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Chitosan: A Green Shield against Insect Pests

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The health and environmental risks associated with chemical pesticides are driving an increasing concern for safer and more environmentally friendly alternatives to pest management. Chitosan, which is derived from chitin present in exoskeletons mostly of crustaceans like shrimp and crabs, is a suggested course of action. Chitosan is well-known for its sustainability and versatility across various industries, particularly in the food, pharmaceutical and agricultural sectors. Recent research has demonstrated that it works well as a bio agent against a variety of insect pests. This article aims to examine the theoretical underpinnings of using chitosan in pest management as well as any potential benefits.

Chitosan: Composition and Properties

Chitosan is a polysaccharide that develops from the de-acetylation of chitin, recognized to be the second most extensive natural polymer following cellulose. A change in its molecular framework allows chitosan to break down in acidic conditions and create both films and gels. Due to its qualities, chitosan can be used in numerous formulations, such as coatings, nanoparticles and complexes. Its capability for biodegradation and small toxicity makes it a wanted alternative compared to typical pesticides.

Mechanism of action in Pest Control

1. **Direct toxicity:** Chitosan disturbs the framework of insect gut membranes, which creates physiological and structural changes that lessen rates of both survival and reproduction.
2. **Enhancement of plant defences:** Chitosan stimulates plants to produce compounds that either hinder or protect against pest activities.
3. **Carrier for active ingredients:** The improvement in delivery and stability of insecticides and essential oils, allowing for higher efficacy with lower dosages.

Chitosan Formulations for Pest Management

1. Plain chitosan: The fundamental form of chitosan exhibits insecticidal properties through a disruption of the insect's digestive function. Research shows that plain chitosan significantly shortens the lifespan of common pests, including the housefly, *Musca domestica*, where 2% chitosan solution drops the insect's survival from 13 to 4 days. Also, chitosan plays a functional role in shielding wooden and paper materials from insect attack. The mortality rates of termite species such as *Reticulitermes flavipes* and *Reticulitermes virginicus* are above 90% when they feed wood that has been treated with chitosan.

2. Chitosan coating: Chitosan makes an excellent choice for coating fruits, vegetables and crops to offer shielding from insect damage. These coatings are a physical barrier and offer bioactive protection. Findings show that chitosan coatings can slow the rate of ripening, as well as diminish fruit fly populations and curtail fungal growth, which improves both the quality and continuity of produce. Coatings of chitosan have demonstrated a considerable

reduction in the development of eggs and larvae of fruit fly species, *Anastrepha ludens* and *Anastrepha obliqua*. Changes in fruit phenolic content and gas exchange by chitosan render treated fruits less desirable to pests. This makes it an ideal response for managing pests after harvest, particularly in systems that follow organic practices.

3. Coating made from chitosan and essential oils: ssential oils (EOs) have become a popular choice for insecticides that are environmentally friendly, but their tendency to evaporate reduces their effectiveness. Chitosan nanoparticles carrying EOs can improve their bioactivity and maintain their stability. The application of chitosan coatings with citronella EOs has shown to strongly inhibit *Bactrocera carambolae* oviposition on guava fruits. In a similar vein, coatings of chitosan fortified with jasmonic acid boosted pre-imaginal mortality of pests such as *Plutella xylostella* and *Myzus persicae.*

4. Chitosan Nanoparticles: Chitosan nanoparticles are becoming increasingly favoured for their potential to improve the performance of active substances. The improved bioavailability and stability of EOs due to nanoparticles leads to a rise in insecticidal activity. Research has demonstrated that chitosan nanoparticles filled with essential oils (EOs) such as peppermint and rosemary show greater toxicity against pests including *Tribolium castaneum* and *Sitophilus oryzae* than pure essential oils.

5. Chitosan with Nematodes: The combination of chitosan and Entomopathogenic Nematodes (EPNs) has produced encouraging outcomes in the area of pest management. Research has shown that chitosan can improve the performance of EPNs against pests, including *Rhynchophorus ferrugineus*, by stimulating plant defense systems and promoting lignification and root development. This combination has produced high larval mortality rates, making it an effective choice for pest control.

6. Chitosan in active packaging: Chitosan is also part of active packaging systems designed to manage insect pests in storage. Active packaging consists of adding active compounds to the packaging material to keep product quality and extend its shelf-life. As an example, cardboard coated with chitosan and lemongrass EO revealed 100% toxicity against *Sitophilus zeamais*, indicating its promise for sustainable pest management in produce packaging.

7. Chitosan Chemical Adjustments: In order to improve chitosan's poor solubility, a number of chemical modifications have been studied. Chitosan derivatives carrying alkyl, benzyl and acyl groups have improved their solubility and exhibited better insecticidal activity. Chitosan oligosaccharides have shown substantial insecticidal activity against insects including *Helicoverpa armigera* and *Plutella xylostella.*

Advantages of using chitosan in agriculture and pest management

1. Biodegradability
2. Biocompatibility
3. Enhanced Plant Growth
4. Pest and Disease Resistance
5. Improved Shelf-Life

Limitations of using chitosan as a pest control agent

1. Solubility issues: Chitosan's low solubility in water may limit its applications. Often, modifications in chemistry are necessary to boost its solubility.
2. Cost: Chitosan production and processing might often incur costs that are more than the usual pesticides.
3. Effectiveness: The performance of chitosan formulations can change according to the type of pest and the prevailing environmental conditions.
4. Formulation challenges: The development of stable and effective chitosan-based formulations can be complicated and needs advanced methods and materials.

5. Regulatory approval: Acquiring regulatory permission for novel chitosan formulations can be both time and money consuming.
6. Consistency: Variations in chitosan sources and manufacturing methods can produce inconsistent results in product quality and performance.

Chitosan effectiveness over traditional synthetic pesticides

1. Multi-functional properties: Chitosan performs the role of an insecticide while also encouraging plant growth and increasing disease resistance.
2. Eco-friendliness: Synthetic pesticides differ from chitosan; chitosan is biodegradable and non-toxic and less risk to the ecosystem and non-target animals.
3. Enhanced delivery: When created as nanoparticles, chitosan may deliver controlled release and greater stability of active ingredients, which could boost its effectiveness in combating pests.
4. Resistance management: The application of chitosan can support in managing pesticide resistance by delivering a different mode of action in comparison to conventional chemicals.
5. Cost and accessibility: Even though chitosan is more expensive to manufacture, its sustainability and environmental benefits may outstrip the costs in the future.

Recent advancements in chitosan-based pest control technologies

1. Nanoparticle formulations: The improvement of chitosan nanoparticles for the regulated release of essential oils and insecticides has shown a rise in pest control efficiency.
2. Chitosan derivatives: Chemical modifications including the generation of chitosan oligosaccharides and several chitosan-metal complexes have improved chitosan's solubility as well as its insecticidal properties.
3. Combination with biological agents: Combining chitosan with entomopathogenic nematodes and beneficial microbes has resulted in synergistic effects, enhancing pest control outcomes.
4. Active packaging: Innovations in active packaging materials incorporating chitosan and essential oils are being used to protect food products from insect pests while extending shelf-life.
5. RNA Interference (RNAi) delivery: Chitosan nanoparticles are being explored as carriers for RNAi technologies, targeting specific genes in pest insects to disrupt their growth and development.

Conclusion

Chitosan, in its various formulations, offers a promising eco-friendly alternative to synthetic pesticides for insect pest management. Its biodegradability, biocompatibility, and non-toxicity make it suitable for use in agriculture, food packaging, and public health. The incorporation of EOs into chitosan nanoparticles has shown enhanced insecticidal activity and prolonged release effects, making it a highly effective pest control tool.

References

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