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Nanotechnology for Agricultural Pest Management - Make in India - A Unique Approach

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Abstract

Nanotechnology has emerged as a pivotal tool in revolutionizing pest management practices in agriculture. Its significance lies in offering targeted, efficient, and eco-friendly solutions to combat pests and diseases while minimizing environmental impact and optimizing resource utilization. Utilizing nanoparticles to enhance the efficacy and delivery of pesticides, to enable better adhesion, controlled release, and reduced environmental contamination. Development of nanotech-based systems has responded to specific environmental cues or pest presence, allowing for precise and optimized deployment of pesticides while minimizing non-target effects. Early detection and monitoring of pests, diseases, or stress factors in plants using nano-scale sensors, enabled timely and targeted interventions. Nanotech-based solutions complement IPM strategies, fostering a holistic and sustainable approach to pest management.

Introduction

Plant pests reduce global crop yields by ~20-40 percent per year. Therefore to produce the world's needed food, this alarming waste must be curtailed. Fortunately, our unique and novel pest control method addresses this daunting challenge. We safeguard crops by detecting and monitoring miniscule amounts of female sex pheromones of agriculturally hazardous pests in agricultural fields early on, before substantial outbreaks have occurred. Necessary and timely action can then be taken to battle any developing pest infestation at its earliest stages.

Helicoverpa armigera (Hubner) and *Scirphophaga incertuals* (Walker) are infamous for their damage to cotton and rice crops among many others. Moths of both species lay eggs on crops, and the larvae that hatch devour and destroy the crops. One way to stop this would be to discourage the laying of eggs by using techniques like pheromone traps for the male insects.

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Since sex pheromones are unique and carry a distinct chemical signature for each species, pheromone traps rely on luring male insects into a physical contraption or trap by smearing it with the insect's signature pheromone. However, this is a tedious and expensive technique and leads to farmers enduring an unnaturally high exposure to pheromone chemicals.

We decided on a different approach by building a portable and highly sensitive device that can detect even minute quantities of sex pheromone in the air at levels naturally secreted by pests. The micro electro mechanical system (MEMS) based technology has micron-sized electronic devices with moving parts, routinely used in gyroscopes and health monitoring sensors. This research marks the suitably functionalized MEMS devices for the first time to selectively detect pest pheromones. In the strategy designed by the authors, they have fabricated a few MEMS devices and then covalently functionalized them for the selective sensing of particular pheromones.1 The silicon dioxide based MEMS devices those were fabricated have no selectivity on their own, it is the chemical functionalization steps, developed by the authors after many standardizations, make these devices specific to the female sex pheromones.

Nanotechnology offers innovative solutions in agricultural pest management by providing more targeted, efficient, and eco-friendly methods to control pests and diseases. Here are some ways nanotech is being applied:

Nano-Pesticides: Nano-sized particles can enhance the effectiveness of pesticides. Nano-formulations ensure better adhesion, penetration, and controlled release of active ingredients. This targeted delivery reduces the amount of pesticide needed and minimizes environmental impact.

Smart Delivery Systems: Nanotechnology enables the development of smart delivery systems that respond to specific stimuli like pH, temperature, or pest presence. This helps in releasing pesticides only when and where needed, reducing non-target effects.

Nano-Encapsulation: Encapsulation of bioactive compounds or biological control agents in nanoscale carriers protects them from degradation and improves their stability and persistence in the field.

Nanobiosensors: These sensors can detect pests, diseases, or stress factors in plants at early stages, enabling timely intervention and targeted treatment.

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Nanostructured Materials: Nanostructured materials like nanoparticles or nanofibers can be used in protective coatings, mulches, or films to enhance plant resistance against pests, UV radiation, or moisture loss.

Precision Agriculture: Nanotech-based sensors and monitoring devices enable real-time data collection and analysis, facilitating precision agriculture practices that optimize pest control strategies.

Nanoparticles in Pest Control:

Nanoparticles in pest control represent a significant advancement in agricultural practices, offering innovative solutions to address pest-related challenges while minimizing environmental impact. Here are key aspects of nanoparticles in pest control:

Enhanced Pesticide Formulations: Nanoparticles are utilized to improve the efficiency of pesticide delivery. By encapsulating active ingredients in nano-sized carriers, formulations achieve better adhesion, penetration, and controlled release. This targeted delivery ensures that pesticides reach the intended target more effectively while reducing the quantity needed, thus minimizing environmental contamination.

Types of Nanoparticles:

Metal Nanoparticles: Silver, copper, zinc oxide, and other metal nanoparticles have shown efficacy in pest control. They exhibit antimicrobial properties and can be used in pest management, including controlling microbial pathogens in soil or on crops.

Polymeric Nanoparticles: These nanoparticles, made from biodegradable polymers, enable controlled release of pesticides. They improve the stability and persistence of pesticides, reducing the need for frequent reapplication.

Mode of Action: Nanoparticles alter the behavior and effectiveness of pesticides:

Increased Surface Area: Nano-sized particles offer a higher surface area-to-volume ratio, enhancing interactions between pesticides and pests.

Penetration Enhancement: Nanoparticles facilitate better penetration through pest cuticles or cell walls, improving the pesticide's access to the target organism.

Reduced Environmental Impact: Controlled release mechanisms and targeted delivery minimize off-target effects and environmental pollution associated with conventional pesticide use.

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Challenges and Considerations: Despite their promise, nanoparticles in pest control face challenges:

Safety Concerns: The potential toxicity of nanoparticles to non-target organisms, including beneficial insects and soil microbes, requires careful assessment.

Regulatory Hurdles: Regulations governing nanotechnology in agriculture need further development to ensure safe and responsible use.

Resistance Development: Pests might develop resistance to nanoparticles or nano-enhanced formulations, necessitating ongoing research into diverse strategies.

Future Directions: The future of nanoparticles in pest control involves:

Innovative Formulations: Continual research into novel nanomaterials and formulations to improve efficacy and safety.

Ecological Risk Assessment: Thorough evaluation of the ecological impact of nanoparticles to ensure their environmental safety.

Integrated Pest Management (IPM): Incorporating nanotechnology into holistic IPM strategies for sustainable pest control.

Nanoparticles hold immense promise in revolutionizing pest control in agriculture. However, their safe and effective application requires ongoing research, collaboration among stakeholders, and a balanced approach to address challenges while harnessing their potential benefits.

Smart Delivery Systems and Nano-Encapsulation:

Smart delivery systems in agriculture involve the use of nanotechnology to create pesticide formulations that respond to specific environmental stimuli or the presence of pests, allowing for targeted and optimized deployment of pesticides. These systems aim to enhance the effectiveness of pest control while minimizing the use of chemicals and reducing environmental impact. Here's an overview of how these systems work:

Types of Smart Delivery Systems:

Trigger-based Systems: These systems are designed to release pesticides in response to specific triggers, such as:

Environmental Factors: Changes in temperature, humidity, pH levels, or light can trigger the release of pesticides.

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Pest Presence: Detection of pests through sensors or indicators initiates the release of the active ingredients.

Responsive Nanocarriers: Nanostructures or carriers encapsulate the pesticide molecules and respond to external stimuli to release the active ingredients when required. These nanocarriers could be:

Nanogels or Nanoparticles: Responsive to changes in environmental conditions like pH or temperature, enabling controlled release of pesticides.

Smart Polymers: These polymers change their structure in response to environmental cues, releasing the encapsulated pesticides accordingly.

Mechanism of Action:

Environmental Triggers: For instance, a nanocarrier responsive to changes in pH levels might remain stable in neutral conditions but release the pesticide payload in more acidic environments, such as those found within pests or diseased plant tissues.

Pest Detection: Sensors or biosensors integrated into the system can detect specific pest-related signals, such as pheromones, volatile organic compounds emitted by pests, or changes in plant physiology due to pest presence. Upon detection, the system triggers the release of pesticides.

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To date, the authors have detected the female sex pheromone of *Helicoverpa armigera* (Hubner),2,3 *Scirphophaga incertulas* (Walker)2,3 and *Bactocera oleae* (Rossi),4,5 because these are three of the most hazardous agricultural pests known globally. Operationally, an increase in pheromone concentration during the detection period can be quantitatively sensed by a proportionate change in frequency or resistance which is continuously measured and monitored. After selective detection of the pheromone, and prior to applying any measure to control the pest plague, a stage will be identified when the pheromone concentration is just below the danger level. Necessary actions can

Then be taken as needed and when needed in a confined region of the alerted pest attack. This approach reduces the possibility of anthropogenic contamination due to the current overuse of pesticides/insecticides.

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The authors have tested the device's durability in the temperature range between 0 to 60 oC and in extreme humidity. In some cases, the devices were dipped in water, dried and then checked. They were found to be active even in that condition. To simulate a real field condition, the devices were tested in a large box of tomato plants with male and female *Helicoverpa armigera* (Hubner) moths. When checked every 6 hours, the functionalized devices clearly showed the presence of pheromones each time. Also, these devices are robust enough to be chemically cleaned and re-used. The devices responded selectively only to pheromone chemicals from *Helicoverpa armigera* (Hubner) and *Scirphophaga incertulas* (Walker) when tested in the presence of interfering pheromones from various other insects present in an agricultural field. Although the results seem

Promising for farmers of cotton, rice and olive field who fight crop losses due to pests, the devices are currently in their nascent form and need to be developed into a handy product for wide usage.6,7 The research team led by Prof. Santanu Bhattacharya have thus used state-of-art technology and developed products for the management of many agricultural pests. These products have the potential to empower the agriculture sector globally.

In a separate case, to control the pest influx in an alerted area of infestation, we have chosen more environment friendly pheromone nanogels.8 In this case, insect pheromones are entrapped in a supramolecular polymeric nanogel, forming an immobile *viscoelastic* semi-solid mass which is easily handled and transported without refrigeration. Due to its slow-release properties, it allows a reduction in the frequency of pheromone recharging in the orchard. Such nanogelled pheromone exhibits a high residual activity and an excellent efficacy in an open orchard, even during rainy seasons. Thus, with the deployment of polymeric nanogel carrier systems, there is less need to use genetically modified crops. Also, the transportation of the nanogelled pheromones is trouble-free, due to the significant mechanical strength of the polymer nanogels. These formulations of nanogel were developed for many pheromones and kairomones and all of them dramatically increase the field-life of various pheromones that disrupt the lifecycles of harmful crop pests, such as Bactrocera *dorsalis* (Hendel); *Helicoverpa armigera* (Hubner) (Lepidoptera, Noctuidae); *Scirphophaga incertulas* (Walker) (Lepidoptera, Pyralidae); *Leucinodes orbonalis* (Guenee) (Lepidoptera: Pyralidae); *Xylotrechus quadripes* (Chevrolat) (Coleoptera: Cerambycidae); *Holotrichia consanguinea* (Blanchard);9, 10 *Hypothenemus hampei* (Ferrari); *Xylosandrus crassiusculus* (Coleoptera: Scolytidae);*Xylosandrus germanus*

(Coleoptera: Curculionidae, Scolytinae); Hylurgops palliatus; Tomicus piniperda; Trypodendron domesticum; Cnestus mutilates; Rhizophagus ferrugineus (Coleoptera: Rhizophagidae); Pollenia species (Diptera: Calliphoridae); Fannia canicularis; Muscina stabulans; Musca domestica etc.

The present inventions8-11 involves the immobilization of the semiochemicals within the 3-D nano-pockets of the nanofibrous gel by using weak non-covalent interactions. At first, gelation was checked with different pheromones/ attractants in various solvents out of which the nanogels were formed specifically in toluene, R-(2)-butanol, ethanol, 1:1 (v/v) ethanol:methanol and methanol. We also varied the molar ratio of the two components and the nanogels were found only when the ratio of the two components was 1:1 equivalent. Also (R)-2-butanol itself acts as a sex pheromone of the white Grub beetles (*Dasylepida ishigakiensis*),11 a serious insect pest of sugarcane. Ethanol alone or a mixture of ethanol and methanol (1:1 v/v) acts as an attractant to various devastating agricultural pests, including coffee berry borer (Hypothenemus hampeiFerrari).

The nanogels loaded with ethanol control the forest pests such as the black stem borer (*Xylosandrus crassiusculus* and *Xylosandrus germanus*). Wood borers/Bark beetles such as Hylurgops palliatus, Tomicus piniperda, Trypodendron domesticum, Cnestus mutilates, *Xylosandrus crassiusculus* (Coleoptera: Scolytidae), Rhizophagus ferrugineus (Coleoptera: Rhizophagidae) and Pollenia species (Diptera:Calliphoridae) are the most devastating forest pests controlled by nanogels loaded with ethanol. Also important are veterinary pests such as Fannia canicularis, Muscina stabulans and Musca domestica because they are carriers of diarrhoeal diseases and cause skin and eye infections. Rheological studies revealed that these nanofibrous matrix are viscoelastic and semi-solid in nature. The remarkable mechanical strength of these nanofibrous matrix makes them ideal to be handled/transported without taking any special care. These nanofibrous matrix samples comprising immobilized semiochemicals may be used in the field for prolonged period of time due to their sustained release properties. The strategy may be applicable even for kairomones such as nanogelled linalool for the attraction of predators and parasitoids, natural enemies of crop pests. Targeted agricultural products that may be benefitted by these products include cotton, pigeon pea, chick pea, tomato, coffee, guava, mango, rice, brinjal etc. Thus this novel approach has the potential to revolutionize the modern agricultural era in a new dimension. A low-cost, portable pesticide sensor for detecting paraquat in the field was developed.12 Red-light emitting water-soluble semiconducting quantum dots

(QDs) have been synthesized using a thiol-type capping agent for the sensing of the herbicide paraquat dichloride. The QDs with their negatively charged nano-surface showed excellent selectivity toward paraquat (PQ) at pH 7.4 over other commonly encountered pesticides/ herbicides, including diquat (DQ). Precoated quartz plates were thus developed as a low-cost, portable sensor for on-site detection of PQ, both in natural water samples and in human urine, adulterated dairy products, with excellent sensitivity, and in the screening of more than 50 different food items including several vegetables, fruits, cereals and fodders. Thus an innovative technology was developed to construct a generalized marker for sensing any residual paraquat in such specimens.

The authors has thus also developed rapid detection of biopesticides containing viruses such as for *Helicoverpa armigera* (Hubner) NPV and *Spodoptera litura* NPV.13, 14 An inexpensive, reusable, portable 'color-strip' was developed by us for the rapid on-field detection of *Helicoverpa armigera* nuclear polyhedrosis virus (HaNPV) in commercial biopesticide formulations. The present system can differentiate between the active and inactive HaNPV without involving any sophisticated instrumental facility. The invention provides a method for obtaining a compound specific for rapid detection of Biopesticides. The method includes obtaining a bromide precursor in acetonitrile at a predefined temperature to obtain a piperazine derivative. Subsequent to obtaining the piperazine derivative, the piperazine is reacted to obtain an intermediate aldehyde derivative. The aldehyde derivative is further refluxed to obtain a carbazole derivative. Further, the invention provides a method for obtaining a probe for rapid detection for biopesticides containing NPV. The invention also provides a device comprising a probe, a detection means and an analyser for rapid detection of Biopesticides containing NPV.

Our laboratory has developed some exceptionally innovative products that are available for the next stage of implementation. The products allow the management of pests by trapping them with the technology available with us for forecasting of early pest detection. Therefore policy makers need to champion these proven products so that their commercialization can enhance agricultural productivity and profits.

Conclusions

Smart delivery systems complement IPM strategies, which emphasize multiple approaches to pest management. By integrating these systems with biological controls, crop rotation, and other sustainable practices, they contribute to a holistic and environmentally friendly pest management approach.

Challenges and Mitigation:

- **Technological Complexity:** Developing and implementing these systems require advanced technological expertise. However, ongoing research and collaborations among scientists, engineers, and agricultural experts help overcome these challenges.
- **Regulatory and Safety Concerns:** Ensuring the safety of nanotech-based systems remains a priority. Rigorous testing, adherence to regulations, and continuous evaluation of their environmental impact are crucial.

Future Prospects:

1. Innovation in Nanomaterials: Continued advancements in nanomaterials will lead to more efficient and cost-effective smart delivery systems. This includes the development of biodegradable nanocarriers and environmentally benign materials.

2. Improved Sensor Technologies: Enhanced sensor technologies will enable more accurate detection of pests, diseases, and environmental triggers, allowing for even more precise and responsive pesticide deployment.

3. Integration of Data and AI: Integration with data analytics and artificial intelligence can optimize the decision-making process, providing real-time insights into pest outbreaks and environmental conditions for timely intervention.

4. Public Awareness and Collaboration: Engaging stakeholders, educating farmers, policymakers, and the public about the benefits and safety measures associated with these technologies is crucial for their widespread acceptance and responsible use.

In conclusion, smart delivery systems based on nanotechnology represent a paradigm shift in pest control practices. They offer a pathway towards sustainable agriculture by reducing chemical inputs, preserving ecosystems, and ensuring food security while addressing the challenges through continuous innovation and responsible implementation.

References

1. Santanu Bhattacharya, Parikshit Moitra and Deepa Bhagat. Surface Functionalization for Sensing of Volatile Organic Carbonyl Compounds. *Indian Patent Filed*, 2016 (IN 2014CH05166 A 20160701).

2. Santanu Bhattacharya, Rudra Pratap, Parikshit Moitra, Deepa Bhagat. A pheromone detector. *Indian Patent Filed*, 2016 (IN 2014CH05201 A 20160701).

3. Santanu Bhattacharya, Rudra Pratap, Parikshit Moitra and Deepa Bhagat. A Pheromone Detector. European Patent applied, 2016 (*International Publication Number* WO 2016/059641 A1).

4. Santanu Bhattacharya, Rudra Pratap, Parikshit Moitra, Deepa Bhagat. Optical nanosensor for early stage detection of Bactocera oleae infestation. Indian Patent Filed, 2017 (IN 2015CH03696 A 20170120).

5. Santanu Bhattacharya, Rudra Pratap, Parikshit Moitra and Deepa Bhagat. Forecasting of Pest Incidence: A Unique Surface Functionalized Template for the Selective Detection of Pheromone of the Olive Fruit Fly, Bactocera oleae. European patent applied, 2017 (application number PCT/IN2017/050025).

6. Moitra, Parikshit; Bhagat, Deepa; Rudra Pratap; & Bhattacharya, S. A novel bio-engineering approach to generate an eminent surface-functionalised template for selective detection of female sex pheromone of Helicoverpa armigera. Scientific Reports 2016, 6, 37355- 37364.

7. Parikshit Moitra, Bhagat Deepa, Rudra pratap and Bhattacharya Santanu. Selective detection of female Sex Pheromone of Helicoverpa armigera by an Eminent surface. Protocol Exchange, 2017, DOI: 10.1038protex.2017.057

8. Santanu Bhattacharya, Deepa Bhagat and Suman Kalyan Samanta. Nanogels, Methods and Device thereof in Pest Management. Indian patent filed, 2015 (IN 2014CH00372 A 20151009).

9. Santanu Bhattacharya, Subham Bhattacharjee and Deepa Bhagat. Nanogels, methods and devices thereof, for managing Holotrichia consanguinea. Indian patent applied, 2016 (application number 2016 41024309).

10. Santanu Bhattacharya, Deepa Bhagat, Subham Bhattacharjee. Nanogels, methods and devices thereof, for managining Holotrichia consanguinea. International patent applied, 2017 (PCT/IN2017/05290).

11. Santanu Bhattacharya, Subham Bhattacharjee, Dipen Biswakarma, Deepa Bhagat. A reusable charge transfer based agrogel. Indian patent applied, 2017 (CS/OC/2016/093).

12. Dey, Nilanjan; Bhagat, Deepa; Cherukaraveedu, Durgadas & Bhattacharya, S. 2017 Efficacious utilization of red light emitting CdTe Nanoparticles for trace-level detection of harmful herbicide in adulterated food and agricultural crops Chem asian J , 12, 76-85.

13. Santanu Bhattacharya, Nilanjan Dey, Deepa Bhagat. Method And Device For Rapid Detection of HearNPV. Indian patent filed, 2017 (application number 2017 41019790).

14. Santanu Bhattacharya,Nilanjan Dey,Dipen Biswakarma, Deepa Bhagat, A kit for specific detection Of SlNPV. Indian patent applied, 2017 (application number 20174104094).