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Integrated Approaches for Pulse Beetle Control with Emphasis on Essential Oils

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A Legumes crops make up 50% of a humans daily diet which contain 25% of the protein and enzymes that humans require to complete their nutritional diet. The responsible output of pulses in India in 2024–2025 is 25 M t, with green gram contributing 3.82 M t, or 70% of the world's total. By N fixing nature, it will improves soil nutrition factors during cropping (PrinceSahu et al.,2023). However, abiotic and biotic stressors, particularly pests like podflies, pod borer, aphids, whiteflies, pulse beetles, and thrips, will still have an impact on its output. Depending on the area, such as temperate or tropical, *C. chinensis* can cause anywhere from 68.9% to 100% damage during storage under ideal conditions (Rajendra,et al.,2023). For the upcoming planting seasons, almost all farmers keep a quantity of pulse seeds in their farm house [3]. There are twenty different species of Callosobruchus in the world, and two common species that produce gram that is unfit for human food due to their damage are *Callosobruchus maculatus Fab* and *Calllosobruchus chinensis Linn* (Rajendra,et al.,2023). Similar to legumes, it causes erratic loss and harm to green grams that are preserved. Several papers suggest methods such as putting grains or pulses in the sun on a regular basis, combining them with sand or ash, or covering them with cooking oil. (Chaudhari et al.,2021). Synthetic insecticides and fumigants are frequently used in storage as part of pest control measures, but the careless use of chemical insecticides in the field and storage has resulted in a number of issues, such as insect resistance to the insecticides, toxic residues in food grains, environmental pollution, and rising application costs. Moreover, traditional farmers' poor storage grains facilities in developing countries are incompatible for effective standard chemical treatment since most storage grains are vulnerable to re-infestation by insect pests(Rajendra,et al.,2023).To protect the stored grains from beetle damage, it's crucial talk to limits their usage of worldwide and implemented the safe alternatives to conventional insecticides and fumigants, notable with imminent WTO regulations in mind. This has fostered a variety of management methods which intent to be both non-toxic, residue free and successful in combating the *C. chinensis* pulse beetle. A Certain compounds extracted from aromatic plants resulted insecticidal properties against bruchid species. As potential grain protectants, plant-based essential oils are target-specific, innocuous to humans and beneficial creatures, less likely to develop insect resistance or revival, biodegradable, and inexpensive. In the view of therefore, IPM (Integrated pest management) utilizing of non chemical, biorational and environmentally friendly technique have been employed over stored pest management and are recognized as a major result and alternatives(Rajendra,et al.,2023. Additionally, they have less harmful effects when applied to seeds and consumed. In order to protect seeds from larval penetration and oviposition, attention must be paid to essential oil administration tactics that control important stages such as eggs and adults of the pulse beetle.

Biology and damages of pulse beetles

Greengram is a major storehouse pest that's responsible for both quantitative and qualitative losses due to the palpitation beetle, *Callosobruchus chinensis*. A individual females laid egg between 71 and 87 eggs, with a mean fecundity of 79 eggs per female(Kumari, et al.2020). The eggs are round, planoconvex, smooth, and translucent. The results of are harmonious with the incubation period, which varies from 3 to 6 days (comprising about 4 days) (Kumari, et al.2020). Following hatching, the delicate-white, apodous, C- shaped naiads bore straight into the seed and fed outside. The pupa is initially cream colored and gradually turns brown before adult emergence(Kumari, et al.2020). Under favorable Conditions larval and pupal stage a development took roughly 20–23 days (Kumari, et al.2020), nevertheless this could vary based on temperature and relative humidity. Small (3–4 mm length), brownish, and adults have an oviposition duration is 6–10 days and a survival duration is 7–11 days for females and 8–14 days for males(Kumari, et al.2020).

The main damage-causing stage is the larval stage, which feeds on the grains, resulting in internal hollowness, exit holes in circular shapes, reduction in weight, reduction in germination, and powdery frass. Greengram seeds that are stored can become completely damaged due to severe infection and become unfit for use.

Integrated Pest Management (IPM) of the pulse beetle

The objective of integrated pest management (IPM) for the pulse beetle (*Callosobruchus chinensis*) is reduce the chemical perils while minimize the grain loss by enclosing a number of effective management strategy(Chaudhari et al.,2021). Every methods has a different functions in reducing the insect populations in pulses that have been kept.

Cultural metheod:

The aim of the cultural practices is to mitigate or lessen the first infection by pest in field its self. Eggs laying and larval growth were restricted through grains are properly dried to the safe moisture levels, which are typically less than 10%. Breeding sites are eliminated by maintaining stringent sanitation in storage spaces(Head et al.,2025)., which includes washing containers, sealing cracks, and eliminating old residues (Chaudhari et al.,2021). Using insect-proof or airtight containers limits the amount of oxygen available to growing stages and further prevents reinfestation.

Physical methods

The various stages of life were directly affected by physical methods. because of adequate exposure is achieved, the eggs and first-instar of larvae in seeds can be eliminated by heat treatment or sun drying (Kumar et al.,2017). Growth and reproduction can be slowed down or halted by cold storage at low temperatures(Head et al.,2025). High concentrations of carbon dioxide (CO_2), for instance, result in low oxygen conditions that cause the death of eggs and larvae and reduce the emergence of adults.

Monitoring and Surveillance:

Early identification requires routine monitoring. Infestations may prove discovered by examining stored pulses for outlet holes, dusty leftovers, or alive adults(Head et al.,2025). The use of traps allows rapid detection of population buildup (Chaudhari et al.,2021). Heavy infestation is avoided and the need for extensive chemical treatments is decreased with early action based on monitoring data.

Biological Control:

Microbial agents and natural enemies are used in biological methods. By parasitizing bruchid larvae and pupae inside seeds, the parasitoid wasp *Dinarmus basalis* decreases the emergence of adult bruchids (Kumar et al.,2017). Toxins release by entomopathogenic microorganisms like *Bacillus thuringiensis* impair in the gastrointestinal function of the larvae and cause a death(Head et al.,2025). Because these compounds are target-specific and, when used appropriately, generally safe for humans and beneficial creatures, they are regarded as environmentally safe.

Botanical and Inert Protectants:

Products extracts from plants, such a neem seed powder and essential oils (like citronella), contain a larvicidal, ovicidal, and the repellant qualities that less the grain damage and mitigates adult emergence(Subedi et al,.2020). Adult beetles death because of the water loss brought on the inert materials like diatomaceous earth, which made damages their cuticle. When employed at the approved levels, these compounds were prized for their low toxicity to the mammals and suitability for a long-term storage protection(Kumar et al.,2017). This a rational why choosing essential oil is best than other IPM approaches in storage periods.

Essential Oils: Properties and Modes of Action Against Pulse Beetle

Extractent from the aromatic plants, essential oils (EOs) are the lipophilic, volatile secondary metabolites. Terpenoids (monoterpenes and sesquiterpenes), phenylpropanoids, and the other low-molecular-weight of substances that easily evaporate(Chaudhari et al.,2021). Their lipophilic nature allows for rapid diffusion through the insect cuticle and egg chorion, disrupting critical physiological processes, while their high volatility allows for fumigant action.

Fumigant and Respiratory Toxicity

In closed storage circumstances, essential oils function as the fumigants because of the volatile nature. Vapors can be affect the respiratory metabolism and nerve transmission by diffusing into the insect's tracheal system(Subedi et al,.2020). It has been documented that substances like 1,8-cineole affect insect survival and behavior by upsetting neuronal signaling and metabolic equilibrium (Herald et al.,2023)

Contact Toxicity and Cuticular Penetration

Essential oils are effectively pervade in the beetle cuticle due to lipophilic nature. Following assimilation, they may be interfere with neurotransmission pathways, enzyme systems, and membrane integrity (Chaudhari et al.,2021). Because of the essential oils frequently contain many of active ingredients, they are less plausible to cause fast resistance development than the standard neurotoxic insecticides, which only act on the one target site(Herald et al.,2023).

Oviposition Deterrence and Anti-fertility Effects

Essential oils create changes in mating communication and a host recognition, which affects the oviposition. PVOCs, or volatile plant compounds, can alter or obscure the chemical cues that direct females to appropriate substrates (Kumar et al.,2017). Ovicidal and anti-fertility characteristics are exhibited by oils that contain bioactive components such ricinine, karanjin, and tetranortriterpenoids.

Repellent Action for beetle

Numerous essential oils has potent repellents the qualities that cause a insects to avoid the contact by activating their smell receptors (Subedi et al,.2020). First colonization and subsequent egg laying in stored grains are decreased by repellency (EKNATH et al., 2020). In preventive grain protection measures, this behavioral of change is especially beneficial because it will reduces the infection pressure without necessarily the resulting in imminent mortality.

Antifeedant Activity

For inhibiting the insect feeding behavior, The essential oils act as feeding discourage and less the grain damage(EKNATH et al., 2020). Active agent that block gustatory receptors make treated grains as unpleasant. Crucially, (Herald et al.,2023) antifeedant actions prevent grain weight loss while maintaining the ecosystem's natural enemies ability to function.

Table 1. ***Impact of plant essential oils on the oviposition of Callosobruchus chinensis L.***

Treatments	**Dosages (mL/kg of seeds)**	**30 DAT**	**60 DAT**	**90 DAT**	**120 DAT**	**Overall mean**
Citronella oil	5	1.67	3.33	5.00	9.33	3.87
Basil oil	5	2.67	5.33	11.67	16.00	8.92
Clove oil	5	3.00	9.67	14.00	21.33	12.00
Karanja oil	5	2.67	7.67	13.33	19.00	10.67
Mustard oil	5	3.33	12.33	19.00	28.67	15.83
Sesamum oil	5	4.00	13.67	21.33	31.67	17.67
Eucalyptus oil	5	2.33	4.67	9.33	12.00	7.08
Coconut oil	5	6.33	15.00	27.67	35.33	21.08
Neem oil	5	0.00	1.67	4.33	7.67	3.42
Control		**63.00**	**87.67**	**112.67**	**127.33**	**97.67**

DAT: Days after treatment

Integration of Essential Oils into IPM Programs

Overuse of synthetic pesticides in stored pulses has led to issues with residue, health hazards, disruption of natural enemies, and sustainability issues in the long run(Rajendra,et al.,2023).Within Integrated Pest Management (IPM) programs, essential oils provide a safer supplementary option in this regard(Chaudhari et al.,2021). Citronella and neem oils were particularly effective in protecting against pulse beetle infestation for up to four months without negatively affecting seed germination, according to studies evaluating oils such as basil, clove, castor, karanja, mustard, soybean, sesamum, eucalyptus, coconut, and neem at 5 mL/kg of seed (Kumar et al.,2017). These oils minimize environmental effect while reducing pest accumulation when integrated into IPM frameworks, in conjunction with cultural practices (appropriate drying and cleanliness), hermetic or better storage, biological regulation, and need-based chemical use (Subedi et al., 2020). Therefore, adding essential oils—particularly citronella and neem—to multi-component IPM techniques improves the sustainability of managing pulse beetles in grains that have been stored.

Challenges and Future Prospects

Although essential oils show strong potential in stored-grain protection, their practical use is limited by high volatility and short residual activity. Variability in plant source and extraction methods affects consistency, and regulatory standards for commercialization are still evolving. Moreover, most findings are laboratory-based, with limited large-scale field validation. Future work should prioritize improved formulations, safety assessment, and testing under real storage conditions to enhance their practical applicability.

Conclusion

Pulse beetle infestation continues to constrain pulse storage worldwide, but integrated approaches that combine cultural, physical, biological, and botanical methods—particularly essential oils—offer sustainable, eco-friendly solutions. Recent research (2020–2024) demonstrates significant insecticidal, repellent, and physiological impacts of essential oils against *Callosobruchus* species. When integrated with hermetic storage and formulation innovations, essential oils can substantially reduce reliance on harmful chemicals, contributing to safer and more resilient pulse storage systems.

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