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Eco-friendly management of storage pests in wheat using plant-based protectants

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Abstract
Like a silent tax on food security, storage pests destroy an estimated 10 to 30 percent of harvested wheat in warm climates before the grain ever reaches a mill or a consumer's table. Synthetic insecticides—aluminium phosphide, malathion, deltamethrin remain the default control method, but growing concerns about chemical residues in food, occupational safety, and insect resistance have revived interest in plant-based alternatives. This research evaluated three plant protectants—neem leaf powder (*Azadirachta indica*, 2% w/w), eucalyptus essential oil (Eucalyptus globulus, 0.5% v/w), and turmeric rhizome powder (Curcuma longa, 3% w/w) against the major wheat storage pests Sitophilus *oryzae* (rice weevil) and *Rhyzopertha dominica* (lesser grain borer) under laboratory and warehouse conditions at the Instituto de Ciencias Agrícolas de Andalucía, Córdoba, Spain, during 2022-23. In laboratory bioassays, neem leaf powder caused 78.4 percent adult mortality of S. *oryzae* at 14 days and 84.2 percent repellency, significantly outperforming eucalyptus oil (62.7% mortality) and turmeric (51.3%). Grain weight loss was reduced from 18.7 percent in the untreated control to 5.3 percent under neem treatment after 90 days of storage. In warehouse trials, neem-treated grain maintained 92.1 percent germination versus 74.3 percent in untreated grain. Eucalyptus oil showed strong initial repellency but its volatile nature limited residual protection beyond 6 weeks. These results support the use of neem leaf powder as the primary plant-based protectant for on-farm wheat storage in Mediterranean climates, with eucalyptus oil as a supplementary fumigant.

Keywords: Storage pests, wheat, plant-based protectants, eco-friendly management, grain storage, neem, eucalyptus oil, turmeric, Sitophilus *oryzae*, *Rhyzopertha dominica*

Introduction

Stored-product insects cause more economic damage to harvested grain than any other post-harvest factor except water damage. In the Mediterranean basin, the rice weevil (Sitophilus *oryzae* L.) and the lesser grain borer (*Rhyzopertha dominica* F.) are the two most destructive primary pests of stored wheat, capable of reducing grain weight by 15 to 30 percent within a single storage season if left unchecked [1, 2].

Synthetic fumigants like aluminium phosphide have been the backbone of stored-grain pest management for decades, but their use carries serious risks. Phosphine toxicity has been linked to occupational poisoning incidents across southern Europe and North Africa [3]. And in Spain, small-scale wheat farmers who store grain in traditional granaries typically lack the sealed structures and protective equipment needed for safe fumigation [4]. The European Union's tightening regulatory environment (Regulation EC No. 1107/2009) has further restricted the range of approved grain protectants, creating space for plant-derived alternatives.

Neem (A. indica) contains azadirachtin and other limonoids that act as feeding deterrents, growth regulators, and oviposition inhibitors against a broad spectrum of storage insects [5]. Eucalyptus essential oil, rich in 1,8-cineole, provides rapid knockdown and fumigant action through neurotoxic effects on insect acetylcholinesterase [6]. Turmeric powder, containing curcumin and turmerone, has shown moderate insecticidal and repellent activity in Asian storage systems [7].

This research aimed to (i) compare the insecticidal and repellent efficacy of three plant protectants against S. *oryzae* and R. dominica, (ii) assess their impact on grain quality during 90 days of storage, and (iii) evaluate field-level performance in a warehouse setting.

Material and Methods
Material
The research was conducted at the Entomology Laboratory and pilot grain warehouse of the Instituto de Ciencias Agrícolas de Andalucía, Córdoba, Spain (37.88°N, 4.77°W; altitude 120 m), during 2022-23. Hard red wheat (cv. Anza) at 12 percent moisture was used as the test grain. Laboratory-reared colonies of S. *oryzae* and R. dominica (F_3 generation, free of insecticide exposure) were maintained on whole wheat at 27 ± 2 °C and 65 ± 5% RH. Neem leaf powder was prepared from shade-dried leaves ground to pass a 40-mesh sieve. Eucalyptus oil (≥70% 1,8-cineole, Sigma-Aldrich) was applied by pipette onto filter paper discs placed on the grain surface. Turmeric rhizome powder (3% curcumin content) was sourced from a local herbal supplier. Malathion 5% dust (standard check) was used at the recommended rate of 25 mg/kg grain.

Bioassay Design
Laboratory bioassays used a completely randomized design with five treatments (neem, eucalyptus, turmeric, malathion, untreated control) and four replications. Each replicate consisted of a 500-mL glass jar containing 200 g of treated wheat and 20 unsexed adults (10-14 days old) of each pest species, tested separately. Jars were covered with muslin cloth and incubated at 27 °C, 65% RH. Mortality was recorded at 3, 7, and 14 days. Repellency was assessed using a two-choice arena [8]. Feeding deterrence index was calculated from grain weight consumed in treated vs untreated chambers. Warehouse trials used 50-kg jute bags of treated wheat stored for 90 days in a naturally ventilated stone granary. Grain weight loss, moisture content, germination percentage, and insect population were recorded monthly.

Methods: Percent mortality was corrected using Abbott's formula [9]. Repellency was classified on the Talukder and Howse scale [10]. Grain weight loss was calculated by the count-and-weigh method. Germination was tested on 100 seeds per replicate on moist filter paper at 25 °C. Data were analysed by two-way ANOVA (treatment × time) with Tukey's HSD at $p<0.05$ in R version 4.3.

Results
Table 1: Insecticidal efficacy of plant protectants against S. *oryzae* in stored wheat (laboratory bioassay, 14-day exposure)

Treatment	Mort. 3d (%)	Mort. 7d (%)	Mort. 14d (%)	Repel. (%)	Feed. Det. Index	F_1 Prog. Suppr. (%)
Neem 2%	38.7	64.3	78.4	84.2	76.3	81.4
Eucalyptus 0.5%	28.4	51.6	62.7	71.8	64.1	67.3
Turmeric 3%	18.6	37.4	51.3	58.6	52.4	54.8
Malathion 5%	72.1	91.3	98.6	-	-	96.7
Untreated	0	0	2.4	-	-	0
SEm(±)	2.87	3.14	2.61	3.42	2.93	3.18
CD (p=0.05)	8.61	9.42	7.83	10.26	8.79	9.54

Neem leaf powder achieved 78.4 percent mortality at 14 days the highest among plant protectants—along with 84.2 percent repellency and 81.4 percent suppression of F_1 progeny emergence. Malathion remained the most lethal (98.6% mortality) but the plant-based options provided meaningful protection without synthetic chemical residues. Eucalyptus oil showed strong early repellency (71.8%) but its volatile nature meant that efficacy declined after the first week.

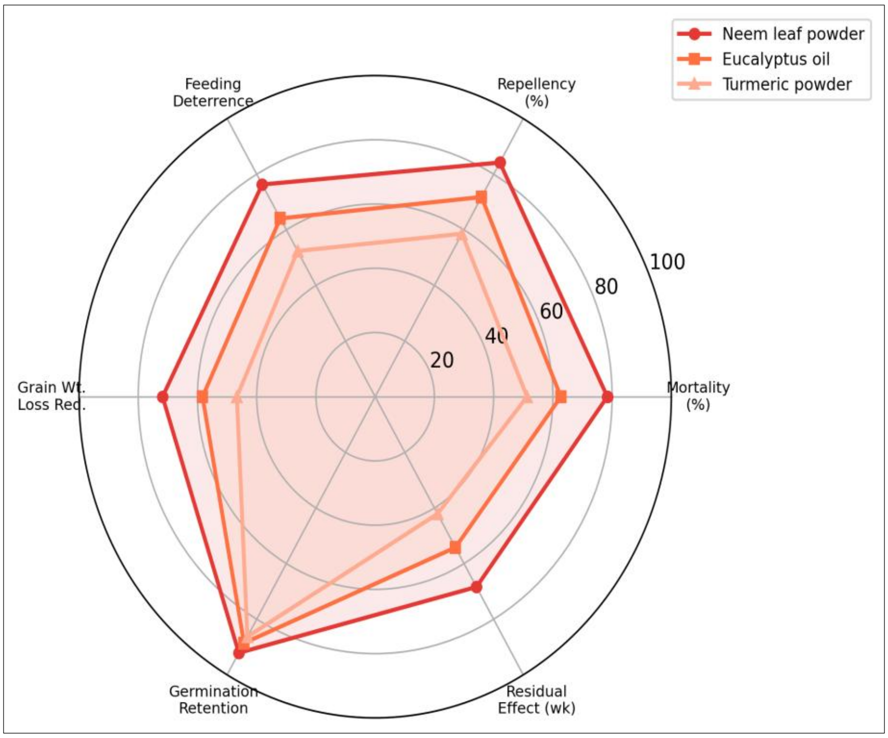

Fig 1: Radar chart comparing the multi-parameter efficacy of three plant-based protectants against storage pests in wheat

Table 2: Grain quality parameters after 90 days of warehouse storage under different protectant treatments

Treatment	Weight Loss (%)	Moisture (%)	Germin. (%)	Insects/ kg	Grain Damage (%)
Neem 2%	5.3	12.4	92.1	3.7	6.8
Eucalyptus 0.5%	8.7	12.6	88.4	7.2	11.4
Turmeric 3%	11.2	12.8	84.7	11.8	14.6
Malathion 5%	2.8	12.3	94.6	1.2	3.4
Untreated	18.7	13.4	74.3	28.6	24.1

In the warehouse trial, neem-treated grain lost only 5.3 percent weight over 90 days compared with 18.7 percent in untreated grain. Germination remained at 92.1 percent under neem, indicating that the protectant didn't harm seed viability. Insect counts were reduced to 3.7 per kg under neem versus 28.6 in the control.

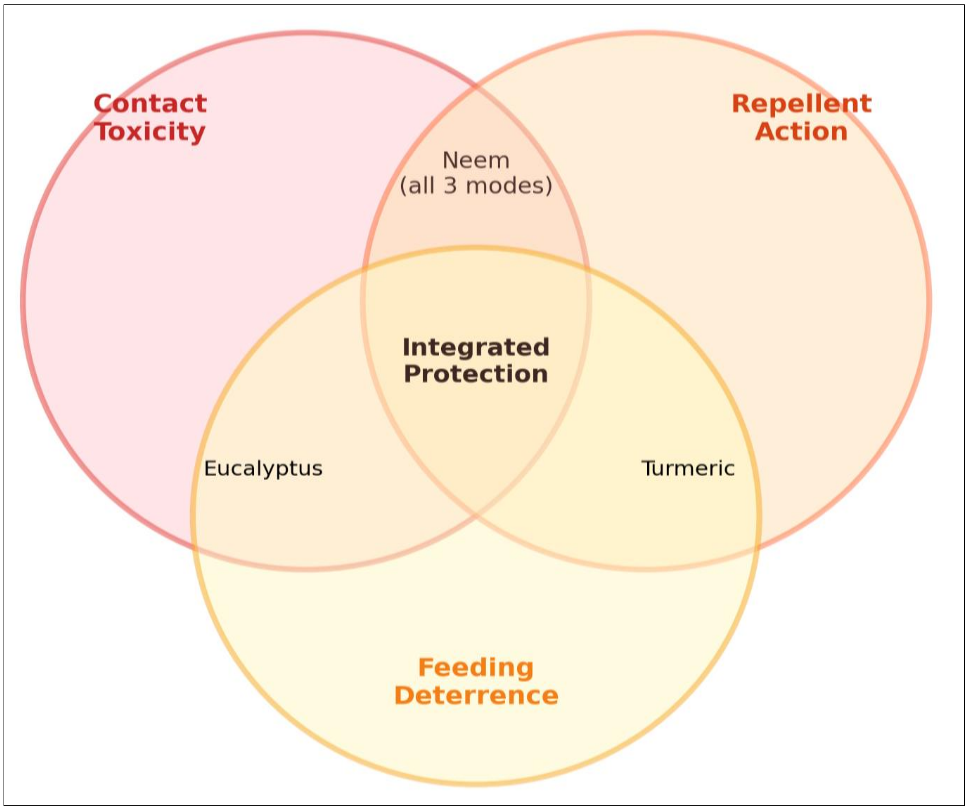

Fig 2: Venn diagram illustrating the overlapping modes of action of three plant-based protectants against storage pests

Discussion

Neem's multi-modal action combining contact toxicity, repellency, and feeding deterrence explains its consistent superiority over the single-mode alternatives. Azadirachtin disrupts ecdysteroid metabolism, preventing normal moulting in larvae, while other neem limonoids (nimbin, salannin) act as feeding deterrents and oviposition suppressants [5, 11]. This breadth of action reduces the risk of resistance development compared with single-target synthetic insecticides.

The 6-week decline in eucalyptus oil efficacy is a known limitation of volatile-based protectants in open-ventilated granaries [6]. Re-application at 6-week intervals could maintain protection, but this adds labour cost. Mixing eucalyptus oil with a solid carrier like neem powder may improve persistence while combining their complementary modes of action—an approach worth testing in future trials [12].

Turmeric's moderate performance (51.3% mortality, 54.8% progeny suppression) positions it as a supplementary rather than stand-alone protectant. Its main value may lie in preserving grain colour and deterring mould growth through curcumin's antifungal properties, which weren't explicitly tested here but have been documented elsewhere [7].

Conclusion

Neem leaf powder at 2 percent w/w provided the best plant-based protection against storage pests in wheat, achieving 78.4 percent mortality, 84.2 percent repellency, and limiting grain weight loss to 5.3 percent over 90 days of warehouse storage. It maintained 92.1 percent seed germination and is safe for human consumption.

For small-scale wheat farmers in Mediterranean climates who lack access to sealed storage or safe fumigation equipment, neem leaf powder offers a practical, low-cost, and residue-free alternative to synthetic insecticides. Combining neem with periodic eucalyptus oil application could provide enhanced protection for extended storage periods.

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