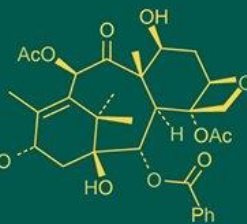
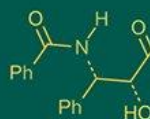


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Efficacy of essential oil-treated storage bags for the management of the lesser grain borer (*Rhyzopertha dominica*) in stored wheat

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Abstract

The lesser grain borer, *Rhyzopertha dominica* (Fabricius), is one of the most destructive primary pests of stored wheat (*Triticum aestivum* L.), causing serious quantitative and qualitative losses during storage. Increasing concerns over insecticide resistance and residues in stored commodities have generated interest in plant essential oils as eco-friendly grain protectants. The present study evaluated the fumigant toxicity of six essential oils (clove, eucalyptus, garlic, citronella, neem and onion seed oil, each at 2.5, 5.0, 7.5 and 10.0%) against adult *R. dominica*, and the efficacy of essential oil-impregnated polypropylene (PP) and jute bags in reducing grain damage in stored wheat over a 180-day storage period. Adult mortality, recorded cumulatively at 1, 3, 5 and 7 days after treatment (DAT), increased significantly with increasing oil concentration and exposure period; clove oil at 10% (T₄) caused the highest adult mortality (83.33%), followed by eucalyptus oil at 10% (70%) and clove oil at 7.5% (53.33%), against 10% in the untreated control. In the storage-bag study, grain damage increased progressively with storage duration in all treatments, but PP bags recorded significantly lower damage than jute bags at every interval (10.59% vs 11.70% at 180 days). Among essential oils, clove oil consistently gave the lowest grain damage (7.77% at 180 days), followed by eucalyptus oil (9.04%), while onion seed oil was least effective (14.86%). The bag × essential oil interaction was statistically non-significant throughout storage, although the PP bag + clove oil combination numerically recorded the lowest grain damage (6.90% at 180 days). These results indicate that clove oil, particularly when impregnated onto polypropylene bags, offers strong fumigant toxicity against adult *R. dominica* and effective, season-long protection of stored wheat against grain damage, supporting its potential as a botanical alternative to synthetic grain protectants.

Keywords: *Rhyzopertha dominica*, essential oils, clove oil, polypropylene bags, jute bags, stored wheat, adult mortality, grain damage

Introduction

Wheat (*Triticum aestivum* L.) is one of the major cereal crops cultivated worldwide and serves as a staple food for a substantial share of the global population. Its annual production has surpassed 790 million tonnes (FAO, 2024) [5]. India ranks second globally in wheat production after China. During 2023-24, wheat was cultivated on approximately 31.83 million hectares in India, with total production reaching about 113.29 million tonnes (Ministry of Agriculture and Farmers' Welfare, 2024) [10]. Since wheat is harvested during a particular season but is required for consumption throughout the year, proper storage is crucial for maintaining grain quality and minimizing quantitative losses until it is processed or marketed.

Insect pests constitute a major cause of deterioration in stored grains, among which the lesser grain borer, *Rhyzopertha dominica* (Fabricius) (Coleoptera: Bostrichidae), is recognized as a major primary pest of stored wheat across the world (Edde, 2012) [4]. The larvae and adults infest intact kernels by boring into the grains and feeding within them. Its concealed feeding behaviour and high reproductive potential allow populations to build up rapidly, often making infestations difficult to detect during the early stages.

Feeding activity of *R. dominica* can leave wheat kernels largely hollow and contaminated with frass, resulting in losses in grain weight and market value and adversely affecting seed

germination. Such infestation may also create favourable conditions for the development of secondary fungal infections (Phillips and Throne, 2010; Magan *et al.*, 2003)^[11, 9]. Insect pests are estimated to account for approximately 9% of stored-grain losses in developed countries, while losses may exceed 20% in developing countries where inadequate storage facilities and management practices prevail (Phillips and Throne, 2010)^[11].

Control of *R. dominica* has largely depended on synthetic insecticides and fumigants. However, their repeated and improper use has contributed to problems such as insecticide resistance, pesticide residues in stored commodities and harmful effects on beneficial or non-target organisms (Arthur, 1996)^[1]. These limitations have encouraged the exploration of plant-based alternatives, particularly essential oils. Such oils can affect insect pests through fumigant, contact and repellent activities, with reported mechanisms including inhibition of acetylcholinesterase and interference with octopaminergic receptors. In addition, many essential oils break down relatively quickly and generally exhibit low toxicity to mammals, making them potential alternatives for stored-grain pest management (Isman, 2006; Bakkali *et al.*, 2008)^[7, 2].

Impregnating storage-bag material with essential oils is a further extension of this approach, in which the packaging itself acts as a physical and chemical barrier to infestation. The performance of such treatments is expected to depend on bag material polypropylene bags, being less porous, may retain volatile oils longer than the more porous jute bags but comparative information on essential oil treated bags of different materials against *R. dominica* in stored wheat remains limited.

The present investigation was therefore undertaken to evaluate the fumigant toxicity of six essential oils against adult *R. dominica* and to assess the efficacy of essential-oil-impregnated polypropylene and jute bags in reducing grain damage in stored wheat, with a view to identifying a safe, effective and practically viable essential oil bag combination for stored-wheat protection.

2. Materials and Methods

2.1 Experimental site and insect culture

The experiment was conducted during July 2025 to January 2026 at the AICRP on Post Harvest Engineering and Technology (PHET), Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola, Maharashtra, under controlled conditions of 27±1 °C, 65±5% RH and 12 h photoperiod. Adults of *Rhyzopertha dominica* were collected from Panchgodown Warehouse, PDKV, Akola, and maintained on sterilized wheat grain in glass jars. Healthy, freshly emerged adults were used for the experiments.

2.2 Wheat grain and essential oils

Clean, sound and untreated wheat (*Triticum aestivum* L.) grain was obtained from the Wheat Research Station, PDKV, Akola. Six essential oils, viz., onion seed, eucalyptus, citronella, clove, neem and garlic, were procured from BRM Herbal Pvt. Ltd. For the fumigant bioassay, oils were evaluated at 2.5, 5.0, 7.5 and 10.0% (v/v), while 10% concentration was used for treatment of bags.

2.3 Experimental procedure

Fumigant toxicity was evaluated using six essential oils at four concentrations along with an untreated control, giving

25 treatments. Ten adult *R. dominica* were exposed to treated filter paper (1.5 × 1.5 cm) along with 20 g wheat grain in sealed plastic containers. The experiment was conducted in a Completely Randomized Design (CRD) with three replications. Mortality was recorded cumulatively at 1, 3, 5 and 7 DAT.

For the storage study, polypropylene (PP) and jute bags were treated with six essential oils at 10% concentration by spraying both surfaces, followed by 24 h drying. One kilogram of wheat grain and five pairs of freshly emerged *R. dominica* adults were placed in each bag. The 12 bag × oil combinations were evaluated in a Factorial Completely Randomized Design (FCRD) with three replications. Grain damage was assessed at 30-day intervals up to 180 days.

2.4 Statistical analysis

Mortality and grain-damage data were subjected to analysis of variance (ANOVA) for CRD and FCRD, respectively. Percentage data were transformed using angular (arcsine) transformation wherever required. Standard error of mean [SE(m)±], critical difference (CD) at 1% and coefficient of variation (CV%) were calculated using standard statistical procedures.

3. Results and Discussion

3.1 Adult mortality of *Rhyzopertha dominica*

All essential oil treatments differed significantly from the untreated control at every observation interval (Table 1). Mortality increased consistently with increasing oil concentration and with increasing exposure period for all six oils. At 1 DAT, mortality ranged from 0.00% (T₂₁, T₂₅) to 36.32% (T₄, clove oil 10%); by 7 DAT it ranged up to 83.33% in T₄, with the untreated control remaining lowest throughout.

On a mean basis (1-7 DAT), clove oil at 10% (T₄) was the most effective treatment, recording 57.41% mortality and differing significantly from all other treatments. It was followed by eucalyptus oil at 10% (T₈, 46.77%), which was statistically at par with clove oil at 7.5% (T₃, 46.05%); this group was followed by garlic oil at 10% (T₁₂, 38.40%). Onion seed oil was the least effective essential oil at every concentration, with its lowest concentration (T₂₁, 2.5%) not differing from the untreated control (T₂₅, 4.25% mean mortality) at 1 DAT. Overall, the ranking of essential oils by fumigant toxicity against adult *R. dominica* was clove oil > eucalyptus oil > garlic oil ≈ citronella oil ≈ neem oil > onion seed oil.

3.2 percent grain damage

Grain damage increased progressively with storage duration in all treatments, reflecting continued feeding activity of *R. dominica*, but the rate and extent of damage differed significantly between bag types and among essential oils at every 30-day interval (Table 2). Bag type (Factor A) was significant throughout: the polypropylene (PP) bag (A1) consistently recorded lower grain damage than the jute bag (A2), the gap widening from 3.09% vs 3.63% at 30 days to 10.59% vs 11.70% at 180 days.

Essential oil (Factor B) was also significant at every interval. Clove oil (B4) recorded the lowest grain damage throughout storage (2.49% at 30 days to 7.77% at 180 days), followed by eucalyptus oil (B2, reaching 9.04% at 180 days) and garlic oil (B6, 10.77% at 180 days); citronella oil (B3) and neem oil (B5) were intermediate, while onion seed oil (B1) recorded the highest grain damage at every interval, reaching 14.86% at 180 days.

The interaction between bag type and essential oil ($A \times B$) was non-significant at all six storage intervals. However, PP bag combined with clove oil (A1B4) consistently recorded the lowest numerical grain damage among the twelve treatment combinations, reaching 6.90% at 180 days. In contrast, jute bag treated with onion seed oil (A2B1) recorded the highest numerical damage of 15.46%. Thus, the combination of the more effective oil, clove oil, with PP bags provided comparatively better protection against grain damage, which was also in agreement with the mortality results.

Similar results were reported by Hamza and Hamza (2018) [6], who observed strong insecticidal activity of clove oil against *R. dominica* in wheat and associated its effectiveness mainly with eugenol, its major constituent. Likewise, Ebadollahi *et al.* (2022) [3] reported significant fumigant

activity of *Eucalyptus* essential oils against *R. dominica*, with toxicity increasing as both concentration and exposure period increased. This finding supports the higher efficacy of eucalyptus oil (T_8) observed in the present investigation.. In the storage-bag study, the superior protection provided by clove oil is supported by Zeng *et al.* (2010) [13], who reported strong toxic and repellent activity of clove oil against *R. dominica* associated with its eugenol content, and by Jayaraj and Shanthi (2026) [8], who reported effective, prolonged protection of stored paddy against *R. dominica* using a clove-oil-based formulation. The better performance of polypropylene bags relative to jute bags agrees with Waheed *et al.* (2022) [22], who found jute bags more susceptible to *R. dominica* infestation owing to their loose fibre structure.

Table 1: Fumigant toxicity of essential oils at four concentrations against adult mortality (%) of *Rhyzopertha dominica* at 1, 3, 5 and 7 days after treatment (DAT)

Treatment	Treatment Detail	1 DAT	3 DAT	5 DAT	7 DAT	Mean
T ₁	Clove oil 2.5%	10.635 (19.01)	20.00 (26.54)	26.67 (31.06)	43.33 (41.17)	25.15 (29.45)
T ₂	Clove oil 5%	15.44 (23.13)	26.67 (31.07)	36.67 (37.25)	50.00 (45.00)	32.19 (34.11)
T ₃	Clove oil 7.5%	30.89 (33.72)	40.00 (39.23)	50.00 (45.00)	63.33 (52.73)	46.05 (42.67)
T ₄	Clove oil 10%	36.32 (37.06)	50.00 (45.00)	60.00 (50.77)	83.333 (66.80)	57.41 (49.90)
T ₅	Eucalyptus oil 2.5%	6.76 (15.07)	16.67 (24.09)	23.33 (28.88)	33.33 (35.26)	20.02 (25.83)
T ₆	Eucalyptus oil 5%	15.94 (23.51)	23.33 (28.86)	30.03 (33.23)	40.00 (39.23)	27.32 (31.21)
T ₇	Eucalyptus oil 7.5%	21.66 (27.74)	30.00 (33.19)	40.00 (39.22)	53.33 (46.91)	36.24 (36.76)
T ₈	Eucalyptus oil 10%	33.78 (35.54)	36.67 (37.26)	46.67 (43.09)	70.00 (56.79)	46.77 (43.17)
T ₉	Garlic oil 2.5%	6.45 (14.71)	13.33 (21.41)	20.00 (26.56)	33.33 (35.26)	18.28 (24.48)
T ₁₀	Garlic oil 5%	10.73 (19.12)	20.00 (26.54)	26.67 (31.07)	36.67 (37.27)	23.51 (28.50)
T ₁₁	Garlic oil 7.5%	12.16 (20.38)	23.33 (28.85)	33.33 (35.23)	40.00 (39.23)	27.20 (30.92)
T ₁₂	Garlic oil 10%	26.67 (31.08)	30.00 (33.21)	40.00 (39.23)	63.33 (52.74)	38.40 (37.99)
T ₁₃	Citronella oil 2.5%	3.52 (10.80)	6.67 (14.94)	13.33 (21.39)	23.33 (28.85)	11.71 (19.00)
T ₁₄	Citronella oil 5%	6.67 (14.95)	13.33 (21.40)	20.00 (26.54)	30.00 (33.21)	17.50 (24.03)
T ₁₅	Citronella oil 7.5%	16.67 (24.05)	23.33 (28.84)	30.00 (33.17)	36.67 (37.23)	26.67 (30.82)
T ₁₆	Citronella oil 10%	23.33 (28.86)	30.00 (33.20)	36.70 (37.29)	53.33 (46.91)	35.84 (36.56)
T ₁₇	Neem oil 2.5%	3.33 (10.52)	3.33 (10.52)	10.00 (18.43)	20.00 (26.56)	9.17 (16.51)
T ₁₈	Neem oil 5%	10.00 (18.41)	13.33 (21.39)	16.67 (24.07)	26.67 (31.06)	16.67 (23.73)
T ₁₉	Neem oil 7.5%	15.43 (23.11)	23.33 (28.86)	26.67 (31.07)	33.33 (35.24)	24.69 (29.57)
T ₂₀	Neem oil 10%	20.28 (26.77)	26.667 (31.07)	36.66 (37.25)	46.67 (43.09)	32.54 (34.54)
T ₂₁	Onion seed oil 2.5%	0.00 (0.57)	3.33 (10.52)	6.67 (14.96)	16.67 (24.09)	6.67 (12.53)
T ₂₂	Onion seed oil 5%	3.33 (10.51)	10.00 (18.42)	13.33 (21.39)	20.00 (26.54)	11.66 (19.21)
T ₂₃	Onion seed oil 7.5%	9.67 (18.09)	16.67 (24.06)	20.00 (26.53)	30.00 (33.18)	19.08 (25.47)
T ₂₄	Onion seed oil 10%	13.33 (21.41)	20.00 (26.56)	26.67 (31.09)	36.67 (37.26)	24.17 (29.08)
T ₂₅	Control	0.00 (0.57)	0.33 (3.31)	6.67 (14.94)	10.00 (18.41)	4.25 (9.31)
	F Test	Sig	Sig	Sig	Sig	-
	S.E. (m) ±	0.66	0.82	0.95	1.28	0.92
	C.D. at 1%	2.48	3.10	3.60	4.83	3.50
	C.V. (%)	5.58	5.47	5.29	5.70	5.51

Table 2: Effect of bag type and essential oil impregnation at 10% concentration on per cent grain damage of stored wheat by *Rhyzopertha dominica*

Treatments	Treatment details	30 days	60 days	90 days	120 days	150 days	180 days
Factor (A) Bags							
A1	PP bag	3.09 (10.12)	4.14 (11.75)	5.31 (13.32)	6.62 (14.91)	8.15 (16.59)	10.59 (18.99)
A2	Jute bag	3.63 (10.98)	4.75 (12.60)	5.94 (14.11)	7.36 (15.74)	9.03 (17.49)	11.70 (20.00)
F test		Sig	Sig	Sig	Sig	Sig	Sig
SE (m±)		0.14	0.14	0.16	0.18	0.20	0.23
CD at 1%		0.55	0.57	0.64	0.72	0.80	0.92
Factor (B) Essential Oils							
B1	Onion seed oil	4.34 (12.03)	5.99 (14.17)	7.80 (16.21)	9.75 (18.19)	11.69 (19.99)	14.86 (22.67)
B2	Eucalyptus oil	2.85 (9.75)	3.38 (11.30)	4.61 (12.40)	5.86 (14.00)	7.08 (15.44)	9.04 (17.50)
B3	Citronella oil	3.55 (10.85)	4.83 (12.70)	6.11 (14.31)	7.65 (16.06)	9.20 (17.72)	11.82 (20.11)
B4	Clove oil	2.49 (9.08)	2.91 (9.82)	3.62 (10.97)	4.52 (12.28)	5.80 (13.94)	7.77 (16.19)
B5	Neem oil	3.96 (11.47)	5.24 (13.23)	6.83 (15.15)	8.54 (16.99)	10.43 (18.84)	13.23 (21.33)
B6	Garlic oil	3.09 (10.12)	4.19 (11.81)	5.25 (13.24)	6.20 (14.42)	7.88 (16.30)	10.77 (19.16)
F test		Sig	Sig	Sig	Sig	Sig	Sig
SE (m±)		0.24	0.25	0.28	0.31	0.35	0.40
CD at 1%		0.96	0.99	1.11	1.25	1.38	1.60
Interaction (A×B)							
A1B1	PP × Onion seed oil	4.10 (11.68)	5.71 (13.83)	7.47 (15.86)	9.24 (17.69)	11.20 (17.85)	14.27 (22.19)
A1B2	PP × Eucalyptus oil	2.56 (9.21)	3.20 (10.31)	4.18 (11.80)	5.38 (13.41)	6.63 (14.92)	8.67 (17.13)
A1B3	PP × Citronella oil	3.36 (10.57)	4.47 (12.21)	5.72 (13.83)	7.26 (15.63)	8.91 (17.35)	11.34 (19.68)
A1B4	PP × Clove oil	2.15 (8.44)	2.72 (9.50)	3.31 (10.48)	4.22 (11.85)	5.46 (13.51)	6.90 (15.23)
A1B5	PP × Neem oil	3.71 (11.11)	5.05 (12.99)	6.66 (14.96)	8.25 (16.69)	9.99 (18.42)	12.32 (20.54)
A1B6	PP × Garlic oil	2.86 (9.73)	4.07 (11.64)	5.07 (13.01)	6.01 (14.19)	7.36 (15.75)	10.77 (19.16)
A2B1	Jute × Onion seed oil	4.59 (12.37)	6.28 (14.51)	8.13 (16.57)	10.27 (18.69)	12.18 (20.43)	15.46 (23.15)
A2B2	Jute × Eucalyptus oil	3.15 (10.22)	4.52 (12.28)	5.07 (13.01)	6.35 (14.59)	7.56 (15.95)	9.42 (17.87)
A2B3	Jute × Citronella oil	3.75 (11.17)	5.20 (13.19)	6.51 (14.79)	8.05 (16.48)	9.63 (18.07)	12.32 (20.55)
A2B4	Jute × Clove oil	2.86 (9.73)	3.10 (10.14)	3.95 (11.46)	4.84 (12.71)	6.16 (14.37)	8.69 (17.15)
A2B5	Jute × Neem oil	4.22 (11.86)	5.43 (13.47)	7.00 (15.34)	8.84 (17.29)	10.88 (19.26)	14.18 (22.12)
A2B6	Jute × Garlic oil	3.33 (10.52)	4.31 (11.99)	5.43 (13.47)	6.40 (14.66)	8.41 (16.86)	10.77 (19.15)
F test		NS	NS	NS	NS	NS	NS
SE (m±)		0.34	0.35	0.39	0.44	0.49	0.57
CD at 1%		1.36	1.41	1.57	1.77	1.96	2.26
C.V.%		5.67	5.08	5.02	5.07	5.03	5.39

*Figures in parentheses are corresponding arcsine transformation values

5. Conclusion

Adult mortality of *R. dominica* increased consistently with increasing essential-oil concentration and exposure period for all six oils tested, with clove oil at 10% (T₄) the most effective treatment at every observation interval and on a mean basis, followed by eucalyptus oil at 10% (T₈) and clove oil at 7.5% (T₃); onion seed oil, especially at 2.5%, and the untreated control were the least effective. In the storage-bag study, the polypropylene bag was consistently superior to the jute bag, and clove oil was consistently the most effective essential oil, in limiting grain damage over 180 days of storage, with the PP bag + clove oil combination (A1B4) giving numerically the best overall protection, although the bag × oil interaction was not statistically significant. Onion seed oil was the least effective essential oil for minimising grain damage. Clove oil, particularly in combination with polypropylene bags, therefore emerges as the most promising treatment among those evaluated for protecting stored wheat against *R. dominica*, based on both adult mortality and grain-damage criteria.

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