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Potential Applications of Nanotechnology in Apiculture

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ABSTRACT

The use of materials with tiny size less than 100 nanometers (nm) to perform specific tasks or nanotechnology is currently applied in many agricultural, industrial, and medicinal aspects. The science of nanotechnology is developed rapidly and there are many techniques available to prepare nanoparticles. In agriculture, nanotechnology has been used mainly to develop nanomaterials to control diseases and pests of plants. So far, very few studies have implemented nanotechnology with beekeeping. Bee products prepared as nanoparticles for medicinal purposes have been studied more than any other aspects. In this article, the potential applications of nanotechnology on beekeeping including; tools, feeding, pollination, swarming, instrumental insemination, control of pests and diseases, and bee products are presented and previous studies are reviewed. Moreover, the potential hazards of nanoparticles on honey bees are also discussed. This article aims to present new trends to enhance beekeeping and to encourage bee researchers to perform more studies on nanotechnology.

Keywords: Honey bees, colonies, pests, diseases, nanoparticles.

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INTRODUCTION

Nanotechnology can be simply defined as the use of nanoparticles or materials at the nanoscale with a size of fewer than 100 nanometers (nm) to perform required tasks [1-4]. Approximately all materials; essential oils, pesticides, or other chemicals can be prepared as nanoparticles. The preparation of nanoparticles can be done using various techniques include gas condensation, chemical vapor deposition, and Sol-Gel techniques [5-7] while nanoencapsulation technology can be achieved using different methods [8]. Various heavy metals are used during the preparation of nanomaterials include Ag, Ni, Fe, or Al [6]. After preparing the nanoparticles their characteristics should be identified including chemical composition, particles shape, and size, and various equipment can be utilized for this purpose include Gas chromatography-mass spectroscopy (GC-MS), X-ray photoelectric energy spectra (XPS), Scanning Electron Microscopy (SEM), Transmission Electron Microscopy (TEM), and UV–vis spectrophotometry [9, 10]. Nanotechnology is currently applied in many fields including agriculture with a focus on developing nanoparticles to control diseases and pests of plants [11]. On the other side, beekeeping is among the agricultural activities which have enormous economic and environmental benefits. Nanotechnology can be applied in many aspects of beekeeping, but the present studies related to beekeeping only focus on the medicinal and nutritional properties of bee products prepared as nanoparticles include propolis [12-15] and bee venom [16]. Therefore, this article presents the points that can be developed using nanotechnology to encourage re-

searchers to perform more investigations to enhance beekeeping.

METHODS

This study depends on reviewing the available publications related to the use of nanotechnology in beekeeping. So, all aspects related to beekeeping were considered during writing and revision of the manuscript. The reviewed papers were classified into categories: beekeeping tools, feeding, pollination, swarming, instrumental insemination, honey bee pests, honey bee diseases, and honey bee products. These categories approximately represent all aspects of beekeeping. Directions for future studies were also presented in each section. The results section was added to present the reviewed papers followed by a section to discuss the potential hazards of nanomaterials on honey bees. It is known that some heavy metals can be used during the preparation of the nanomaterials. Thus, the discussion section covered this point. Moreover, a general conclusion was presented in light of the reviewed papers. Indeed, relatively few publications are available on this topic.

RESULTS

Beekeeping tools

Many tools are very necessary for beekeeping. These tools include beehives, smokers, hive tools, pollen and propolis traps [17, 18], bee venom collectors [19-21], and traps for bee pests [22]. Many materials are used to make these tools including; plastic, metals, wood, or fibers. On the other side, nanotechnology has many industrial applications to boost the properties of manufactured tools to tolerate hot or cold weather, and to be stronger, and to bear heavy work. For example, wall painting with silica-containing nano-composite emulsion showed high performance and solvent resistance [23]. Therefore, nanotechnology can be utilized to make better beekeeping tools. For example, beehives can be painted with specific materials to protect them from sun, rain, or unsuitable conditions. Beehives provided with insulation showed higher performance than control hives under high-temperature conditions [24]. It is expected that using hives coated with specific nanoparticle insulators will have better performance and productivity than those coated with traditional insulators. All beekeeping tools can be enhanced either if coated or made from specific materials utilizing nanotechnology to be strong and suitable for various environmental conditions. Especially, climate change and the elevation of temperature are serious threats to beekeeping [25]. Additionally, beehives can be painted using hygienic materials to save the health of honey bees. Such hygienic materials can be developed utilizing nanotechnology. High growth rates of applied bacteria, detection of disease symptoms, and reduction in bee population were detected in uncoated hives while nano-silver coated hives showed efficacy to protect bees against diseases [26]. Studies are highly required to enhance the properties of beekeeping tools which greatly help the development of beekeeping.

Feeding

Honey bees depend mainly on nectar and pollen for feeding [27, 28]. Beekeepers tend to supply bee colonies with artificial feeding when few or no natural flowering plants are available. This artificial feeding is divided into two categories; sugar feeding and protein feeding. Sugar feeding is necessary for the survival of colonies especially during winter and can be prepared using different materials including honey, sugar, and water [29]. Protein feeding depends on using pollens or pollen alternatives [30, 31]. The poor feeding can cause problems to honey bees and increases the susceptibility to diseases [32, 33]. It is expected that food prepared as nanoparticles can have different properties than its normal form. This may lead to enhance the health and the digestive ability of honey bees. Therefore, studies are needed to utilize nanotechnology to prepare nano-food for honey bees especially if mixed with specific medications against gut or hemolymph pathogens.

Pollination

Pollination is very essential for many plants and honey bees are the major pollinators to many crops [34]. It is possible to use some chemicals to attract the forager bees to specific plants or to regulate foraging activity [35-37]. The properties of such chemicals including pheromones or attractants can be enhanced if prepared as nanoparticles. The pheromones prepared as nano-

particles showed efficacy in some studies, for example, chitosan nano-conjugated pheromone showed the ability to manipulating reproduction in fish [38]. Future studies on regulating foraging activity and pollination are recommended.

Swarming

Swarming is very essential for the reproduction of colonies. Natural swarming is considered a problem for beekeepers because it can weaken the colonies especially mother queens are mostly lost. Therefore, it is important to catch bee swarms utilizing some methods include swarm lures, especially pheromones have an essential role in swarming [39, 40]. Preparing swarm lures as nanoparticles can attract swarms effectively and the validity of these lures can be extended due to the changes in properties than traditional lures.

Instrumental insemination

Queen mating naturally occurs in the air and at specific areas known as drone congregation areas (DCAs) [41, 42] without human control. Thus, instrumental insemination is an essential technique to control the mating of honey bee queens [43]. The major steps of instrumental insemination depend on collecting semen from drones, narcotizing the virgin queens, and injecting the semen inside the queens using specific tools [44]. Nanotechnology can be utilized to enhance the hygienic and physical properties of instrumental insemination tools. Molecular-based targeting of cells through safe and biocompatible magnetic nanoparticles bring new possibilities in a selection of damaged spermatozoa from boar semen [45]. Nanopurification can be used as a non-invasive approach to epigenetic-based sperm selection [46]. A similar combination of biomolecular technology and nanotechnology could be used in drones' semen purification. Also, it could be a way to select sperms which are not from the bee queen's drones out of an insemination dose (genetic paternity purification).

Honey bee pests

Some hornets, beetles, and moths can attack beehives for feeding on bees or wax and stored food. These pests are geographically distributed and their damages to colonies varied from one country to another. Hornets especially from the *Vespa* genus attack flying adult bees and can invade colonies to feed on honey and bees. The invasion of new *Vespa* hornets, *Vespa velutina*, in some parts of Europe has been recently reported [47, 48]. Small hive beetles are very dangerous to bee colonies and are existed in some African, European, American, and Asian countries [49, 50]. Also, wax moths are serious pests to bee colonies, and they can destroy wax combs either inside or outside the hives [51]. Nanotechnology can be utilized to develop attractant to these pests to trap them especially various trap types with baits are available to bee pests [22, 52, 53]. Additionally, some herbal extracts and essential oils showed efficacy against wax moths [54], and some volatiles against small hive beetles [55]. These extracts can be prepared as nanoparticles to enhance their efficacy. These points require further investigations.

Mites and honey bee diseases

Some mite species attack honey bees to feed on their hemolymph. *Varroa* mites, *Varroa destructor*, attack immature and mature stages [56] while *Tropilaelaps* mites attack only immature stages [57]. Honey bees can also be infected with some bacterial, viral, *Nosema,* and fungal diseases [58, 59]. Previous studies on plant diseases have shown that nanomaterials have more efficacy than traditional ones [10, 60]. The control of these mites and some diseases can be accomplished with various techniques and materials include herbal extracts of plants and propolis or essential oils [61-65]. The efficacy of these materials can be enhanced if prepared as nanoparticles. Nanosilver 25 ppm added to bee feeding showed the ability to decrease the number of *Nosema* spores under laboratory conditions [66]. More investigations are recommended to find out developed and safe materials to control mites and diseases of honey bees. Label-free colorimetric nanodiagnostic method can be used for direct detection of unamplified *Melissococcus plutonius* DNA (the cause of European Foulbrood or EFB) using unmodified gold nanoparticles; therefore it is possible to detect the specific EFB pathogen quickly and exactly [67]. A similar principle can be used for the diagnostic of many diseases especially American Foulbrood (AFB) which presents a huge problem to honey bee colonies.

Honey bee products

Beekeepers can produce many valuable products (honey, pollen, royal jelly, beeswax, bee venom, and propolis) from bee colonies. The marketing of these products constitutes the main income source for most beekeepers. Fortunately, these products are used as human food and for medicinal purposes and can be used for industrial purposes especially beeswax. The marketing value of bee products can be increased if their efficacy is enhanced. Nanotechnology can help to improve the properties of bee products, for example using propolis as a nanofood to treat cancer [12], the nano-propolis showed more effective antimicrobial activity than Chinese propolis [13], propolis-loaded nano-in-microparticles showed enhanced anticancer activity [15]. Also, bee venom loaded chitosan nanoparticles showed efficacy against amoebiasis [68], and melittin nano-liposomes showed the ability to inhibit the survival of hepatocellular carcinoma (HCC) cells [16]. More studies are required on bee products prepared as nanoparticles to prove their efficacy against human and animal diseases, and indirectly to increase the marketing value.

DISCUSSION

Currently, there are many nanoparticles available for application in agriculture. Therefore, it is expected that the agricultural environment becomes polluted with these materials especially heavy metals used in preparing nanoparticles. Some studies showed negative impacts on honey bees include nanosilver 25 ppm added to bee feeding reduced the longevity of workers under laboratory conditions [66], and the high concentrations of ZnO NMs decreased feeding rate [69]. Also, ZnO NMs could cause metabolic impairment (decrease in total protein brain level), decrease in survival, and elevation of AChE and GST activities. That could indicate a significant effect of ZnO NMs on the neuronal system of bees [70]. The toxic effect of TiO_2, ZnO-TiO_2, and Ag-TiO_2 nanoparticles on *Apis mellifera* increased along with the increase in the concentration and the exposure time [71]. Cerium (IV) oxide nanoparticles (nCeO2s) caused sublethal changes in bees after chronic oral exposure [72], and the sublethal concentrations of CdO or PbO nanoparticles added to sugar syrup showed negative impacts on the histological and cellular structure of midgut cells of bee workers [73].

On the other side, acceptable levels of silver without risk to humans were detected in combs and honey from nano-silver coated hives [26], suggesting the safety of using nanomaterials with beekeeping tools. Nanoemulsion of hexanal showed no adverse effect on bees without causing any mortality [74, 75], and no adverse chronic effects on bees exposed to nanosized carbon black and titanium dioxide were detected on enzymatic activity, feeding, and survival [76]. Different concentrations of ZnO nanomaterials showed no impact on the survival of bees or enzymatic activity of glutathione S-transferase and the neurotoxicity biomarker acetylcholinesterase [69]. The residues of nanoparticles in bee products due to the direct applications of nanoparticles on plants have not been widely investigated. It is known that honey bees are utilized as bio-indictor for environmental pollution with different contaminants [77-79]. Thus, honey bees and bee products can be also used to monitor environmental contamination with nanoparticles. More studies either under laboratory or field conditions are required to assess the potential hazards of nanoparticles on bee behaviors, physiology, activities, the productivity of colonies, and on bee diseases and pests. In general, it could be expected that the hazards of these materials are less than traditional pesticides due to the small amounts used during field applications. However, the effects of nanoparticles on honeybees should be fully evaluated before they are incorporated into sustainable agriculture [80].

CONCLUSION

It is clear that nanotechnology is promising to develop beekeeping and can be applied in many aspects. Researchers are encouraged to perform more studies on applications of nanotechnology in beekeeping and to select the most suitable formulations to accomplish the required tasks. The potential hazards of nanoparticles on honey bees as target or non-target organisms worth additional investigations.

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