4 Agriculture and Nanoparticles

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Abstract

Herbal, animal and agricultural activities that have been applied to meet human needs in harmony with nature throughout human history have not harmed the ecosystem and have not caused environmental problems. However, the current ecosystem balance continues to deteriorate as a result of classical agricultural practices to get more products from the unit area to meet the food needs of the rapidly growing population. Therefore, new approaches to agricultural production and techniques such as nanotechnology are needed. In this context, nanoparticles that form the basis of nanotechnology have emerged as a versatile platform for solving the problems encountered. Nanoparticles have the potential in agricultural applications to be used in plant nutrition, plant and animal breeding and in the fight against herbicides and harmful insects.

Keywords

Agriculture · Nanoparticle · Field · Plant · Nanotechnology

Headings

1. The effects of nanoparticles on the growth and development of plants are important.
2. Nanoparticular fertilizers can increase the effective use of plant nutrients.

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3. Nanotechnology applications in agriculture aim to reduce excessive use of chemical-containing plant protection products.
4. Nanoparticles are important in the increase of agricultural productivity.

4.1 Introduction

The need for food to feed the population of billions of people around the world is increasing. Global climate changes, rapid population growth, and inadequate food production have begun to worry all countries. The adverse effects of excessive chemical use in agriculture for the purpose of controlling microorganisms that are responsible for virus and fungi infections, which cause diseases before and after harvesting, are still unsolved. Therefore, research is focused on the search for alternatives that may be environmentally friendly and may be effective for microbial control. Therefore, the importance of agriculture has gradually increased and the use of new techniques has become extremely important. Nowadays, traditional agriculture techniques have reached saturation, and modern agricultural technologies aimed at increasing efficiency have also ignored environmental factors especially in developing countries and have caused a damaged ecosystem. In this context, people have needed to mention crop productivity increase and sustainable environmental management; thus, novel, big, friendly and cost-effective approaches to agriculture and environment are needed for drought conditions. Today, many types of research are being carried out on the use of nanotechnology, which can help with overcoming the issues mentioned. Therefore, agricultural nanotechnology can play a fundamental role as an environmentally friendly, cost-effective green technology for sustainable agriculture. Historically, nanotechnology was developed for industrial applications half a century ago, and then the use of nanotechnology in agriculture attracted attention (Mukhopadhyay and Sharma 2013). The applications of nanotechnology in agriculture aim to reduce the excessive use of chemical-containing plant protection products and to increase nutrient intake and productivity with effective fertilization.

At least one dimension of nanoparticles which originate from nanotechnology have a minimum size of ≤100 nm and are made of metals such as silver, copper, carbon and silicon (0.1–100 nm diameter). Because of their extremely small dimensions, nanoparticles are used in many areas such as medicine, environment and energy and the food industry. They are derived from biopolymers such as proteins and carbohydrates, which have a low negative impact on human health and the environment. Biosynthesized nanoparticles are obtained from plant extracts with various analytical techniques.

Because plants contain alkaloids, flavonoids, phenols, terpenoids, alcohols and sugars, their extracts are used in the synthesis of gold nanoparticles (Siddiqi and Husen 2016).

Increasing the use areas and applications of nanomaterials is thought to cause a significant increase in their interactions with the environment and lead to very different environmental behaviours and effects of their distinctly different physicochemical properties, such as the higher surface-to-volume ratio of nanoparticles, electronic structure, intermediate surface reactivity, etc. (Ma and Wang 2010).

Nanoparticles with different concentrations can have both positive and negative biological effects. Physical nanoparticles have a less toxic effect than chemical nanoparticles (Taran et al. 2017).

Nanoparticles are effective in the fight against herbicides and harmful insects and have the ability to provide effective use of water and fertilizers in agricultural production, and are important in the increase of agricultural productivity. It is also used in the production of insecticides, insect-repellents (Bhattacharyya et al. 2010), herbicides, and fungicides (Worrall et al. 2018). However, in molecular studies, nanoparticles provide significant contributions in many areas, such as the development of a gene transferred transgenic plant such as Medicago truncatula, Zea mays, Nicotiana tabacum, Gossypium hirsutum and Oryza sativa L. that is resistant against stress factors, developing defence mechanisms against diseases caused by pathogens, etc. (Aras et al. 2015). The use of nanoparticles as biosensors in the diagnosis of plant disease has also been among the research subjects (Elmer and White 2018).

Nanoparticles can pass through the cell wall, membrane and ultimately penetrate the double membranes of chloroplasts. Thus, by injecting genes directly into plant chloroplasts, DNA transmission to the cells is possible. In a study, with gene transfer, new plants with the desired characteristics were obtained as a result of genetic modification. In some plants such as cotton, because in vitro regeneration is difficult, troublesome and complex, DNA was injected into pollen through nanoparticles, and direct transgenic seeds were obtained as a result of pollination (Zhao et al. 2018). In another study, to produce transgenic seeds of cotton directly without tissue culture, transgenic seeds were obtained by transferring the plasmid DNA loaded magnetic nanoparticles carrying functional genes to the pollens (Zhang et al. 2018). However, it was reported that when soybean was exposed to cerium dioxide nanoparticles (CeO_2-NPs), the nanoparticles caused mutations by showing a toxic effect on DNA and genes in soybean (López- Moreno et al. 2010). Another significant breakthrough of nanotechnology to ensure improvement in agricultural production is the development of insect-resistant varieties as a result of DNA transfer through nanoparticles in plants.

Nanoparticles, which have gained extensive usage, participate in the ecosystem but their environmental impact is not fully known. The number of studies that determine the effects of nanoparticles on plants that form the basis of the ecosystem is few. Nanoparticles sometimes adversely affect the ecosystem by causing toxicities on living organisms, environment and plants, i.e. by producing free radicals or reactive oxygen derivatives that can cause oxidative stress in organisms. Nano-pesticides that are very effective at even low doses and cause environmental pollution, are placed in the leaf and flower parts of plants during air transport, blocking stoma, causing a layer on the stigma that prevents pollen germination and affecting the transport of water, food and assimilation products adversely by entering the conductive tissues.

Although research has reported harmful effects on human health and environment, nanoparticles have innovative features in the economic field. Today, with the development of nanotechnology, nanoparticle availability for agriculture has increased. Because of their small sizes, wide and reactive surface areas, they can be used as bactericide, fungicide, nanofertilizers and used in the diagnosis of plant diseases and agricultural chemicals.

Pesticides used in agriculture are not very efficient, and also pollute both terrestrial and aquatic environments as a result of their widespread use. Therefore, in agriculture, a positive effect on ecology can be made by using nano-agrochemicals instead of conventional pesticides. Nano-agrochemicals containing polymeric nanoparticles, silver ions, gold nanoparticles and iron oxide nanoparticles are used as pesticides (Al-Samarrai 2012).

4.2 Effects of Nanoparticles on Plant Development

The effect of many nanoparticles on the growth and metabolic functions of plants varies according to plant species; research examining their effects on plant growth and development have been conducted, with both positive and negative results.

In agriculture, rapid and homogeneous seed germination and seedling emergence are important in terms of yield. In recent years, numerous nanoparticles have been applied as pretreatment agents to wheat (Taran et al. 2017; Li et al. 2019; Jhanzab et al. 2019), corn (Mahakham et al. 2016) and spinach (Srivastava et al. 2014) seeds to stimulate seed germination, seedling growth and stress tolerance. Mahakham et al. (2017) reported that silver nanoparticles (AgNPs) induced seed germination and starch mobilization in rice, and their work will shed light on the future of nano-priming for sustainable agricultural practices and seed industry. However, extensive studies on the physiological and molecular mechanisms of nano-priming effects on seed germination are insufficient. Therefore, further research is needed specifically to determine the effect of nanoparticles on seed germination.

It has been reported that in the (Bt)-transgenic and non-transgenic cotton plant, $Si0_2$NPs applications inhibit the growth of plants, and also that the nanoparticles are located in the xylene tissue of transgenic cotton roots, and this condition is risky for human health (Le et al. 2014) Copper oxide (CuO) nanoparticles have been reported to prevent the growth of wheat crops grown in the sand, changing the structure of the roots (Tang et al. 2016). However, starch-based nanoparticles are biodegradable and can also be used in food packaging technology (Aldao et al. 2018), which are not toxic to plants, animals or the environment, may be an alternative to the chemicals in agriculture and are suitable for sustainable agriculture (Marchiol 2018). A study concluded that carbon-based nanoparticles (CNP_S) created a physiological response in the mung bean and positively influenced its growth (Li et al. 2016).

Research has reported that zinc oxide nanoparticles (ZnONPs) are harmless at low concentrations, stimulate certain enzymes in plants, inhibit diseases (Singh et al. 2017), increase yield under cadmium (Cd) stress by increasing wheat development and photosynthesis (Hussain et al. 2018), and can be used in the fight against rice bacterial leaf blight (*Xanthomonas oryzae* pv. oryzae) (Ogunyemi et al. 2019).

Since antique times, silver and its salts have been used, and the effect of silver nitrate particles in plants is important because of their easy distribution in the environment. Silver nanoparticles have been tested for antimicrobial effects against many diseases caused by pathogens in animals and plants and are also plant growth stimulators. A study indicated that copper oxide (CuO) and titanium dioxide (TiO_2) nanoparticles in the leaves of rose plant caused an increase in the zeatin riboside (ZR) phytohormone, thereby the nanoparticles had antifungal effects against the *Podosphaera pannosa* pathogen causing powdery mildew, and that it could be used as a new plant protection strategy (Hao et al. 2019).

In a study conducted in greenhouse conditions, silver nanoparticles (AgNPs) applied to *Triticum aestivum, Brasica juncea* and *Vespertilio sinensis* plants increased the length of shoot and root in plants (Mehta et al. 2016).

Small-size chitosan nanoparticles (ChNPs) can be used in agriculture, genetic engineering, food industry, environmental pollution control, water treatment, paper production and so on. In the conducted studies, it was reported that ChNPs inhibited the growth of *Fusarium oxysporum* in vitro (Oh et al. 2019) and Cu-chitosan nanoparticles increased germination rate, shoot and root length, number of roots, seedling length and wet and dry weight (Saharan et al. 2016).

Silicon dioxide nanoparticles (SiO_2NPs) are also used in agriculture. It has been reported that these nanoparticles have an important effect on seed germination potential in tomatoes and can be used as a fertilizer source in sustainable agriculture (Siddiqui and Al-Whaibi 2014). Lack of water in drought conditions in agricultural production is an important problem. Hydrogels containing silicon dioxide nanoparticles (SiO_2NPs) can help conserve water in agricultural soils (Pathak and Kumar 2017).

In a study of barley (*Hordeum sativum distichum*), it was revealed that copper oxide nanoparticles (CuO-NPs) reduce the number of chloroplasts but increase the size of chloroplast (Rajput et al. 2018).

Titanium dioxide nanoparticles (TiO_2-NPs) can be used in nano-agriculture, but limited studies on photosynthesis are available (Dias et al. 2018). Abiotic stress factors in plants such as drought, salinity and heavy metals affect the development, germination and some physiological developments in plants. The application of TiO_2-NPs can be a promising approach in preventing the adverse effects of wheat seed germination and cadmium (Cd) stress in plant development (Faraji and Sepehri 2018).

Due to excessive and irregular use of chemical fertilizers in agriculture, many problems have occurred, such as atmospheric and groundwater pollution, decreased soil efficiency and loss of biodiversity. For this reason, instead of traditional fertilizers, environmentally friendly bio- and nano-fertilizers that tend to increase soil efficiency have been obtained with nanotechnology methods. Thus, the increase in the quantities of nitrogen and phosphoric compounds in waters (eutrophication) and groundwater pollution are prevented (Mukhopadhyay and Sharma 2013).

Nano-structured fertilizers can increase the effective use of plant nutrients through mechanisms such as being target-oriented and having slow or controlled release. In recent studies, nano-fertilizers have been reported to have the ability to control plant diseases and to increase the rate of seed germination, seedling growth, photosynthetic activity, nitrogen metabolism, carbohydrate and protein synthesis and also product quality and efficiency (León-Silva et al. 2018; El-Ghamry et al. 2018; Shinde et al. 2018; Hussein et al. 2019).

Due to the nano size of the particles, their permeation to the plant cells is too high and can be effective at very low doses. They increase the benefits of micro and macronutrients, interacting with plants and causing various physiological and morphological changes due to their different physicochemical properties. Thus, they can increase the photosynthetic efficiency of the plants and achieve higher productivity in the unit area. Magnesium hydroxide ($Mg(OH)_2$) nanoparticles help promote seed germination and plant growth in corn (*Zea mays* L.), and therefore such nanoparticles have been expressed to be used as nano-feeders for effective plant development.

4.3 Conclusion

With intensive, irregular application of traditional agriculture, enough yield can be achieved in the desired product, but natural resources are exhausted simultaneously, biodiversity is decreased and ecosystem balance deteriorates due to air pollution, water pollution and soil pollution, leading to irreversible problems. With the application of excessive agriculture such as excessive use of natural resources, faulty farming practices and unconscious and excessive use of chemical drugs in agriculture, it is inevitable to continue the loss of soil. This situation has become critical to global agricultural production. Therefore, the use of nanoparticles in agricultural nanotechnology has gained importance. A number of analytical studies should be performed to determine and characterize the intake, translocation and intracellular biotransformation of nanoparticles in plants, and further studies should be carried out to provide adequate information about the interaction between nanoparticles and plants.

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