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Potential of Turmeric (*Curcuma longa*) as an Insect and Its Prospective Rodent Repellent Effects on Lowland-based Rice Farming Systems: A Review

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Abstrak: Hewan pengerat dan serangga di area pertanian padi dataran rendah merusak tanaman, yang berdampak pada masalah serius terkait ketahanan pangan. Penggunaan rodentisida kimia secara luas di masyarakat menyebabkan pencemaran lingkungan, menimbulkan risiko toksisitas bagi organisme non-target, serta berkontribusi terhadap timbulnya resistensi. Tinjauan ini mengevaluasi potensi kunyit (*Curcuma longa* L.) sebagai alternatif nabati yang berkelanjutan untuk pengendalian hama (pengusir serangga dan hewan pengerat) serta efek antijamur dan alelopatinya. Para peneliti melakukan tinjauan pustaka sistematis yang menganalisis studi telaah sejawat (*peer-reviewed*) dari tahun 1988 hingga 2025 dan menemukan 34 artikel yang memenuhi kriteria penelitian. Hasil penelitian menunjukkan bahwa kunyit mengandung senyawa bioaktif—termasuk kurkuminoid dan minyak atsiri seperti *ar-turmerone*—yang memiliki efek insektisida, antijamur, serta daya usir (*repellent*) terhadap hewan pengerat. Senyawa-senyawa tersebut bekerja melalui mekanisme yang mengganggu indra penciuman dan menghambat nafsu makan, serta menunjukkan potensi kuat untuk memengaruhi perilaku hewan pengerat berkat sifat biologisnya. Sifat antijamur dan alelopati yang dimiliki kunyit memungkinkannya melindungi tanaman sekaligus meningkatkan kesehatan tanah. Kunyit menjanjikan sebagai metode pengendalian hama yang berkelanjutan karena berfungsi sebagai solusi yang ramah lingkungan.

Kata kunci: Alelopati; Kurkuminoid; *Ar-turmerone*; Demetoksikurkumin; Pengusir hama (*repellent*); Antijamur; Antibakteri; Olfaktori.

Abstract: *Rodents and insects in lowland rice farming areas destroy crops, which leads to severe food security problems. The widespread use of chemical rodenticides in society leads to environmental contamination, poses toxic risks to non-target organisms, and contributes to the development of resistance. This review evaluates the potential of turmeric (Curcuma longa L.) as a sustainable, plant-based alternative for insect, rodent repellent and its antifungal and allelopathic effects management. The researchers performed a systematic literature review that analyzed peer-reviewed studies from 1988 to 2025 and found 34 articles that met their research requirements. The findings demonstrate that turmeric contains bioactive compounds, which include curcuminoids and volatile oils such as ar-turmerone that show insecticidal and antifungal, and repellent effects to rodents. The compounds produce their effects through mechanisms that cause olfactory disruption and feeding deterrence and show strong potential to impact rodent behavior through its biological properties. The antifungal and allelopathic properties of the substance enable it to protect crops and enhance soil health. Turmeric shows promise as a sustainable pest control method because it functions as an environmentally friendly solution.*

Keywords: Allelopathy; Curcuminoids; Ar-turmerone; Demethoxycurcumin; Repellent; Anti-fungal; Antibacterial; Olfactory.

Introduction

Turmeric, or Curcuma longa, is a small rhizomatous perennial herb that belongs to the Zingiberaceae family of ginger. It is most likely native to India and Southeast Asia. The commercially available spice turmeric is derived from the plant's fleshy rhizomes, which are bright yellow to orange in color. Turmeric is used as a spice, food coloring agent, and food preservative in the form of root powder. In addition to its medicinal uses, the plant's fresh juice, aqueous extracts, and essential oil are said to have intriguing pesticidal qualities against some agriculturally significant pests, as well as a discernible repellent effect against harmful mosquito species (Damalas, C. A., 2011).

Rodents and insects exist in all parts of the world because they create problems for humans through disease transmission and their destructive behaviour, which damages agricultural fields and consumes stored food. In storage, depending on region, 3.2–9.1% (mean 7.6%) of rice was lost to rodents when rice was stored indoors in unprotected polyethylene bags. Netting around bags reduced damage by 89% - equivalent to the annual rice consumption of one person per storage facility, reduced the presence of rodent droppings by 92% and the bag area damaged by rodents by 96% (Htwe, N. et. al, 2021). Thus, rodents are one of the major problems directly concerning the production, storage, and processing of the agricultural crops and their eventual utilization by man and his livestock as food (Sarwar et al., 2011; Sarwar, 2015a; Sarwar, 2015b). On that, rodents represent a major threat to all agricultural systems across the world because they become most destructive when they invade lowland rice ecosystems that provide ideal conditions for their breeding and survival. The rattus argentiventer and rattus species create severe damage to crops, which lasts from the planting stage until the harvest stage because the result is crop yield losses between 5% and 60% under extreme levels of infestation (Singleton et al., 2010; Brown et al., 2016).

Thus, the main method for controlling rodents in traditional systems depends on using chemical rodenticides, which create major environmental problems through both direct contamination and non-target organism secondary poisoning and rodent population resistance development (Stenseth et al., 2003; Buckle & Smith, 2015). Using a Soxhlet apparatus, fifty grams (50 g) of dried, coarsely ground turmeric (Curcuma longa L.) were extracted successively using four different solvents in ascending order of polarity. Solvent-fractionated turmeric extracts from hexane, dichloromethane (CH2Cl2), ethyl acetate (EtOAc), and methanol (CH3OH) were dissolved in water to a concentration of 100 parts per million. The degree of repellency of the common tick species Rhipicephalus sanguineus was measured using a modified olfactometer. While other fractions displayed lower repellence, the hexane extract from dried turmeric powder demonstrated the highest repellence of 80%. Additional research on purification, dose-dependent repellency, and persistence (Perera, W. J. et, al, 2022).

Consequently, the turmeric, nutmeg, ginger, clove, oregano, cinnamon, anise, fennel, basil, black cumin, and black pepper showed antifungal activity against the plant pathogens Colletotrichum acutatum, Colletotrichum fragariae, and Colletotrichum gloeosporioides (Radwan et. al., 2014). However, developing countries rely on rice production for their food supply, face serious threats to their food security because of these losses. Furthermore, the existing challenges have led to higher demand for pest management solutions that use plant-based methods to protect both the environment and integrated pest management

(IPM) systems. Botanical pesticides, which extract their active ingredients from plants, have demonstrated effective results because their components break down in nature and their active substances exhibit less harmful effects on non-target organisms while they operate through different mechanisms (Isman, 2006). Moreover, the plant Curcuma longa L., which people refer to as "turmeric," has drawn scientific interest because of its extensive range of medicinal properties. In fact, the United Nations Sustainable Development Goals (SDGs) require agricultural systems to adopt sustainable practices that enhance farming efficiency and preserve natural resources while securing farmers' income.

Turmeric

Turmeric comes from the Zingiberaceae family and grows throughout tropical areas, including Southeast Asia. The rhizomes of the plant contain bioactive compounds, including curcumin and demethoxycurcumin, as well as volatile oils that contain ar-turmerone. The study notably shows that turmeric functions as a safe and effective insect repellent that people can use in their homes. In connection with the study by Kumar et al. (2017), it was established that turmeric functions as an effective insect repellent that libraries and museums can use to protect books and artefacts from insect damage. Hence, turmeric exists as a rhizomatous perennial herb that belongs to the Zingiberaceae family and grows throughout Southeast Asia. The product serves three main functions: flavoring food, preserving its freshness, and acting as a coloring agent. In addition, turmeric serves as a main ingredient in home remedies because of its important health benefits, which also make it a fundamental component of Indian and Asian traditional medicine.

Therefore, the natural products of turmeric exhibit multiple health benefits, which include analgesic properties, antibacterial effects, antifungal activity, anti-inflammatory effects, antioxidant capacity, and digestive function. As a result, the research established that turmeric functions as an effective insecticide against various agricultural and domestic insect pests. The substance exhibits repellent effects that target harmful mosquito species. The research demonstrates that turmeric products serve as eco-friendly and cost-effective alternatives to traditional chemical pesticides. However, previous studies have demonstrated that turmeric exhibits insecticidal, antifungal, antibacterial, and repellent properties, which make it suitable for use as a botanical pesticide (Tavares et al. 2016; Tripathi *et al.* 1988). The documented insect pest control effects of the product have been studied extensively; yet researchers have not investigated its ability to repel rodents. The strong-odor plant-derived compounds, together with their antifeedant properties, create effective solutions for controlling rodent populations because rodents rely on olfactory cues to determine their feeding habits.

This review examines existing research about turmeric's bioactive compounds while assessing its effectiveness as an insect and rodent repellent in lowland rice agricultural systems. It benefited small holding farmers to utilize turmeric as a bioactive compound to control pest such as insects and rodents. More importantly, promoting sustainable and cost-effective pest control in rice farming systems that enhance soil fertility and chemically free farming practices.

Methodology

This study used a Systematic Literature Review (SLR) approach, through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)

framework to bring together scientific findings about how turmeric (*Curcuma longa*) might work as a biological control tool in lowland rice farming systems. We mainly looked at its insecticidal effects, rodent repellent activity, antifungal potential, and allelopathic behavior, even though those mechanisms are often discussed in different ways. The review was done through steps that included identification, then screening, then checking eligibility, and finally a qualitative synthesis stage.

For the search part, the literature was pulled systematically from Scopus, ScienceDirect, PubMed, and Web of Science. We used Boolean operator combinations, like "Curcuma longa" AND pesticidal activity, and also "turmeric essential oil" AND repellency. Other strings included turmeric AND "botanical rodent control," and turmeric AND "plant-based pest management" AND rice. The coverage included peer-reviewed English-language articles published from January 1988 up to March 2025, and the last search was carried out on March 15, 2025. The time window was not chosen randomly; it was linked to the rise of major investigations in the late 1980s on turmeric-derived bioactive compounds, including curcuminoids and essential oils, for pesticidal and antimicrobial uses in sustainable agriculture.

In total, 52 records were found at first. After duplicates were removed, the screening of titles and abstracts was performed, and then studies that were not related to agricultural pest management, non-peer-reviewed papers, incomplete reports, and articles without any experimental evidence were left out. A full-text eligibility assessment was carried out, using set inclusion criteria that approved peer-reviewed experimental studies, review papers, and meta-analyses dealing with turmeric's biological activities that relate to rice farming systems. Meanwhile, papers centered only on pharmaceutical use or those lacking methodological clarity were ruled out. In the end, 34 studies made it into the final synthesis. From each article, we extracted details such as the author and publication year, study location and research design, as well as the type of turmeric compound or extract, the target organism, application method, and the reported biological effects with their main takeaways.

To ensure reliability, we conducted a quality assessment and a risk of bias check, mainly focusing on methodological rigor, how reproducible the work seemed, whether controls were adequate, how transparent the statistical analysis was, and whether reporting was complete. Only studies that fell into moderate to high-quality categories were retained. The results were synthesized thematically, to identify recurring patterns, practical effectiveness, limitations, and the real-world applications of turmeric-based biological control approaches, so overall transparency, reproducibility, and scientific trust in the review process were enhanced.

Result and Discussion

Author(s)	Target Organism/Pathogen	Active Compound/Extract	Testing Method	Key Results
Tripathi et al. (1988)	*Tribolium castaneum*, *Rhyzopertha dominica*	Turmeric essential oil	Repellency bioassay on stored-product pests	Essential oil showed strong repellent activity, with higher concentrations producing greater effectiveness against storage pests.

Author(s)	Target Organism/Pathogen	Active Compound/Extract	Testing Method	Key Results
Tavares et al. (2016)	*Trichoplusia ni*	Turmeric derivatives	Insecticidal toxicity assay	Turmeric derivatives demonstrated insecticidal effects capable of controlling agricultural insect pests.
Susilowati et al. (2021)	Mosquito larvae	Turmeric essential oil	Larvicidal assay	Essential oil caused significant larval mortality, indicating potential use as a botanical mosquito control agent.
Ali et al. (2025)	Mosquitoes and insect pests	*Curcuma longa* rhizome oil, leaf oil, and curcuminoids	Chemical composition and repellency analysis	Ar-turmerone was identified as the major component in oils and extracts, contributing to mosquito-repellent and larvicidal activity.
Sulhath (2024)	*Callosobruchus chinensis*, *Lasioderma serricorne*, *Tribolium castaneum*	Wild turmeric leaf aromatic oil	Contact toxicity and fumigant assays	Essential oil showed strong insecticidal and fumigant effects, especially against *C. chinensis*, with low LC50 values indicating high toxicity.
Chintala et al. (2023)	*Rhizoctonia solani*	Turmeric extracts	Antifungal inhibition assay	Extracts inhibited fungal growth responsible for rice sheath blight disease.
Ramly (2019)	Weeds and microorganisms in rice systems	Phenolic compounds and flavonoids from turmeric	Allelopathic evaluation	Secondary metabolites suppressed competing weeds and microorganisms, demonstrating allelopathic properties.
Sanit (2016)	Agricultural weeds	Turmeric essential oil	Post-emergent bioherbicide testing	Essential oil functioned as an effective bioherbicide without causing phytotoxic effects on crops.
Dethoup et al. (2022)	Rice sheath blight and dirty panicle pathogens	*Curcuma longa* powder	Greenhouse and field fungicidal trials	Turmeric powder reduced sheath blight severity by 92% and demonstrated strong fungicidal activity under field conditions.
Hossen et al. (2017)	Rodents (rats)	Turmeric bioactive compounds	Mammalian metabolic and antioxidant studies	Turmeric influenced antioxidant and metabolic activity in rats, suggesting possible indirect effects on rodent

Author(s)	Target Organism/Pathogen	Active Compound/Extract	Testing Method	Key Results
				behavior and feeding activity.
Isman (2006)	Agricultural insect pests	Turmeric volatile oils and ar-turmerone	Botanical pesticide evaluation	Volatile compounds disrupted pest nervous systems and feeding behavior, supporting turmeric's role as a natural pesticide.

Table 1. The synthesis table highlights the broad-spectrum bioactivity of Curcuma longa against insect pests, fungal pathogens, weeds, and potentially rodents. Across the reviewed studies, turmeric essential oils, curcuminoids, and volatile compounds such as ar-turmerone consistently demonstrated insecticidal, antifungal, larvicidal, fumigant, and allelopathic properties. The reviewed evidence supports the potential application of turmeric as a sustainable botanical pesticide within integrated pest management systems for lowland rice farming.

Phytochemical Composition and Bioactivity

The medicinal properties of turmeric result from its various biological compounds, which work together to create its effects. The primary active compounds of the product include curcuminoids, which are made up of curcumin, demethoxycurcumin, and bisdemethoxycurcumin, as well as volatile oils that contain ar-turmerone, α-turmerone, and zingiberene (Prasad & Aggarwal 2011; Gupta *et al*. 2013). The compounds exhibit active properties that researchers have confirmed through studies conducted in medical settings and agricultural environments (Hewlings & Kalman 2017). As a result, the plants contain bioactive molecules that show pharmacological effects, including anti-inflammatory, antimicrobial, hypocholesterolemic, antirheumatic, antiviral, antifibrotic, antivenomous, antihepatotoxic, antidiabetic, antinociceptive, anticancerous, and gastroprotective functions (Padalia et al. 2023; Policegourda et al. 2010; Srivasta *et al*. 2006). Additionally, the turmeric volatile fraction contains ar-turmerone, which produces a strong scent that enables the compound to function as a natural pesticide because it drives away insects and acts as a bioactive substance. Furthermore, the essential oils that are processed from turmeric show evidence of producing harmful effects while repelling various pest species, thus establishing their value as natural pest management solutions (Isman, 2006). The compounds interfere with pest nervous systems while disrupting their feeding activities, resulting in a decrease in their population numbers. However, the existing research on *Curcuma* species only provides information about their phytochemistry and pharmacological effects, whereas further research needs to examine the nutritional value, culinary uses, and health benefits of edible Curcuma species (Rajkumari and Sanatombi, 2017).

Insecticidal and Repellent Activity

Scientists have established through their extensive research studies that turmeric functions as an insect repellent and insecticide. To clarify, Tripathi *et al*. (1988) study proved that turmeric essential oil successfully repels stored-product pests, which include T*ribolium castaneum* and *Rhyzopertha dominica*, with higher concentrations showing better performance. Thus, the Tavares *et al*. (2016) research proved that turmeric derivatives kill *Trichoplusia ni* through insecticidal action, demonstrating that the compound can protect against all agricultural pests. In addition, research conducted by Susilowati *et al*. (2021) demonstrates that turmeric essential oils kill mosquito larvae, proving the active compound

functions as an insect pest control agent. The larvicidal and mosquito-repelling properties of essential oils and extracts of Curcuma longa, ar-turmerone, and curcuminoids were assessed. The percentages of ar-turmerone and curcuminoids in rhizome oil, leaf oil, and rhizome extract were 36.9, 24.9, and 50.6%, respectively. The main component of the rhizome oil (36.9%) and leaf oil (24.9%) was ar-turmerone (Ali *et. al* 2025). Researchers found that turmeric oil effectively kills ticks and other ectoparasites, according to their research, which indicates that the oil can be used in both agricultural and veterinary applications. Moreover, the research by Sulhath (2024) demonstrated that wild turmeric leaf aromatic oil possessed insecticidal properties through two methods, allowing it to repel three essential stored grain pest species. The results of the study showed that the essential oil had higher contact toxicity against *C. chinensis* as opposed to *L. serricorne* and *T. castaneum*, indicating that after a day, the LC50 for *chinensis* was 1.50 mg/cm². C. was impacted by the leaf essential oil's more potent fumigant effects. With an LC50 of 2.04 mg/L air at 24 hours, *chinensis* outperformed L. The LC50 for serricorne was 13.28 mg/L air and T. The LC50 for *castaneum* was 18.18 mg/L air. According to the study, turmeric acts as a botanical pesticide in three different ways: it interferes with smell perception, has toxic effects, and stops feeding.

Antifungal and Allelopathic Effects in Rice Systems

Turmeric exhibits insecticidal effects while also providing substantial antifungal and allelopathic benefits that benefit lowland rice agricultural systems. Its extracts have demonstrated their ability to prevent the development of plant pathogens, which include *Rhizoctonia solani*, the primary pathogen responsible for sheath blight in rice (Chintala *et al*., 2023). Moreover, aqueous extracts of *Curcuma longa* rhizomes (TRE) were used for inhibition against a series of plant-infecting fungi. The antifungal activity helps plants develop better health, resulting in higher agricultural yields. It contains secondary metabolites, including phenolic compounds and flavonoids that produce allelopathic effects because they inhibit the development of competing weeds and microorganisms (Ramly, 2019). The antifungal activity of turmeric plant extracts has been documented, but their effectiveness in controlling plant diseases limits their application in agricultural settings (Chintala *et al*., 2023). It has essential oil can be an effective post-emergent bioherbicide against the tested weeds without phytotoxicity to crops (Sanit, S. 2016). It was found also by Dethoup et. al, (2022) that the *Zingiber cassumunar Roxb.* and *Curcuma longa L.* powders suppressed sheath blight disease severity by 93 and 92%, respectively, on treated rice leaves at 10 g L−1. The activity of the selected five plant powders that showed potent fungicidal activity in controlling dirty panicle disease under greenhouse conditions were evaluated in field trials at 25 g L−1. The various properties of turmeric make it a versatile agricultural resource that helps control pests while protecting crops and maintaining soil health.

Implications for Rodent Repellency

The evidence base shows that the evidence for turmeric's effectiveness against rodent repellent studies remains untested and lacks calibration. Rodents use their sense of smell to locate food and choose their living spaces, which makes them vulnerable to strong odors that plants release (Singleton *et al*., 2010). Turmeric releases volatile compounds, including turmerones, that interfere with the natural olfactory signals that rodents use to search for food, resulting in their decreased movement through the treated spaces. Moreover, research

shows that turmeric has antifeedant effects, which stop rodents from eating the crops that have been treated. On the other hand, research on rats demonstrates that turmeric acts as a biological substance that affects mammalian systems by modulating their antioxidant and metabolic activities (Hossen, M. S. *et al*., 2017). In addition, research shows that turmeric affects rodent behaviour through indirect methods that need more testing to verify. Also, research shows that plant-based repellents protect multiple animal species because their insect-repellent compounds also repel mammals. The research shows that turmeric has pesticide properties that support its development as a rodent repellent for use in agricultural fields.

Application in Lowland Rice Farming Systems

The rice ecosystems in lowland areas create perfect environments that enable rodents to expand their populations because they provide both food resources and water sources, as well as safe hiding places. The introduction of turmeric into these systems provides an environmentally friendly method for controlling agricultural pests. Farmers can use three methods: planting turmeric as a border around rice fields, using turmeric extracts as spray solutions, and applying turmeric residues to their fields. Consequently, these methods that serve as pest control solutions follow the principles of integrated pest management, which makes use of eco-friendly techniques to reduce insect populations while protecting the environment. Turmeric functions as a botanical pesticide, helping farmers decrease their need for synthetic chemical products while supporting sustainable farming methods (Isman 2006).

Limitations and Research Gaps

The true potential of turmeric needs further development because multiple obstacles stand between us and achieving its full capacity. The most important research need of the study depends on direct testing, which needs to demonstrate how well the system functions against rodent pests. Thus, the study results do not provide enough information about the actual methods that should be used to apply the solution, which amounts should be applied, and what effects will last in practical situations. The solution operates effectively when specific turmeric components exist in the surrounding environment. Moreover, research should focus on controlled laboratory and field studies to evaluate how insects and rodents respond to turmeric-based treatments. Hence, the development of standardized formulations and application methods is necessary for their effective use in real-world situations. Research studies need to evaluate the cost-effectiveness and environmental impact of turmeric pest control methods to assist farmers in adopting this approach.

Discussion

The review shows how *Curcuma longa* functions as a versatile plant-based resource for sustainable rice farming systems. The research results demonstrate that turmeric contains bioactive substances, which include curcuminoids and volatile oils that show strong insecticidal, antifungal, and allelopathic effects. The research results demonstrate that plant secondary metabolites function as natural defense systems, which serve as effective substitutes for chemical pesticides within integrated pest management systems. The bioactive properties of turmeric provide practical solutions that help solve major problems impacting rice production in lowland areas through their protection against pests,

their control of fungal infections, and their reduction of chemical environmental damage. The product shows its worth as an agricultural solution because it can repel insects while controlling pathogens and blocking the growth of other organisms. This initiative supports sustainable agricultural practices while decreasing the need for traditional agricultural chemical products.

The existing research base receives a new expansion through this study, which presents turmeric as a rodent repellent potential. The existing evidence remains indirect at this point; yet, turmeric shows strong odor and antifeeding abilities, which create a possible pathway to modify rodent behaviour. The research provides partial evidence that supports the larger theory that plant-based insect repellents will also protect against mammal pests. The research lacks essential proof because it depends on direct experimental testing, which requires both field research and controlled laboratory investigations. The research results hold essential value for both theoretical research work and practical implementation. The study demonstrates that plant-based pest control methods have ecological significance while solving major challenges related to food security, environmental protection, and sustainable agricultural practices. Turmeric serves as an effective substitute for chemical pesticides; yet, its complete effectiveness, especially in rodent control, needs additional research work before it can be used in real-world situations.

Conclusion

This review highlights the scientific contributions of Curcuma longa as a multifunctional botanical resource; it possesses insecticidal, antifungal, and allelopathic properties, and it could quietly support sustainable agriculture and integrated pest management (IPM) systems, especially in lowland rice farming. The bioactive compounds found in turmeric, mainly curcuminoids and volatile oils like ar-turmerone, demonstrate the ability to suppress insect pests, block or inhibit plant pathogenic fungi, and even reduce weed interference via allelopathic interactions. When you consider these biological effects together, it appears that turmeric might help lower reliance on synthetic pesticides while also supporting environmentally friendly crop protection approaches.

The synthesis of the available literature suggests that turmeric's insecticidal and antifungal effects are more strongly supported by experimental evidence than any potential rodent repellency. While the strong odor and antifeedant properties of turmeric may influence rodent behaviour, current evidence remains limited. It also tends to be mostly indirect, making it feel somewhat uncertain. For that reason, claims that turmeric works as a rodent repellent should be approached cautiously until more solid lab and field experiments provide sufficient support.

Overall, the study highlights how plant-based approaches for pest management still feel quite relevant in terms of ecological sustainability, environmental safety, and agricultural resilience. When turmeric is woven into IPM systems, it could provide farmers with some real-world perks, such as aiding in pest suppression, supporting crop protection, and reducing chemical contamination. Still, before turmeric-based technologies can be suggested for large-scale farming, more work is needed. Going forward, future studies should concentrate on controlled lab experiments and field trials, along with formulation standardization, then refining the application methods and selecting the right dosages. They should also assess long-term performance across varying farming settings and conduct thorough economic feasibility evaluations. These next investigations matter significantly to

confirm that turmeric-derived pest control strategies are genuinely practical, consistent, and sustainable for today's agriculture, not just theoretically promising.

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