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Exploring the Role of Nanotechnology in Enhancing Apiculture Practices

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ABSTRACT

Nanotechnology, which involves the use of materials smaller than 100 nanometers to perform specific tasks, has gained attention in agriculture, industry, and medicine. As this field has advanced, various techniques for preparing nanoparticles have been developed. While nanotechnology has mainly focused on creating for managing plant diseases and pests, its applications in beekeeping are limited. Most research in this field has examined the use of bee products as nanoparticles for medical purposes. This article reviews the applications of nanotechnology in beekeeping, covering areas such as tools, instrumental insemination, nutrition, pollination, swarming, pest and disease control, and bee products. It also addresses the potential risks posed by nanoparticles to honeybees. This review aims to highlight emerging trends in beekeeping and to encourage further research on nanotechnology's role in improving bee management practices.

Keywords: Honey bees, Colonies, Pests, Diseases, Nanoparticles

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Introduction

Nanotechnology refers to the use of materials or particles smaller than 100 nanometers to carry out specific tasks [1-4]. Nearly all substances, such as essential oils, and pesticides can be transformed into nanoparticles. Various techniques are employed for nanoparticle preparation, including gas condensation, chemical vapor deposition, and Sol-Gel methods [5-7], with nanoencapsulation achievable through several approaches [8]. Heavy metals like Ag, Ni, Fe, and Al are often used in nanomaterial production [6]. Once nanoparticles are created, their properties—such as chemical composition, shape, and size—must be analyzed, with tools like Gas Chromatography-Mass Spectrometry (GC-MS), X-ray Photoelectron Spectroscopy (XPS), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and UV–Vis Spectrophotometry playing crucial roles [9, 10]. While nanotechnology has been widely applied in agriculture, particularly for controlling plant diseases and pests [11], its use in beekeeping remains relatively underexplored. Beekeeping, however, offers significant economic and environmental value, and nanotechnology holds potential for various applications in the field. Current research on nanotechnology in beekeeping primarily focuses on the medical and nutritional properties of products by bees, such as propolis [12-15] and venom of bees [16]. This article outlines the possible advancements in beekeeping through nanotechnology, encouraging further research to enhance the industry.

Materials and Methods

This study is based on a comprehensive review of existing literature concerning the application of nanotechnology in beekeeping. All relevant aspects of beekeeping were taken into account during the manuscript's development and revision. The selected articles were organized into distinct categories: honey bee pests, feeding, beekeeping tools, pollination, swarming, instrumental insemination, honey bee diseases, and honey products of bees. These categories encompass the major areas of beekeeping. Each section also highlights suggestions for future research. A results section was included to summarize the reviewed studies, followed by a discussion on the potential risks associated with nanomaterials for honey bees. The discussion specifically addressed the use of heavy metals in nanomaterial preparation. Finally, a conclusion was provided, summarizing the findings from the reviewed studies. It should be noted that there is limited research on this area.

Results and Discussion

Beekeeping tools

Beekeeping requires a variety of essential tools, including beehives, hive tools, smokers, pollen and propolis traps, bee venom collectors, and traps for pests. These tools are typically made from materials such as plastic, metal, wood, or fibers. Nanotechnology, which has numerous industrial applications, can enhance the performance of these tools by improving their durability, strength, and resistance to extreme temperatures. For instance, wall coatings with silica-based nano-composite emulsions have shown improved solvent resistance and performance. Similarly, nanotechnology can be applied to enhance beekeeping equipment. Beehives, for example, can be coated with materials that protect them from environmental factors like sun and rain. Insulated hives have demonstrated better performance under high temperatures compared to uninsulated ones. It is anticipated that beehives treated with nanoparticle-based insulation will outperform those using conventional materials. Nanotechnology can also improve the strength and adaptability of other beekeeping tools, making them better suited for varying environmental conditions. This is especially important as climate change and rising temperatures pose significant challenges to beekeeping. Additionally, beehives could be treated with hygienic materials developed through nanotechnology to protect the health of honey bees. For example, hives coated with nano-silver have been found to protect against diseases, while uncoated hives showed higher bacterial growth and greater disease symptoms. More research is needed to enhance beekeeping tools and promote the growth and sustainability of the beekeeping industry [17-22].

Feeding

Honey bees primarily rely on nectar and pollen for nourishment. However, beekeepers often supplement their colonies with artificial feed when natural flowering plants are scarce or absent. Artificial feeding is typically categorized into two types: protein feeding and sugar feeding. Sugar feeding, which is vital for the survival of colonies, particularly in winter, can be made from various ingredients such as honey, sugar, and water. Protein feeding is based on the use of pollen or its substitutes. Inadequate nutrition can lead to health problems for honey bees, making them more vulnerable to diseases. Research suggests that food formulated as nanoparticles may have distinct properties compared to its conventional form, potentially improving the health and digestive functions of honey bees. Therefore, further research is suggested to explore the use of nanotechnology in creating nano-foods for honey bees, especially those that could be combined with specific medications to combat gut or hemolymph pathogens [23-30].

Pollination

Pollination is crucial for the reproduction of many plants, and honey bees play a significant role in pollinating a wide range of crops. Chemicals, such as pheromones and attractants, are sometimes used to direct foraging activity toward particular plants. When these chemicals are prepared as nanoparticles, their properties can be enhanced. For instance, studies have shown that chitosan nano-conjugated pheromones can influence reproductive behavior in fish. Further research is encouraged to examine the potential of nanoparticles in regulating foraging behavior and enhancing pollination efficiency [30-35].

Swarming

Swarming plays a crucial role in the reproduction of bee colonies. However, natural swarming is often problematic for beekeepers, as it can lead to weakened colonies, especially when the mother queen is lost in the process. To manage swarming, beekeepers employ various methods, including swarm lures, with pheromones being particularly effective in attracting swarms. When swarm lures are developed as nanoparticles, they may offer more efficient attraction capabilities. Moreover, the effectiveness of these nanoparticle-based lures could last longer due to their altered properties compared to traditional lure formulations [36-42].

Instrumental insemination

In honey bee colonies, queen mating occurs naturally in the air within specific areas called drone congregation areas (DCAs). However, instrumental insemination is a critical technique for controlling queen mating. This process involves collecting semen from drones, narcotizing the virgin queens, and then inseminating the queens using specialized tools. Nanotechnology can improve the physical and hygienic properties of the tools used in instrumental insemination. By using biocompatible magnetic nanoparticles, molecular-based targeting can aid in the selection of healthy sperm from samples like boar semen. Nanopurification methods can offer non-invasive techniques for sperm selection based on epigenetics. A similar approach could be applied to the purification of drones' semen, allowing for the selection of the most viable sperm and ensuring the genetic quality of insemination (genetic paternity purification) [43-50].

Honey bee pests

Various pests, including hornets, moths, and beetles, can threaten beehives by feeding on bees, wax, and stored food. These pests are distributed across different regions, and their impact on colonies varies by location. Hornets, particularly those from the Vespa genus, attack adult bees in flight and invade colonies to feed on honey and bees. The recent invasion of *Vespa velutina* hornets in some European areas has raised concerns. Small hive beetles are highly destructive to bee colonies and are found in several countries across Africa, Europe, America, and Asia. Wax moths also pose a significant threat to bee colonies, damaging wax combs inside or outside hives. Nanotechnology can play a role in developing attractants for these pests, which can be used in various trap designs to capture them. Additionally, herbal extracts and essential oils have shown effectiveness in controlling wax moths and small hive beetles. When formulated as nanoparticles, these substances could enhance their pest-control efficacy. Further research is needed to explore these potential applications [51-55].

Mites and honey bee diseases

Mites, such as Varroa destructor, attack honey bees by feeding on their hemolymph at both immature and mature stages, while Tropilaelaps mites target only the immature stages. Honeybees are also susceptible to a range of bacterial, viral, fungal, and protozoan diseases, including Nosema. Previous studies on plant diseases have demonstrated that nanomaterials can be more effective than conventional treatments. For mites and diseases affecting honey bees, several control methods and materials, such as herbal extracts, propolis, and essential oils, have been explored. The effectiveness of these substances can be improved when formulated as nanoparticles. For instance, adding nanosilver (25 ppm) to bee feed has been shown to reduce the number of Nosema spores in laboratory conditions. Further research is required to develop safe, effective materials to control mites and honey bee diseases. Additionally, novel diagnostic techniques, such as a label-free colorimetric nanodiagnostic method, can be used to detect specific pathogens, such as Melissococcus plutonius, which causes European Foulbrood (EFB). This method, based on unmodified gold nanoparticles, offers a rapid and precise way to detect EFB and could be adapted for diagnosing other diseases like American Foulbrood (AFB), which presents a significant challenge to honey bee colonies [56-61].

Honey bee products

Beekeepers produce a range of valuable products from bee colonies, including royal jelly, honey, pollen, bee venom, beeswax, and propolis. These products serve as a significant source of income for many beekeepers and are utilized for both human consumption and medicinal purposes. In addition, beeswax is particularly useful in various industrial applications. The commercial value of these products of bees can be increased by improving their effectiveness. Nanotechnology offers the potential to enhance the properties of these products. For instance, nano-formulated propolis has shown promise as a treatment for cancer, with its antimicrobial properties exceeding those of traditional Chinese propolis. Propolis-loaded nano-in-microparticles have also demonstrated improved anti-cancer activity. Furthermore, chitosan nanoparticles carrying bee venom have proven effective against amebiasis, and melittin-loaded nano-liposomes have shown the ability to inhibit the growth of hepatocellular carcinoma (HCC) cells. More research is needed to explore the potential of bee products in nanoparticle form, particularly in their ability to combat human and animal diseases, which could also boost their commercial appeal [62-66].

There is a wide variety of nanoparticles available for use in agriculture, and as their application increases, there is concern about the potential environmental pollution caused by these materials, particularly heavy metals in their production. Several studies have highlighted the negative effects of nanoparticles on honey bees. For instance, nanosilver at a concentration of 25 ppm added to bee feed was found to reduce the lifespan of worker bees in lab conditions. Similarly, high concentrations of ZnO nanoparticles were shown to lower the feeding rate of bees, potentially causing metabolic disruptions, such as reduced brain protein levels, decreased survival rates, and increased activities of AChE and GST, indicating a significant impact on the bees' nervous systems. Other studies revealed that the toxic effects of nanoparticles, including TiO2, ZnO-TiO2, and Ag-TiO2, on *Apis mellifera* increased with higher concentrations and prolonged exposure. Furthermore, cerium (IV) oxide nanoparticles led to sublethal changes in bees after chronic oral exposure, and sublethal concentrations of CdO or PbO nanoparticles in sugar syrup were found to negatively affect the histological and cellular structure of bee workers' midgut cells [67-73].

On a more positive note, certain studies have indicated that some nanoparticles pose no significant threat to honey bees. For example, silver nanoparticles, when used in beekeeping tools, did not show any harmful effects in honey or combs, suggesting that nanomaterials can be safely used in beekeeping. Additionally, nanoemulsions of hexanal and nanosized carbon black or titanium dioxide did not cause mortality or adverse chronic effects on bees' survival, feeding, or enzymatic activity. Similarly, ZnO nanoparticles at certain concentrations showed no negative impacts on bee survival or enzymatic functions, such as glutathione S-transferase and acetylcholinesterase [72-76].

The presence of nanoparticle residues in the products of bees due to direct applications on plants remains underexplored. However, honey bees are often used as bio-indicators for environmental pollution, so they, along with their products, could serve to monitor contamination levels from nanoparticles. Further research, both in laboratory and field settings, is needed to evaluate the potential risks of nanoparticles on bee behavior, physiology, colony productivity, and the impact on bee diseases and pests. While the risks associated with nanoparticles may be lower than those of traditional pesticides, a thorough assessment of their effects on honey bees is necessary before their widespread use in sustainable agriculture [76-80].

Conclusion

Nanotechnology shows great potential in advancing beekeeping practices, with various applications across the field. Further research is needed to explore its potential and identify the most effective formulations for different tasks. Additionally, the potential risks posed by nanoparticles to honey bees, whether as target or non-target organisms, warrant further investigation.

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