ± 0.54 d	4.20 ± 0.89 d	6.40 ± 1.22 c
Control	0.00 ± 0.54 b	0.20 ± 0.48 c	0.20 ± 0.54 d	0.40 ± 0.26 e	0.20 ± 0.43 e	0.20 ± 0.44 e
LSD Value	1.12	1.44	1.42	1.34	1.36	1.46

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

Cumulative mortality after 48 hours

Mortality of pulse beetle adults observed after 48 hours differed significantly among treatments compared with the control (Table 3). Garlic powder caused the highest mortality (23.00%), followed closely by neem (22.40%) and turmeric (20.80%). Ajwaen and tumha showed moderate effectiveness, whereas bitter cress exhibited the lowest mortality (14.80%) among the treatments. The control treatment recorded only 3.40% mortality.

Mortality increased with increasing concentration of plant powders. The highest concentration (3%) resulted in mortality ranging from 14.80% to 23.00%, whereas the lowest concentration (0.5%) resulted in comparatively lower mortality. Overall, all plant powder treatments were significantly more effective than the untreated control.

Table 3. Adult mortality (%) of *Callosobruchus analis* 48 h after treatment with plant powders at different concentrations.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	7.80 ± 0.84 a	12.60 ± 0.55 a	15.20 ± 0.84 a	17.20 ± 1.14 a	19.60 ± 1.30 a	22.40 ± 1.14 a
Turmeric	5.60 ± 0.54 b	9.20 ± 0.84 b	12.20 ± 0.84 b	13.80 ± 0.84 b	19.20 ± 0.84 a	20.80 ± 1.30 b
Garlic	4.80 ± 1.30b	14.20 ± 0.84 a	15.80 ± 1.48 a	18.60 ± 1.79 a	20.20 ± 1.48 a	23.00 ± 1.30 a
Ajwaen	2.20 ± 0.84 c	4.60 ± 0.89 c	5.20 ± 0.84 c	6.80 ± 0.84 d	9.20 ± 1.14 c	20.40 ± 0.84 b
Tumha	2.80 ± 0.83 c	3.60 ± 1.30 cd	12.40 ± 1.00 b	14.20 ± 1.00 b	19.20 ± 1.14 a	19.80 ± 1.30 b
Bitter cress	3.20 ± 1.14 c	3.80 ± 0.83 c	6.80 ± 1.30 c	9.20 ± 1.48 c	12.80 ± 1.14 c	14.80 ± 1.14 c
Control	1.80 ± 0.43 c	2.00 ± 0.54 d	2.80 ± 0.83 d	2.60 ± 0.84 e	2.80 ± 0.84 d	3.40 ± 0.84 d
LSD Value	1.42	1.61	1.70	1.72	1.54	1.52

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

Cumulative mortality after 72 hours

Cumulative mortality recorded after 72 hours showed significant differences among treatments (Table 4). Garlic powder showed the highest mortality (35.60%) at 3% concentration, followed by neem (34.40%) and turmeric (34.20%), which were statistically similar. Tumha and bitter cress produced moderate mortality (28.20% and 24.00%, respectively), while ajwaen showed the lowest mortality (22.80%) among the treatments.

The results also showed that higher concentrations of plant powders resulted in greater mortality. The maximum mortality was observed at 3% concentration, whereas the lowest concentration (0.5%) resulted in comparatively lower mortality. These findings suggest that mortality of pulse beetles increases with both exposure time and dosage of plant powders.

Cumulative mortality after 7 days

Mortality of pulse beetle adults recorded after seven days of exposure showed significant differences among plant powder treatments compared with the control (Table 5) (Figure 1). Garlic and turmeric powders were found to be the most effective treatments, causing 76.60% and 74.60% mortality, respectively. Neem powder also showed considerable effectiveness with 69.20% mortality, whereas tumha resulted in 52.20% mortality.

In contrast, ajwaen and bitter cress were comparatively less effective, causing 36.40% and 39.00% mortality, respectively. The control treatment recorded minimal mortality (12.60%). The results also indicated that mortality increased with increasing concentration and exposure period, with the highest concentration (3%) producing the greatest mortality.

Table 4. Adult mortality (%) of *Callosobruchus analis* 72 h after treatment with plant powders at different concentrations.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	21.00 ± 0.71 a	23.20 ± 0.84 a	24.80 ± 0.84 ab	26.00 ± 0.55 a	30.80 ± 1.79 a	34.40 ± 1.48 a
Turmeric	15.20 ± 0.84 b	20.60 ± 0.84 b	23.60 ± 0.84 b	26.00 ± 0.84 a	31.40 ± 1.14 a	34.20 ± 1.82 a
Garlic	14.20 ± 1.14 b	22.40 ± 0.84 ab	25.00 ± 1.14 a	27.20 ± 0.89 a	32.40 ± 1.48 a	35.60 ± 1.92 a
Ajwaen	10.80 ± 0.84 c	12.60 ± 1.14 c	13.20 ± 1.00 d	16.40 ± 1.00 b	20.40 ± 1.00 c	22.80 ± 1.14 c
Tumha	11.20 ± 1.00 c	13.40 ± 1.14 c	15.20 ± 1.00 c	17.60 ± 1.00 b	23.20 ± 1.14 b	28.20 ± 1.52 b
Bitter cress	9.80 ± 1.30 c	11.60 ± 1.14 c	14.20 ± 1.30 cd	16.60 ± 1.14 b	21.20 ± 1.30 c	24.00 ± 1.58 c
Control	6.80 ± 0.84 d	7.80 ± 0.84 d	7.60 ± 1.22 e	8.00 ± 0.84 c	8.20 ± 1.00 d	8.20 ± 0.84 d
LSD Value	1.55	2.06	1.40	1.34	1.64	1.68

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

Table 5. Adult mortality (%) of *Callosobruchus analis* 7 days after treatment with plant powders at different concentrations.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	30.80 ± 0.84 b	35.20 ± 0.84 a	40.20 ± 0.55 b	45.80 ± 0.84 b	58.20 ± 0.84 b	69.20 ± 1.14 b
Turmeric	34.00 ± 0.71 a	35.20 ± 0.84 a	42.40 ± 0.84 a	51.20 ± 1.22 a	60.00 ± 2.58 b	74.60 ± 1.52 a
Garlic	26.20 ± 1.52 c	34.60 ± 1.00 a	42.00 ± 1.92 ab	51.20 ± 2.07 a	62.60 ± 1.82 a	76.60 ± 1.14 a
Ajwaen	22.00 ± 1.22 de	22.80 ± 0.89 c	24.00 ± 1.14 d	28.60 ± 1.30 d	32.00 ± 1.30 e	36.40 ± 1.22 e
Tumha	23.20 ± 1.14 d	25.20 ± 1.48 b	29.40 ± 0.84 c	33.20 ± 1.30 c	46.20 ± 1.14 c	52.20 ± 1.51 c
Bitter cress	20.00 ± 0.83 e	23.40 ± 1.30 bc	24.20 ± 1.30 d	30.20 ± 0.83 d	34.00 ± 1.14 d	39.00 ± 1.52 d
Control	13.00 ± 0.71 f	13.40 ± 1.14 d	13.00 ± 1.14 e	13.00 ± 1.41 e	12.60 ± 1.48 f	12.60 ± 1.14 f
LSD Value	2.16	1.89	2.01	2.12	1.93	2.22

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

Number of eggs per grain^{-20}

The number of eggs laid by female pulse beetles differed significantly among treatments (Table 6). All plant powder treatments significantly reduced oviposition compared with the untreated control. The lowest number of eggs was recorded in grains treated with garlic powder (2.60 eggs per 20 grains), followed by tumha (2.80 eggs) and neem (3.20 eggs). Turmeric and bitter cress treatments also reduced oviposition, recording 3.40 and 5.00 eggs, respectively.

In contrast, the untreated control recorded the highest number of eggs (19.60 eggs per 20 grains). Egg laying decreased with increasing concentration of plant powders, indicating that higher doses effectively suppressed oviposition of pulse beetles.

Days to adult emergence

The developmental duration of pulse beetle was significantly affected by plant powder treatments (Table 7). Maximum developmental duration was observed in turmeric and neem treatments (25.00 days), followed by garlic (24.80 days). In contrast, the untreated control recorded the shortest developmental period (21.60 days).

These findings indicate that plant powders can delay the development of pulse beetle, thereby slowing population growth under storage conditions.

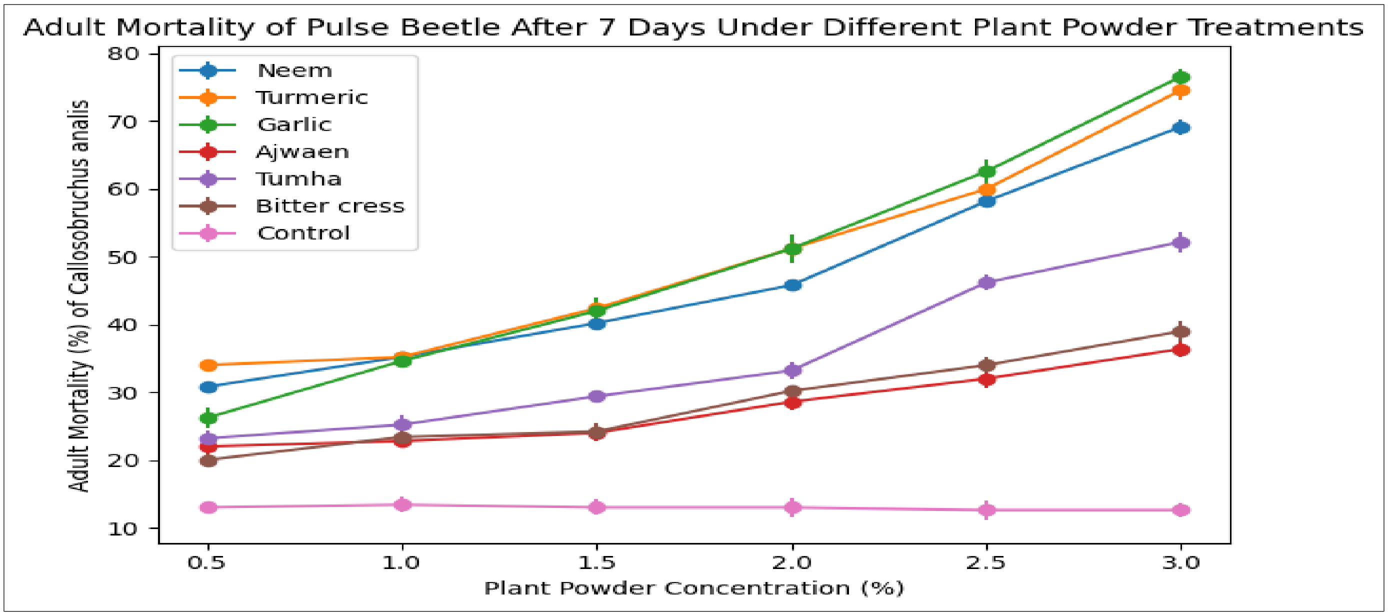

Figure 1. Adult mortality (%) of *Callosobruchus analis* after 7 days under different plant powder treatments at varying concentrations (mean ± SE).

Table 6. Number of eggs laid per 20 grains of mung bean by *Callosobruchus analis* under different plant powder treatments.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	6.60 ± 1.14 bcd	6.00 ± 0.71 cd	5.20 ± 0.84 d	4.60 ± 0.55 c	4.00 ± 0.71 cd	3.20 ± 0.84 d
Turmeric	6.40 ± 1.14 cd	6.20 ± 0.84 cd	5.20 ± 0.84 d	4.20 ± 0.84 c	3.80 ± 0.84 d	3.40 ± 1.14 cd
Garlic	5.20 ± 0.84 d	4.80 ± 0.84 d	4.60 ± 0.89 d	3.80 ± 0.84 c	2.80 ± 0.84 d	2.60 ± 0.54 d
Ajwaen	8.80 ± 0.84 b	9.20 ± 0.84 b	8.20 ± 0.84 b	7.60 ± 1.14 b	6.80 ± 0.84 b	6.40 ± 0.89 b
Tumha	6.40 ± 1.14 cd	6.20 ± 0.84 cd	5.60 ± 0.89 cd	4.20 ± 0.89 c	3.60 ± 0.54 d	2.80 ± 0.84 d
Bitter cress	8.20 ± 1.30 bc	7.60 ± 1.14 bc	7.20 ± 0.84 bc	6.40 ± 0.54 b	5.80 ± 0.84 bc	5.00 ± 0.71 bc
Control	15.00 ± 1.64 a	15.20 ± 1.14 a	16.80 ± 1.30 a	18.60 ± 1.14 a	15.00 ± 1.58 a	19.60 ± 1.14 a
LSD Value	2.34	2.05	1.87	1.75	1.87	1.79

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

Total adult emergence

Plant powder treatments significantly reduced the emergence of adult pulse beetles compared with the control (Table 8). Garlic powder resulted in the lowest adult emergence (43.20 adults), followed by turmeric (50.40 adults) and neem (59.60 adults). Higher numbers of adults emerged in treatments with ajwaen and bitter cress, whereas the control recorded the highest adult emergence (150.20 adults).

These results demonstrate that plant powders can effectively suppress population buildup of pulse beetles in stored mung bean.

Percent infestation

After 40 days of treatment, the percentage of infested mung beans differed significantly among treatments compared with the untreated control (Table 9) (Figure 2). All plant powder treatments reduced grain infestation to varying degrees. The lowest infestation levels were recorded in turmeric and garlic treatments (14.77% and 15.24%, respectively), which were statistically similar. These were followed by neem and tumha treatments with 18.99% and 19.89% infestation, respectively. In contrast, higher infestation levels among the botanical treatments were observed in bitter cress (21.16%) and ajwaen (22.84%). The untreated control recorded the highest infestation (47.43%), indicating severe grain damage.

Grain infestation decreased progressively with increasing dosage of plant powders. The lowest infestation (14.77%) was observed at the 3% concentration, followed by 15.65% at 2.5% and 15.95% at 2%, which were statistically similar. These findings suggest that higher concentrations of plant powders were more effective in protecting mung bean grains from pulse beetle infestation. Among the tested botanicals, turmeric (T2), garlic (T3), and neem (T1) performed best in reducing grain infestation at higher concentrations.

Table 7. Developmental duration (days) to F_1 adult emergence of *Callosobruchus analis* under different plant powder treatments.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	24.20 ± 0.84 a	25.20 ± 0.84 a	24.80 ± 0.84 a	25.00 ± 1.00 a	25.00 ± 1.00 a	25.00 ± 1.00 a
Turmeric	24.40 ± 0.54 a	24.20 ± 0.41 ab	24.60 ± 0.54 a	25.00 ± 0.71 a	25.00 ± 0.71 a	25.00 ± 1.00 a
Garlic	23.00 ± 0.71 ab	23.20 ± 0.84 bc	24.20 ± 0.84 a	24.20 ± 0.84 a	24.80 ± 0.84 a	24.80 ± 0.84 a
Ajwaen	23.40 ± 1.14 a	23.00 ± 0.71 bc	23.20 ± 0.84 ab	23.60 ± 0.54 a	23.60 ± 0.89 a	24.00 ± 0.71 a
Tumha	24.40 ± 0.71 a	24.20 ± 0.84 ab	24.20 ± 0.84 a	24.40 ± 0.89 a	24.00 ± 1.00 a	24.40 ± 0.54 a
Bitter cress	23.00 ± 0.71 ab	23.20 ± 0.84 bc	23.60 ± 0.89 a	24.20 ± 0.84 a	24.20 ± 0.84 a	24.20 ± 0.84 a
Control	21.40 ± 1.00 b	22.00 ± 1.00 c	21.80 ± 0.84 b	21.80 ± 0.84 b	22.20 ± 0.84 b	21.60 ± 1.14 b
LSD Value	1.68	1.60	1.63	1.64	1.76	1.78

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

Table 8. F_1 adult emergence of *Callosobruchus analis* under different plant powder treatments.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	100 ± 2.12 c	89.80 ± 1.92 b	76.40 ± 2.59 d	68.00 ± 2.24 d	62.60 ± 2.07 e	59.60 ± 2.70 d
Turmeric	70.20 ± 2.39 d	66.60 ± 2.30 c	63.40 ± 2.70 d	68.00 ± 1.92 d	52.00 ± 2.39 f	50.40 ± 2.77 e
Garlic	58.40 ± 2.41 e	54.20 ± 2.88 d	51.60 ± 2.88 d	48.40 ± 2.39 d	47.40 ± 2.55 f	43.20 ± 2.59 e
Ajwaen	120.00 ± 2.70 bc	117.80 ± 2.86 b	114.40 ± 2.39 b	114.40 ± 2.30 b	100.20 ± 2.07 b	87.60 ± 2.55 b
Tumha	104.80 ± 2.88 bc	100.00 ± 2.07 b	89.80 ± 2.86 c	75.80 ± 2.39 c	66.40 ± 1.30 d	67.60 ± 2.07 c
Bitter cress	119.80 ± 2.59 b	118.00 ± 1.58 b	117.60 ± 2.12 b	105.40 ± 2.77 b	98.00 ± 2.21 c	91.20 ± 2.70 c
Control	138.60 ± 2.86 a	141.20 ± 2.70 a	149.60 ± 2.74 a	150.00 ± 2.92 a	149.60 ± 2.54 a	150.20 ± 2.59 a
LSD Value	5.12	6.24	4.94	7.29	7.54	8.03

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

Table 9. Percent grain infestation caused by *Callosobruchus analis* under different plant powder treatments.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	26.74 ± 0.82 b	24.55 ± 0.63 c	24.15 ± 0.78 c	22.15 ± 0.90 cd	20.75 ± 0.86 c	18.99 ± 1.08 d
Turmeric	22.09 ± 0.69 c	18.88 ± 0.93 e	16.99 ± 1.01 e	15.95 ± 0.77 e	15.65 ± 0.76 d	14.77 ± 0.59 e
Garlic	22.82 ± 0.93 c	19.77 ± 0.63 e	18.45 ± 0.98 e	17.29 ± 0.86 e	16.77 ± 0.88 d	15.24 ± 1.02 e
Ajwaen	26.80 ± 0.87 b	25.61 ± 1.25 bc	26.73 ± 0.86 b	26.13 ± 0.66 b	23.67 ± 0.80 b	22.84 ± 0.80 b
Tumha	23.54 ± 0.72 c	21.92 ± 1.04 d	21.57 ± 1.03 d	21.29 ± 0.56 d	20.88 ± 0.75 c	19.89 ± 0.59 cd
Bitter cress	27.58 ± 1.11 b	26.61 ± 0.99 b	24.91 ± 1.14 bc	23.87 ± 1.23 c	22.87 ± 0.92 b	21.16 ± 0.97 bc
Control	47.43 ± 1.01 a	46.87 ± 1.12 a	46.95 ± 0.93 a	47.43 ± 1.39 a	47.25 ± 1.40 a	47.24 ± 1.26 a
LSD Value	1.93	1.94	1.94	1.91	1.88	1.87

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

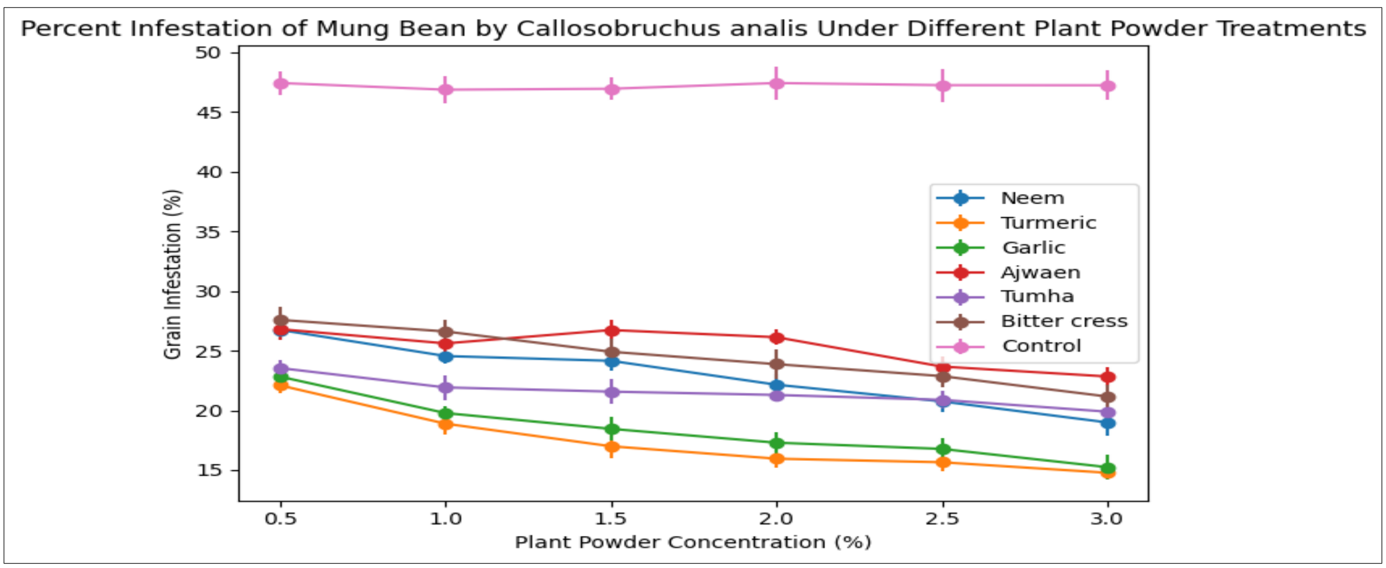

Figure 2. Percent grain infestation of mung bean caused by *Callosobruchus analis* under different plant powder treatments at varying concentrations (mean ± SE).

Grain weight loss

Weight loss of mung bean grains caused by pulse beetle infestation was significantly reduced in all plant powder treatments compared with the untreated control (Table 10) (Figure 3). Among the botanicals, garlic and turmeric powders resulted in the lowest grain weight loss (6.14% and 7.20%, respectively), and both treatments were statistically similar. Neem and tumha treatments showed moderate effectiveness with 7.76% and 10.48% weight loss, respectively. In contrast, bitter cress and ajwaen treatments were comparatively less effective, both recording 12.69% weight loss. The untreated control showed the highest grain weight loss (26.78%), indicating severe damage caused by pulse beetle infestation.

Regarding concentrations, the highest dosage levels (3%, 2.5%, and 2%) were most effective in reducing grain weight loss, recording 6.14%, 6.24%, and 7.36%, respectively. These values were statistically similar and substantially lower than those observed at lower concentrations. The lowest concentrations (0.5% and 1%) resulted in comparatively higher grain weight loss (12.38% and 10.82%, respectively). Overall, all concentrations of plant powders significantly reduced grain weight loss compared with the untreated control.

Table 10. Percent weight loss of mung bean grains caused by *Callosobruchus analis* under different plant powder treatments.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	13.34 ± 0.50 cd	12.11 ± 0.63 c	11.39 ± 0.62 c	10.68 ± 0.48 d	9.35 ± 0.69 d	7.76 ± 0.57 d
Turmeric	12.38 ± 0.57 d	10.82 ± 0.53 d	8.30 ± 0.74 d	8.06 ± 0.41 e	7.83 ± 0.50 e	7.20 ± 0.47 de
Garlic	13.24 ± 0.47 cd	12.88 ± 0.33c	9.21 ± 0.55 d	7.36 ± 0.60 e	6.24 ± 0.43 f	6.14 ± 0.63 e
Ajwaen	15.91 ± 0.49 b	15.15 ± 0.57 b	14.56 ± 0.44 b	14.39 ± 0.75 b	13.46 ± 0.47 b	12.69 ± 0.76 b
Tumha	13.99 ± 0.56 c	12.99 ± 0.41 c	12.22 ± 0.63 c	11.91 ± 0.53 c	11.19 ± 0.39 c	10.48 ± 0.76 c
Bitter cress	16.08 ± 0.55 b	15.77 ± 0.35 b	14.55 ± 0.44 b	14.07 ± 0.31 b	13.57 ± 0.41 b	12.69 ± 0.38 b
Control	23.07 ± 1.08 a	26.78 ± 0.95 a	22.76 ± 1.12 a	23.11 ± 0.97 a	23.19 ± 0.65 a	23.33 ± 0.74 a
LSD Value	1.27	1.15	1.37	1.23	1.04	1.27

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

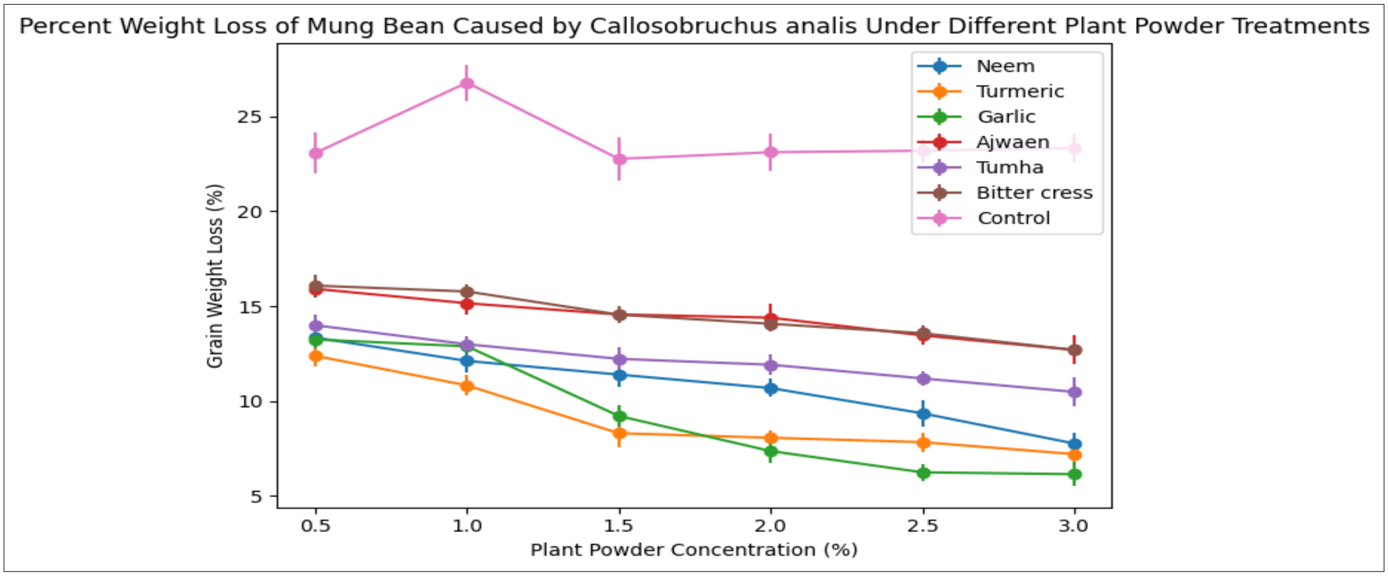

Figure 3. Percent weight loss of mung bean grains caused by *Callosobruchus analis* under different plant powder treatments at varying concentrations (mean ± SE).

Sex ratio

The sex ratio of adult *C. analis* emerging from treated and untreated grains did not differ significantly among treatments (P > 0.05) (Table 11). In all treatments, the number of females was slightly higher than males; however, the differences among treatments were not statistically significant. These results indicate that the application of plant powders had no noticeable effect on the sex ratio of emerging pulse beetles.

Table 11. Sex ratio of *Callosobruchus analis* emerging from mung bean grains under different plant powder treatments.

Treatments	Concentrations (%)					
	0.5 ^{NS}	1.0 ^{NS}	1.5 ^{NS}	2.0 ^{NS}	2.5 ^{NS}	3.0 ^{NS}
Neem	45.40 ± 0.89	45.40 ± 0.55	45.00 ± 0.71	45.20 ± 0.84	45.00 ± 1.00	45.40 ± 0.89
Turmeric	45.60 ± 0.55	45.20 ± 0.84	45.20 ± 0.84	44.80 ± 0.84	45.00 ± 1.00	45.00 ± 1.00
Garlic	45.00 ± 0.71	45.00 ± 1.00	45.00 ± 1.00	45.20 ± 0.84	45.60 ± 0.89	45.00 ± 0.71
Ajwaen	45.80 ± 0.84	46.00 ± 0.71	45.40 ± 0.89	45.20 ± 0.84	46.00 ± 0.71	45.40 ± 0.89
Tumha	45.80 ± 1.30	45.40 ± 0.55	45.40 ± 0.55	45.80 ± 0.84	45.20 ± 0.84	45.20 ± 0.84
Bitter cress	45.60 ± 1.14	45.40 ± 0.89	44.80 ± 0.84	45.60 ± 0.55	45.80 ± 0.84	45.00 ± 0.71
Control	45.80 ± 0.45	45.40 ± 0.89	45.80 ± 0.84	45.40 ± 0.89	45.60 ± 1.14	45.60 ± 0.55
LSD Value	1.78	1.59	1.64	1.63	1.86	1.63

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

Adult life span

The longevity of adult pulse beetles was significantly affected by plant powder treatments compared with the untreated control (Table 12). Among the treatments, the shortest adult lifespan was observed in turmeric (7.60 days) followed by garlic and neem (8.00 days each). Tumha and bitter cress treatments resulted in slightly longer adult longevity (8.40 and 8.80 days, respectively), but these values were still significantly lower than the untreated control, which recorded the longest lifespan (12.80 days).

Concentration also influenced adult longevity. Higher concentrations of plant powders (3%, 2.5%, 2%, and 1.5%) resulted in shorter adult lifespan, ranging between 7.60 and 8.40 days, and these values were statistically similar. In contrast, lower concentrations (0.5% and 1%) resulted in relatively longer adult longevity (8.80 days). These findings indicate that plant powders reduce the lifespan of adult pulse beetles, particularly at higher concentrations.

Table 12. Adult longevity (days) of *Callosobruchus analis* under different plant powder treatments.

Treatments	Concentrations (%)					
	0.5	1.0	1.5	2.0	2.5	3.0
Neem	9.20 ± 0.84 b	8.80 ± 0.84 b	8.40 ± 0.55 bc	8.40 ± 0.55 b	8.00 ± 0.71 b	8.00 ± 0.71 bc
Turmeric	8.80 ± 0.84 b	9.00 ± 0.71 b	8.20 ± 0.44 b	8.40 ± 0.55 b	8.00 ± 0.71 b	7.60 ± 0.55 c
Garlic	9.40 ± 0.55 ab	8.80 ± 0.84 b	9.00 ± 0.71 bc	9.40 ± 0.55 b	8.60 ± 0.55 b	8.00 ± 0.71 bc
Ajwaen	10.00 ± 0.71 ab	9.60 ± 0.55 ab	9.40 ± 0.55 b	9.20 ± 0.84 b	8.80 ± 0.45 b	9.00 ± 0.71 b
Tumha	9.40 ± 0.55 ab	9.60 ± 0.55 ab	9.20 ± 0.45 bc	8.80 ± 0.84 b	8.80 ± 0.45 b	8.40 ± 0.55 bc
Bitter cress	9.60 ± 0.55 ab	9.40 ± 0.55 ab	9.20 ± 0.45 bc	9.00 ± 0.71 b	9.20 ± 0.45 b	8.80 ± 0.45 bc
Control	12.80 ± 0.84 a	10.80 ± 0.84 a	10.60 ± 0.89 a	11.00 ± 1.00 a	10.80 ± 0.84 a	10.80 ± 0.84 a
LSD Value	1.42	1.41	1.20	1.48	1.22	1.31

Values represent mean ± SE. Means followed by different letters within a column are significantly different according to LSD test at P ≤ 0.05.

DISCUSSION

A large variety of terrestrial plants have been found to possess insecticidal properties against a large variety of insect pests. These plants carry repellent, anti-feedant, growth inhibition and progeny inhibition properties. In the current investigations, a dose dependent potential of selected botanical powders was found against pulse beetle. Among the tested plant powders, the powders of turmeric and garlic carried maximum potential of protecting the green gram seeds in storage. It was observed that rate of mortality increased with the increase of exposure period and concentration of plant powders. Among all the treatments garlic and turmeric powders showed highest mortality (77.60% and 74.60%) of pulse beetle adults at seven days after treatment of mung bean grains. Similar findings were reported by (Kaur et al., 2019). They documented that after seven days of treatment, highest mortality (98.89%) of beetles was recorded when the grains were treated with sweet flag powder followed by neem (67.78%). Similar results were also reported by (Zafar et al., 2018), they tested various plant powders against pulse beetle and found neem, turmeric and tumha powders effective in killing the *C. chinensis* in stored mung bean after 24 hours of the application of plant powders. Similar to present study, (Pathania, 2013) also reported 86.67% mortality of *C. chinensis* caused by neem leaf powder after seven days.

The higher effectiveness of garlic and turmeric powders observed in the present study may be attributed to the presence of biologically active compounds in these plants. Garlic (*Allium sativum*) contains sulfur-containing compounds such as allicin and diallyl sulfides, which have strong insecticidal, repellent, and anti-feeding properties. These compounds may interfere with the respiratory system and metabolic enzymes of insects, leading to increased mortality and reduced feeding activity. Similarly, turmeric (*Curcuma longa*) contains bioactive constituents such as curcumin and essential oils that exhibit insecticidal and growth-regulating effects against stored-product insects. These compounds may disrupt normal physiological processes, inhibit feeding, and reduce oviposition of adult beetles. Neem (*Azadirachta indica*) is also known to contain azadirachtin and related limonoids, which act as insect growth regulators and feeding deterrents, thereby reducing survival and reproduction of insects. Previous studies have also reported that botanical insecticides containing such bioactive compounds can effectively suppress populations of stored-grain pests and reduce post-harvest losses in stored commodities (Trivedi et al., 2018; Vijayan et al., 2023; Rajashekar et al., 2025).

Among the treatments minimum number of eggs were laid on grains treated with garlic, tumha and neem powders (2.60, 2.80 and 3.20 eggs grain^{-20}) being statistically at par with each other. (Devi & Devi, 2015) tested various plant powders and reported that all the tested plant powders significantly reduced the rate of oviposition by *C. analis*. (Kaur et al., 2019) recorded minimum number of eggs laid by pulse beetle in stored grains treated with sweet flag rhizome and neem leaf powders. The results of present research verify the results of (Gupta et al., 2015) they documented the potential of neem leaf powder in reducing the fecundity of *C. maculatus* on green gram seeds. Reduction in egg laying may be due to the anti-feeding anti ovipositional effects of plant powders against adult pulse beetles.

Results of the experiment indicated that plant powders are very effective against pulse beetle in reducing the egg laying or reduction in hatching of eggs which eventually reduced the numbers of adults emerged. Efficacy of various plant powders in reducing the number of F_1 adult emergence has also been reported to be significantly effective against *C analis* and *C chinensis* by (Devi & Devi, 2015; Islam et al., 2013; Khan et al., 2015).

From the above results it was observed that among the six plant powders T2, T3 and T1 at higher concentrations performed well in reducing the percent infestation of mung beans. Similar results were also reported by several research scientists. (Devi & Devi, 2015) reported that various plant powders including *Azadiracta indica* reduced significantly the percentage grain damage caused by *C. analis*. Similar results were also reported by (Khan et al., 2015), they found that all the tested plant powders along with neem leaf powder were very effective in reducing the percent infestation by *C. chinensis* in stored mung bean.

Among the treatments minimum weight loss was recorded in garlic and turmeric powders (6.14% and 7.20% respectively) being statistically at par with each other. Losses in weight of mung bean grains are caused by feeding of pulse beetle larvae inside the grains. Reduction in weight loss of mung bean grains might be due to the early mortality and less oviposition of pulse beetle adults.

Among the treatments minimum adult longevity was recorded in turmeric, garlic, neem, tumha and bitter cress powders (7.60, 8.00, 8.00, 8.40 and 8.80 days respectively) being statistically similar with each other. (Rehman & Khan, 2014) tested neem seed powder at different concentrations. They found no significant effect of neem seed powder on the life span of adult pulse beetle *C. chinensis.* (Yankanchi & Lendi, 2009) tested various plant powders against pulse beetle and found them effective in reducing the longevity and oviposition by *C. chinensis*.

Overall, the findings of the present study highlight the potential of indigenous plant powders as effective and environmentally friendly alternatives to synthetic insecticides for the management of pulse beetle in stored mung bean. The significant reduction in adult mortality, oviposition, adult emergence, grain infestation, and weight loss observed in treated grains suggests that plant powders can play an important role in protecting stored legumes from insect damage. The use of such locally available botanical materials may provide a sustainable and safer approach for small-scale farmers and storage managers to reduce post-harvest losses while minimizing the risks associated with chemical insecticides.

CONCLUSION AND RECOMMENDATIONS

The present study demonstrated that both chemical fungicides and botanical extracts possess significant inhibitory effects against *Colletotrichum falcatum,* the causal agent of red rot of sugarcane. All tested fungicides effectively suppressed fungal growth, with propineb + Iprovalicarb, Pyraclostrobin + Metiaram, and thiophanate methyle showing almost complete inhibition at higher concentration *in-vitro* conditions. among the botanical treatments, garlic extract exhibited the highest antifungal activity, completely inhabiting the mycelial growth of *C. falcatum* at the highest concentration, followed by neem and moringa extracts. These results confirm the strong antifungal potential of chemical fungicides and botanical extracts for the effective management of the pathogen.

Overall, the findings suggest that while chemical fungicides give rapid and effective suppression of the pathogen, botanical extracts represent environmentally safe and sustainable alternative. Therefore, integrating effective fungicides with plant-based extracts may provide a promising strategy for the sustainable management of red rot disease in sugarcane.

According to the findings of this research, the following recommendations can be offered:

The use of garlic and turmeric powders at a concentration of 2.5-3.0% could be suggested to the protection of mung bean when stored against *Callosobruchus analis* in a small scale and farm storage condition.

Their usefulness and cost-effectiveness should be proven with the help of further studies conducted in the fields and under real storage conditions.

Research on isolation and identification of active bioactive compounds that cause insecticidal activity are proposed to improve development of formulations.

They should also consider using effective plant powders incorporated into Integrated Pest Management (IPM) programs of the stored grains as a way of minimizing the use of synthetic insecticides.

AUTHOR CONTRIBUTIONS

All authors contributed equally.

COMPETING OF INTEREST

The authors declare no competing interests.

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