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BOTANICAL MANAGEMENT OF *CALLOSOBRUCHUS CHINENSIS* IN STORED RED GRAM: IMPACT ON SEED DAMAGE, GERMINATION, AND VIABILITY

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ABSTRACT

Pulse beetle (*Callosobruchus chinensis* L.) is a major storage pest in red gram (*Cajanus cajan* L.), causing substantial seed damage, weight loss, and viability decline. In this study, the efficacy of six plant-derived seed protectants namely neem oil, neem leaf powder, tulsi leaf powder, tobacco leaf powder, marigold leaf powder, and turmeric rhizome powder was evaluated against *C. chinensis* under ambient storage conditions for up to six months. The experiment was conducted for two consecutive years using a completely randomized design (CRD) with eight treatments, including a synthetic check (Deltamethrin 2.8 EC) and an untreated control, replicated thrice. Observations on seed damage, weight loss, germination percentage, and moisture content revealed that all botanical treatments significantly reduced storage losses compared to the control. Neem oil and neem leaf powder consistently outperformed other botanicals, with effectiveness comparable to the chemical check, especially in minimizing seed damage and preserving germination. Turmeric rhizome powder was the least effective across all parameters. The untreated control consistently recorded the highest damage, weight loss, and moisture accumulation, alongside the lowest germination. These findings support the use of neem-based botanicals as sustainable, eco-friendly alternatives to synthetic insecticides for protecting red gram seeds during storage.

***Keywords*:** *Callosobruchus chinensis*, red gram, seed storage, neem oil, botanical insecticides, seed viability, weight loss, moisture content.

Introduction

Pulses are an essential component of Indian agriculture and nutrition, especially in a country with a predominantly vegetarian population. Rich in protein (20–30%), essential amino acids, and micronutrients, pulses play a vital role in ensuring nutritional security and improving soil health through biological nitrogen fixation, thereby supporting sustainable farming systems (Singh *et al.*, 2015; Gupta *et al.*, 1983).

India is the world's largest producer and consumer of pulses, accounting for around 31% of the global pulse-growing area and 28% of global production (Directorate of Pulses Development, 2022). According to the Ministry of Agriculture and Farmers Welfare (2024), pulse production in 2023–24 is estimated at 26.06 million tonnes from 30.36 million hectares. Among major pulse crops, red gram (*Cajanus cajan* L.), also known as arhar or tur, holds significant importance ranking second after chickpea. In 2021–22, Karnataka and Maharashtra together contributed over 50% of the country's total red gram output. Nutritionally, red gram is valued for its high protein content (21.7%) along with carbohydrates (63.6%), crude fibre (6.9%), and essential minerals like calcium and iron.

Despite its importance, red gram is highly vulnerable to post-harvest losses caused by storage pests, particularly the pulse beetle (*Callosobruchus chinensis* L.). This insect infests grains both in the field and in storage, with larvae boring into and hollowing out seeds, rendering them unfit for consumption or sowing (Rathore & Sharma, 2002). Infestation can lead to seed weight losses of 10% to 95% and reductions in protein content by up to 66%, severely compromising seed quality, viability, and market value (Gujar & Yadav, 1978). Additionally, *C. chinensis* promotes microbial contamination, accelerating grain spoilage (Neelgund & Kumari, 1983).

Traditionally, chemical insecticides such as organophosphates and fumigants have been the primary method of pest control. However, excessive and indiscriminate use has resulted in serious issues such as pest resistance, non-target toxicity, pesticide residues, and environmental pollution (EPA, 2001; Garriga & Caballero, 2011). In response, global and national agricultural bodies including the FAO and the UN are promoting sustainable and climate-resilient pest management practices.

Plant-derived products, or botanicals, have emerged as eco-friendly alternatives to synthetic chemicals. More than 2,400 plant species possess insecticidal properties, and various powders and extracts from plants like neem, mustard, clove, black pepper, and turmeric have shown promising results in suppressing pulse beetle infestation (Grainge & Ahamed, 1988; Jilani, 1984; Mahdi, 2016). These botanicals are cost-effective, biodegradable, and safer for human health and the environment, making them particularly suitable for use by smallholder farmers.

Hence, the present study aims to evaluate the efficacy of selected plant-based powders and extracts for the botanical management of *Callosobruchus chinensis* in stored red gram, with the objective of identifying effective, sustainable, and farmer-friendly alternatives to chemical pesticides.

Materials and Methods

Laboratory Location and Experimental Variety

The laboratory studies were conducted at the All India Coordinated Research Project (AICRP) on Nematodes in Agriculture, Department of Agricultural Entomology, Mohanpur, Nadia, West Bengal. The red gram variety used for the experiments was UPAS 120 (*Cajanus cajan* L.). The experiment was conducted during the year 2023 (Year-1) and 2024 (Year-2).

Seed Collection and Disinfestation

Fresh seeds of red gram and other pulses were procured from the local market. To eliminate prior infestations, seeds were fumigated with aluminium phosphide tablets (3 g each) at a rate of 1 tablet per 3 quintals of seed, with an exposure period of seven days before experimentation.

Experimental Design

experiment was conducted under ambient conditions following a Completely Randomized Design (CRD) with three replications and eight treatments. The seeds were packed in gunny bags of 0.5 kg capacity. The test insect used was *Callosobruchus chinensis* L.

Treatments and Preparation of Botanicals

Eight treatments were tested against *C. chinensis* infestation. Details are given in the table below.

Sl. No.	Common Name	Rate (g or ml/kg seed)	Source/ Manufacturer
1	Neem oil	5 ml	Local market
2	Neem leaf powder	5 g	Local farm
3	Tulsi leaf powder	5 g	Local farm
4	Tobacco leaf powder	5 g	Local farm
5	Marigold leaf powder	5 g	Local farm
6	Turmeric rhizome powder	5 g	Local farm
7	Deltamethrin (Shastra 2.8 % EC)	0.04 ml	Local market
8	Control (Untreated)	-	-

Preparation of Botanical Powders

- **Neem leaf powder:** Mature *Azadirachta indica* leaves were harvested, shade-dried, cleaned, crushed, and sieved through a 20-mesh sieve.
- **Tulsi leaf powder:** Fresh *Ocimum sanctum* leaves were air-dried for five days, ground into fine powder, and sieved through a 20-mesh sieve.
- **Tobacco leaf powder:** Tobacco leaves were washed, shade-dried, ground, and sieved through a 20-mesh sieve.
- **Marigold leaf powder:** *Tagetes* leaves were harvested, dried for 5–7 days, crushed, and sieved through a 20-mesh sieve.
- **Turmeric rhizome powder:** Turmeric rhizomes were ground and sieved through a 20-mesh sieve.

Other seed protectants such as neem oil and deltamethrin were procured from the local market.

Methodology

For each treatment and replication, 300 grams of red gram (UPAS 120) seeds were treated with the respective seed protectants according to the experimental design. The experiment was conducted using a Completely Randomized Design (CRD) with three replications. Treated seeds were packed in 0.5 kg gunny (jute) bags and stored on laboratory racks under ambient conditions for durations of 3 and 6 months.

Observations were recorded periodically on seed germination percentage, moisture content, grain damage, and weight loss as per the experimental program. The same experiment was conducted again in the next year keeping all the aspects unchanged.

Observations Recorded

Seeds were randomly drawn from each treatment and replication for evaluation of the following parameters:

Percentage Seed Damage by *C. chinensis*

One hundred seeds were randomly selected from each sample, and using a 10x magnifying lens, seeds were sorted into healthy and damaged categories. The percentage of damaged seeds was calculated using the formula (Mohan and Sundar Babu, 1999):

$$Percentage\ seed\ damage = \frac{Number\ of\ bored\ seeds\ in\ sample}{Total\ number\ of\ seeds\ in\ sample} \times 100$$

Determination of Percentage Weight Loss of Seed

One hundred seeds were randomly selected from each treatment replication. Bored seeds were separated with the help of a 10x magnifying lens. Percentage weight loss was calculated by the formula (Dawae, 2008):

$$Percentage\ weight\ loss = \frac{Weight\ of\ damaged\ seeds\ in\ sample}{Total\ weight\ of\ seeds\ in\ sample} \times 100$$

Seed Germination Percentage

Seed germination was evaluated using the standard petri dish method as described by ISTA (2015). Fifty seeds from each treatment replication were placed on moistened filter paper in petri dishes, covered, labelled, and kept under suitable temperature and light conditions. Germination percentage was recorded on the 7th day using the formula:

$$Percentage\ seed\ germination = \frac{Number\ of\ germinated\ seeds}{Total\ number\ of\ seeds} \times 100$$

Seed Moisture Content

Moisture content of the red gram seeds was measured using an electronic moisture meter for each replication.

Statistical Analysis

The experiment was carried out under ambient storage conditions using a Completely Randomized Design (CRD) with three replications. Data were transformed as necessary prior to statistical analysis to meet assumptions of the tests applied.

Results and Discussions

Effect of botanicals on % seed damage in red gram by pulse beetle during various storage periods

The study revealed notable variations in the percentage of seed damage in red gram across different storage durations (Table 1). Overall, all botanical treatments significantly mitigated seed damage over six months of storage compared to the untreated control.

In the first year of treatment, at 3 months of storage, seed damage across treatments ranged from 4.77% to 14.55%. Turmeric rhizome powder applied at 5 g kg^{-1} seed recorded the highest damage (14.55%), followed by Tulsi leaf powder (12.33%), Marigold leaf powder (11.34%), and Tobacco leaf powder (10.00%). Neem oil (7.17%) and Neem leaf powder (9.20%) demonstrated superior protective effects among the botanicals, while the synthetic insecticide Deltamethrin (4.77%) consistently exhibited the lowest seed damage. All treatments significantly outperformed the untreated control, which exhibited a notably higher damage level (19.33%), with the exception of Turmeric rhizome powder, which showed comparatively reduced efficacy.

After 6 months, the extent of seed damage increased across all treatments, ranging from 8.00% to 25.33%. Neem oil maintained the lowest damage level among botanicals (13.67%), followed by Neem leaf powder (18.67%). Conversely, Turmeric rhizome powder continued to be the least effective, causing the highest damage (25.33%). Tulsi, Marigold, and Tobacco leaf powders exhibited moderate damage levels (22.33%, 21.33%, and 19.67%, respectively). The untreated control recorded significantly elevated damage (43.00%).

The observations in the second year mirrored the first, reinforcing the consistency and reliability of the treatments. At 3 months, Deltamethrin again recorded the least damage (5.10%), closely followed by Neem oil (7.50%) and Neem leaf powder (9.70%). Turmeric rhizome powder exhibited the highest damage (15.20%), reaffirming its limited protective capacity.

By 6 months, seed damage increased as anticipated, with Deltamethrin (8.50%) and Neem oil (14.00%) continuing to provide the most effective protection. Turmeric rhizome powder (26.80%), Tulsi leaf powder (23.10%), Marigold leaf powder (21.50%), and Tobacco leaf powder (20.00%) showed progressively higher damage levels. The untreated control remained significantly more susceptible to damage (45.00%).

These consistent trends across two consecutive years highlight the efficacy of Neem oil and Neem leaf powder as potent botanical protectants against pulse beetle infestation during storage. Conversely, Turmeric rhizome powder demonstrated limited effectiveness in reducing seed damage. These findings underscore the potential of certain botanicals as sustainable alternatives to synthetic insecticides in seed storage management. These findings also align with those reported by Mishra *et al.* (2008), Lal and Raj (2012), Mandali and Raddy (2014) who observed the efficacy of neem-based treatments and the general trend of increasing insect damage with prolonged storage duration.

Effect of Botanicals on Percent Seed Weight Loss in Red Gram During Storage Periods

The evaluation of seed weight loss in red gram over different storage periods demonstrated significant differences among treatments, highlighting the efficacy of botanical seed protectants in minimizing storage losses.

In the first year of treatment at 3 months of storage, the percent weight loss varied from 2.80% to 9.67% across the treatments. The synthetic insecticide Deltamethrin provided the most effective protection, recording the lowest weight loss of 2.80%. Among botanicals, Neem oil was the most effective, limiting weight loss to 4.33%, followed by Neem leaf powder (5.67%). Tulsi leaf powder, Tobacco leaf powder, and Marigold leaf powder exhibited moderate weight loss ranging from 7.90% to 8.67%. Turmeric rhizome powder caused the highest weight loss among botanicals at 9.67%. The untreated control, as expected, suffered the greatest loss at 15.00%.

At 6 months, weight loss increased in all treatments, ranging from 7.67% to 20.33%. Deltamethrin continued to minimize losses effectively (7.67%), with Neem oil (10.33%) and Neem leaf powder (12.00%) demonstrating good protective effects. Turmeric rhizome powder again showed the least protection with a 20.33% loss, while Tulsi, Marigold, and Tobacco leaf powders recorded intermediate weight losses (15.90% to 18.48%). The untreated seeds sustained the highest weight loss of 28.67%.

The trends observed in the second year closely paralleled those from Year 1, underscoring the reliability of the findings. At 3 months, Deltamethrin again recorded the least weight loss (3.00%), followed by Neem oil (4.50%) and Neem leaf powder (6.00%). Turmeric rhizome powder resulted in the highest weight loss (10.20%) among the botanicals.

After 6 months, weight loss naturally increased, with Deltamethrin maintaining superior efficacy (8.10%). Neem oil and Neem leaf powder exhibited moderate control over seed weight loss (10.90% and 12.50%, respectively). Turmeric rhizome powder caused the greatest weight loss (21.00%), followed by Tulsi, Marigold, and Tobacco leaf powders with losses ranging from 16.50% to 18.90%. The untreated control continued to exhibit the most significant weight loss, reaching 30.00%.

These consistent results over two consecutive years demonstrate that Neem oil and Neem leaf powder are the most promising botanical treatments for reducing seed weight loss due to pulse beetle infestation during storage. The comparatively poor performance of Turmeric rhizome powder suggests limited efficacy. Such insights support the adoption of effective botanical protectants as sustainable alternatives to synthetic chemicals in seed storage management.

The present results are in agreement with the findings of Tripathi *et al.* (2006), Pandey *et al.* (2013), Tabu *et al.* (2012), and Hasan *et al.* (2020), who also reported the efficacy of neem-based products in reducing weight loss in various pulses during storage.

Effect of Seed Protectants on Percent Germination of Red Gram Seeds During Storage Periods

The germination percentage of red gram seeds varied significantly across different seed protectant treatments and storage durations in both Year 1 and Year 2. Overall, all treatments maintained higher germination rates compared to the untreated control, underscoring the protective effect of both chemical and botanical seed treatments against deterioration during storage.

In Year 1, at 3 months of storage, the highest germination was observed with Deltamethrin (87.78%), followed closely by Neem oil (85.56%) and Neem leaf powder (83.33%). These treatments proved most effective in preserving seed viability. Among botanicals, Tulsi, Marigold, Tobacco, and Turmeric powders demonstrated moderate protection, with germination percentages ranging from 74.44% to 77.78%. The untreated control showed a markedly lower germination of 53.33%, indicating significant viability loss due to pest damage and natural deterioration.

At 6 months of storage in Year 1, a decline in germination percentage was evident across all treatments, which is consistent with typical seed aging effects. However, Deltamethrin (81.11%) and Neem oil (76.67%) still maintained superior seed viability compared to other treatments. The control treatment showed the steepest decline, with germination dropping to 41.11%.

Year 2 results reflected a similar trend, validating the consistency of the treatments' effects. At 3 months, Deltamethrin (85.00%), Neem oil (83.00%), and Neem leaf powder (80.00%) retained the highest germination percentages. By 6 months, germination declined slightly but remained significantly higher in these treatments compared to control. The control seeds again suffered the most, with only 40% germination after 6 months.

This consistency over two consecutive years confirms that Deltamethrin and Neem oil are the most reliable protectants for preserving seed germination under storage conditions. Neem leaf powder also shows promise as an eco-friendly alternative. The moderate performance of Tulsi, Marigold, Tobacco, and Turmeric powders suggests potential but may require optimization of dose or formulation.

Overall, these findings highlight the importance of seed treatment in maintaining red gram seed viability during storage and support the use of botanicals as sustainable alternatives to synthetic insecticides. These results are consistent with the findings of Lal and Raj (2012), and Singh *et al*. (2014who also reported the efficacy of neem-based treatments in preserving seed viability during storage.

Effect of Botanicals on Moisture Content (%) in Red Gram Seeds during Storage Periods

The moisture content of red gram seeds showed a gradual increase over the storage period in both Year 1 and Year 2. Across all treatments, seeds treated with botanicals and insecticide retained lower moisture levels compared to the untreated control, indicating better seed quality maintenance during storage.

In Year 1, at 3 months of storage, Neem oil treatment exhibited the lowest moisture content (10.83%), closely followed by Neem leaf powder (11.67%) and Marigold leaf powder (11.83%). The control recorded the highest moisture content at 12.83%. By 6 months, a similar trend was observed with Neem oil maintaining the lowest moisture level (11.00%), while the control reached 13.33%, indicating moisture accumulation which could favor seed deterioration.

Year 2 results reflected a consistent pattern with slight variations. Neem oil again showed superior performance in restricting moisture gain, recording 11.10% and 11.35% moisture content at 3 and 6 months, respectively. The untreated control in Year 2 exhibited the highest moisture content (13.05% at 3 months and 13.60% at 6 months). Other botanicals like Neem leaf powder, Marigold leaf powder, and Tobacco leaf powder also showed effective moisture control, falling between the insecticide and control treatments.

The observed differences in moisture content among treatments were statistically significant ($p < 0.05$) according to Duncan's Multiple Range Test in both years, reinforcing the efficacy of botanicals and insecticide in preserving seed quality by limiting moisture uptake during storage.

Overall, these findings suggest that botanicals such as Neem oil and Neem leaf powder can effectively maintain lower seed moisture content, reducing the risk of deterioration and prolonging the storage life of red gram seeds under ambient conditions. The consistency of results across both years underscores the reliability of these treatments for practical seed storage management. These findings are supported by earlier studies conducted by Patole and Mahajan (2008) and Pal and Katiyar (2013), who highlighted the moisture-regulating effects of neem-based treatments during storage.

Conclusion

The study demonstrated that selected botanicals particularly neem oil and neem leaf powder are effective in reducing seed damage, weight loss, and moisture accumulation while maintaining germination in red gram seeds stored under ambient conditions. Their performance was consistent across two years, indicating reliability and potential for practical application. Among the tested treatments, Deltamethrin remained the most effective, but neem-based botanicals offered comparable protection with the added benefits of being biodegradable, cost-effective, and environmentally safe. Conversely, turmeric rhizome powder showed limited efficacy.

Given the increasing emphasis on sustainable agriculture and the need to reduce chemical pesticide use, neem oil and neem leaf powder emerge as promising alternatives for on-farm storage protection against *Callosobruchus chinensis*. Adoption of such botanicals could help mitigate post-harvest losses, improve seed quality, and support integrated pest management strategies in pulse storage systems.

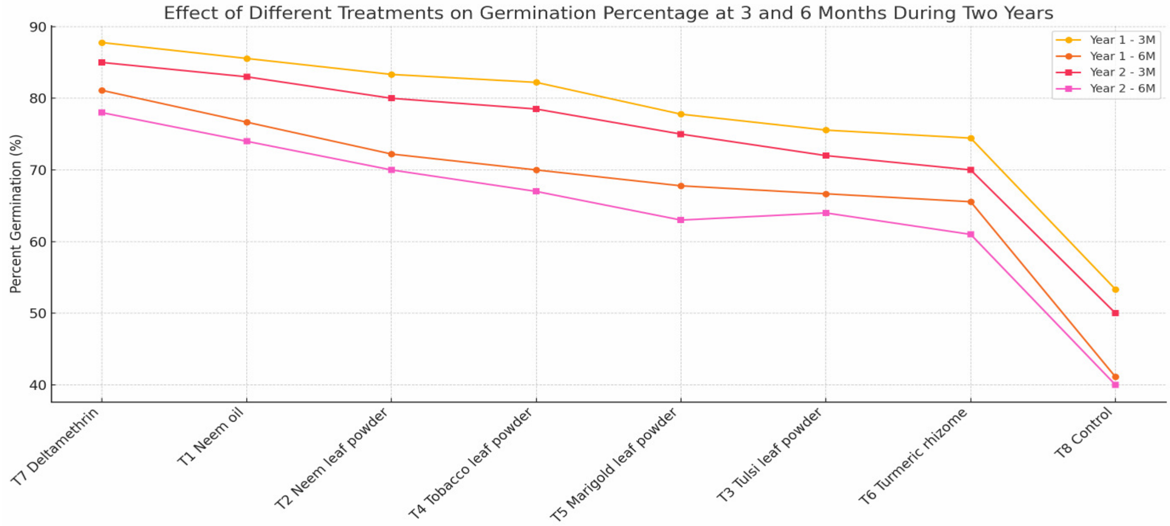

Fig. 1: Effect of Different treatments on germination percentage at 3 and 6 months during two years.

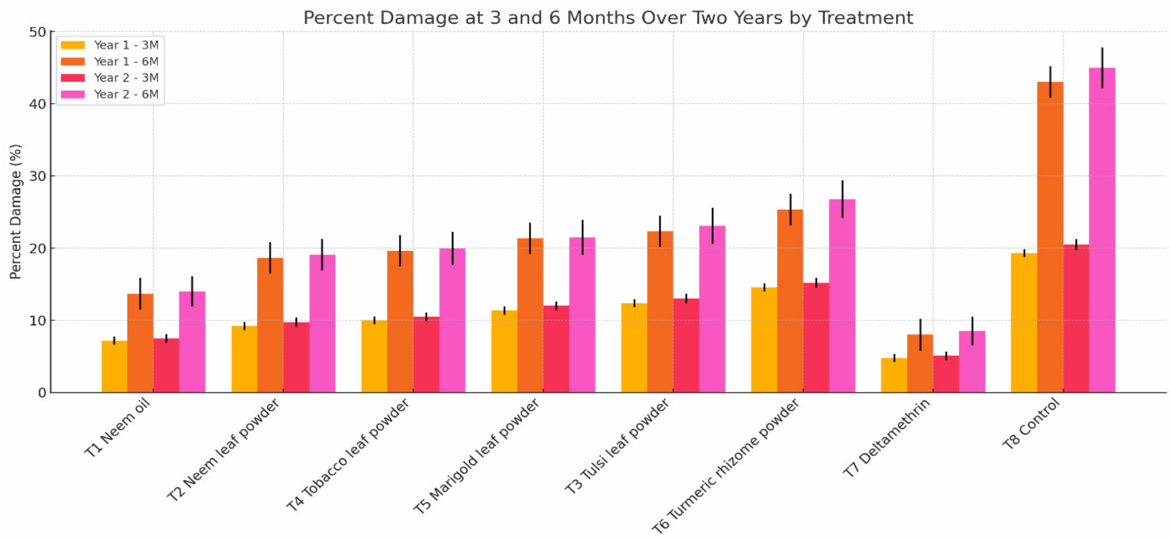

Fig. 2: Percent damage at 3 and 6 months over two years by reatment

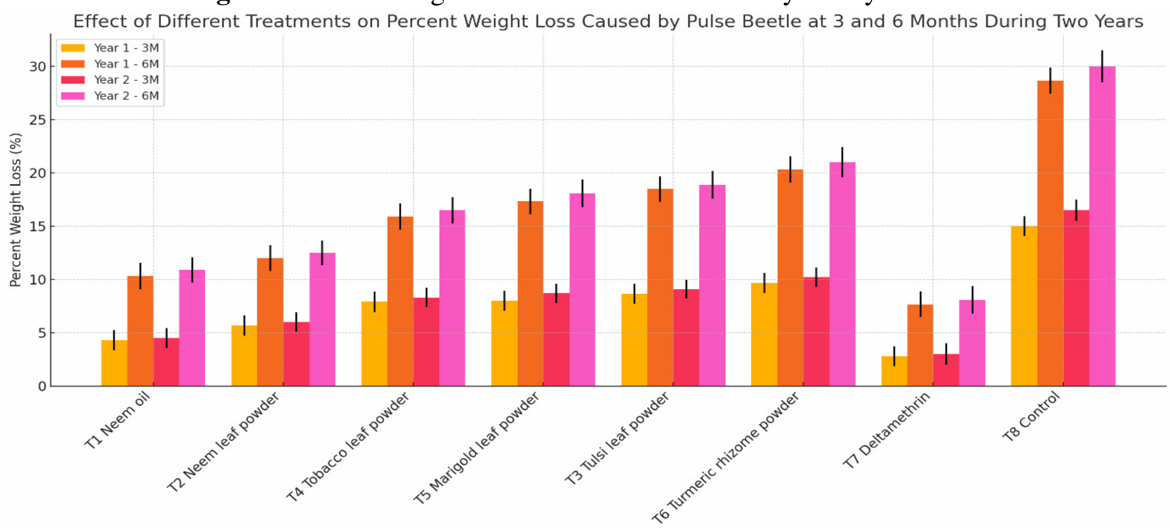

Fig. 3: Effect of different treatments on percent weight loss caused by pulse beetle at 3 and 6 months during two years.

Table 1: Percent Damage (%) at 3 and 6 Months

Treatment	Year - 1		Year -2	
	3 Months Damage (%)	6 Months Damage (%)	3 Months Damage (%)	6 Months Damage (%)
T1 Neem oil	$7.17^{ab} \pm 0.56$	$13.67^{ab} \pm 2.19$	$7.50^{ab} \pm 0.60$	$14.00^{ab} \pm 2.10$
T2 Neem leaf powder	$9.20^{b} \pm 0.56$	$18.67^{bc} \pm 2.19$	$9.70^{bc} \pm 0.65$	$19.10^{bc} \pm 2.20$
T4 Tobacco leaf powder	$10.00^{bc} \pm 0.56$	$19.67^{bc} \pm 2.19$	$10.50^{bc} \pm 0.60$	$20.00^{bc} \pm 2.30$
T5 Marigold leaf powder	$11.34^{bc} \pm 0.56$	$21.33^{cd} \pm 2.19$	$12.00^{cd} \pm 0.60$	$21.50^{cd} \pm 2.40$
T3 Tulsi leaf powder	$12.33^{cd} \pm 0.56$	$22.33^{cd} \pm 2.19$	$13.00^{cd} \pm 0.65$	$23.10^{cd} \pm 2.50$
T6 Turmeric rhizome powder	$14.55^{d} \pm 0.56$	$25.33^{d} \pm 2.19$	$15.20^{d} \pm 0.70$	$26.80^{d} \pm 2.60$
T7 Deltamethrin	$4.77^{a} \pm 0.56$	$8.00^{a} \pm 2.19$	5.10a ± 0.60	$8.50^{a} \pm 2.00$
T8 Control (untreated)	$19.33^{e} \pm 0.56$	$43.00^{e} \pm 2.19$	$20.50^{e} \pm 0.75$	$45.00^{e} \pm 2.80$

Values are means ± standard error (SE) of three replications.
Means followed by the same letter(s) in a column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

Table 2: Percent Weight Loss (%) at 3 and 6 Months

Treatment	Year - 1		Year -2	
	3 Months Weight Loss (%)	6 Months Weight Loss (%)	3 Months Weight Loss (%)	6 Months Weight Loss (%)
T1 Neem oil	$4.33^{ab} \pm 0.94$	$10.33^{ab} \pm 1.21$	$4.50^{ab} \pm 0.95$	$10.90^{ab} \pm 1.20$
T2 Neem leaf powder	$5.67^{bc} \pm 0.94$	$12.00^{bc} \pm 1.21$	$6.00^{bc} \pm 0.90$	$12.50^{bc} \pm 1.15$
T4 Tobacco leaf powder	$7.90^{cd} \pm 0.94$	$15.90^{cd} \pm 1.21$	$8.30^{cd} \pm 0.90$	$16.50^{cd} \pm 1.25$
T5 Marigold leaf powder	$8.00^{cd} \pm 0.94$	$17.33^{cd} \pm 1.21$	$8.70^{cd} \pm 0.90$	$18.10^{cd} \pm 1.30$
T3 Tulsi leaf powder	$8.67^{cd} \pm 0.94$	$18.48^{cd} \pm 1.21$	$9.10^{cd} \pm 0.85$	$18.90^{cd} \pm 1.30$
T6 Turmeric rhizome powder	$9.67^{d} \pm 0.94$	$20.33^{d} \pm 1.21$	$10.20^{d} \pm 0.90$	$21.00^{d} \pm 1.40$
T7 Deltamethrin	$2.80^{a} \pm 0.94$	$7.67^{a} \pm 1.21$	$3.00^{a} \pm 1.00$	$8.10^{a} \pm 1.30$
T8 Control (untreated)	$15.00^{e} \pm 0.94$	$28.67^{e} \pm 1.21$	$16.50^{e} \pm 1.00$	$30.00^{e} \pm 1.50$

Values are means ± standard error (SE) of three replications.
Means followed by the same letter(s) in a column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

Table 3: Percent Germination (%) at 3 and 6 Months (Year 1 and Year 2)

Treatment	Year -1		Year -2	
	3 Months	6 Months	3 Months	6 Months
T7 Deltamethrin	$87.78^{a} \pm 0.97$	$81.11^{a} \pm 1.30$	$85.00^{a} \pm 1.10$	$78.00^{a} \pm 1.20$
T1 Neem oil	$85.56^{ab} \pm 0.97$	$76.67^{ab} \pm 1.30$	$83.00^{ab} \pm 1.00$	$74.00^{ab} \pm 1.15$
T2 Neem leaf powder	$83.33^{bc} \pm 0.97$	$72.22^{bc} \pm 1.30$	$80.00^{bc} \pm 1.05$	$70.00^{bc} \pm 1.20$
T4 Tobacco leaf powder	$82.22^{bc} \pm 0.97$	$70.00^{bc} \pm 1.30$	$78.50^{cd} \pm 1.00$	$67.00^{cd} \pm 1.25$
T5 Marigold leaf powder	$77.78^{cd} \pm 0.97$	$67.78^{cd} \pm 1.30$	$75.00^{de} \pm 1.00$	$63.00^{de} \pm 1.20$
T3 Tulsi leaf powder	$75.56^{de} \pm 0.97$	$66.67^{de} \pm 1.30$	$72.00^{ef} \pm 1.00$	$64.00^{ef} \pm 1.15$
T6 Turmeric rhizome	$74.44^{ef} \pm 0.97$	$65.56^{ef} \pm 1.30$	$70.00^{f} \pm 1.05$	$61.00^{f} \pm 1.20$
T8 Control (untreated)	$53.33^{g} \pm 0.97$	$41.11^{g} \pm 1.30$	$50.00^{g} \pm 1.00$	$40.00^{g} \pm 1.25$

Values are means ± standard error (SE) of three replications.
Means followed by the same letter in each column are not significantly different ($p < 0.05$, DMRT).

Table 4 : Moisture Content (%) at 3 and 6 Months (Year 1 and Year 2)

Treatment	Year 1 3 Months (%)	Year 1 6 Months (%)	Year 2 3 Months (%)	Year 2 6 Months (%)
T1 Neem oil	$10.83^{a} \pm 0.22$	$11.00^{a} \pm 0.28$	$11.10^{a} \pm 0.25$	$11.35^{a} \pm 0.30$
T2 Neem leaf powder	$11.67^{ab} \pm 0.22$	$12.00^{ab} \pm 0.28$	$11.80^{ab} \pm 0.20$	$12.20^{ab} \pm 0.25$
T5 Marigold leaf powder	$11.83^{bc} \pm 0.22$	$12.17^{bc} \pm 0.28$	$12.00^{bc} \pm 0.22$	$12.45^{bc} \pm 0.28$
T4 Tobacco leaf powder	$12.00^{bc} \pm 0.22$	$12.33^{bc} \pm 0.28$	$12.10^{bc} \pm 0.20$	$12.55^{bc} \pm 0.22$
T7 Deltamethrin	$12.33^{cd} \pm 0.22$	$12.67^{cd} \pm 0.28$	$12.50^{cd} \pm 0.22$	$12.80^{cd} \pm 0.25$
T3 Tulsi leaf powder	$12.17^{bc} \pm 0.22$	$12.50^{bc} \pm 0.28$	$12.30^{c} \pm 0.25$	$12.75^{cd} \pm 0.30$
T6 Turmeric rhizome	$12.50^{cd} \pm 0.22$	$13.00^{d} \pm 0.28$	$12.70^{d} \pm 0.20$	$13.10^{d} \pm 0.25$
T8 Control (untreated)	$12.83^{d} \pm 0.22$	$13.33^{d} \pm 0.28$	$13.05^{d} \pm 0.22$	$13.60^{d} \pm 0.30$

Values are means ± standard error (SE) of three replications.
Means followed by the same letter(s) in a column are not significantly different according to Duncan's Multiple Range Test ($p < 0.05$).

Author's Contributions

Shantanu Bista: Preliminary Draft, Formal Analysis, Data Collection, and Conceptualisation, **Sushovan Majhi**: Investigation, Methodology, Validation, **Shanowly Mondal Ghosh**: Supervision, Project Administration, Writing – Review & Editing, **Gautam Chakraborty**: Methodolgy finalization, Supervision, **Pritipriya Pal**: Resources, Software, Visualization.

Declaration

We confirm that our submitted manuscript is original work not published before in any form. The final paper has been reviewed and approved for submission by all stated authors, and this work is not available for publishing anywhere else. The authors state they have no conflicts of interest, financial or otherwise, that might influence how these findings are interpreted or presented.

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