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Nanoparticles in Agriculture: Impact on Soil Health and Crop Growth

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ABSTRACT

Nanotechnology has emerged as a promising avenue to address critical challenges in agriculture, aiming to enhance crop productivity while minimizing the environmental impact of conventional agricultural practices. This abstract provides an overview of the impact of nanoparticles (NPs) on soil health and crop growth. Engineered NPs, with their unique physicochemical properties, offer new opportunities for improving nutrient delivery, pest control, and stress tolerance in crops. However, their introduction into agricultural systems raises questions about potential adverse effects on soil ecosystems and the environment.

The use of NPs in agriculture can lead to both positive and negative consequences. Positive effects include increased nutrient availability through enhanced fertilizer delivery, improved water retention, and controlled release of agrochemicals, contributing to enhanced soil health and crop yields. On the other hand, the release of NPs into soil can pose risks such as soil contamination, alterations in microbial communities, and potential bioaccumulation in crops, with unknown consequences for food safety.

This abstract highlights the need for a balanced approach to harness the benefits of nanotechnology in agriculture while carefully considering its potential environmental impacts. To ensure sustainable agricultural practices, comprehensive research efforts must be directed toward understanding the fate and behavior of NPs in soils, assessing their long-term effects on soil ecosystems, and developing responsible guidelines for their application. Achieving this balance will be pivotal in harnessing the full potential of nanotechnology to address the growing global food security challenges while safeguarding our environment.

KEYWORDS: *nanoparticles, environmental, impact, crop, yield, potential, bioaccumulation, soil, contamination*

INTRODUCTION

In the current scenario, it is an urgent requirement to satisfy the nutritional demands of the rapidly growing global population. Using conventional farming, nearly one third of crops get damaged, mainly due to pest infestation, microbial attacks, natural disasters, poor soil quality, and lesser nutrient availability. More innovative technologies are immediately required to overcome these issues. In this regard, nanotechnology has contributed to the agrotechnological revolution that has imminent potential to reform the resilient agricultural system while promising food security. Therefore, nanoparticles are becoming a new-age material to transform modern agricultural practices. The variety of nanoparticle-based formulations, including nano-sized pesticides, herbicides, fungicides, fertilizers, and sensors, have been widely investigated for plant health management and soil improvement. In-depth understanding of plant and nanomaterial interactions opens new avenues toward improving crop practices through increased properties such as disease resistance, crop yield, and nutrient utilization. In this review, we highlight the critical points to address current nanotechnology-based agricultural research that could benefit productivity and food security in future.[1,2,3]

Nanotechnology has gained intense attention in recent years due to its wide applications in several areas like medicine, medical drugs, catalysis, energy and materials. Those nanoparticles with small size to large surface area (1–100 nm) have potential medical, industrial and agricultural applications. Scientists have carried out significant efforts toward the synthesis of nanoparticles by different means, including physical, chemical and biological methods [1]. These methods have many disadvantages due to the difficulty of scale-up of the process, separation and purification of nanoparticles from the micro-emulsion (oil, surfactant, co-surfactant and aqueous phase) and consuming large amount of surfactants [2]. Green methods for synthesizing nanoparticles with plant extracts are advantageous as it is simple, convenient, eco-friendly and require less reaction time. Nanomaterials prepared by eco-friendly and green methods could increase agriculture potential for improving the fertilization process, plant growth regulators and pesticides [3]. In addition, they minimize the amount of harmful chemicals that pollutes the environment. Hence, this technology helps in reducing the environmental pollutants [4], and nanotechnology has recently gained attention due to its wide applications in different fields such as in medicine, environment and agriculture [5]. Particularly, the large surface area offered by the tiny nanoparticles, which have high surface area, makes them attractive to address challenges not met by physical, chemical pesticides and biological control methods.

Nanotechnology in agriculture has gained good momentum in the last decade with an abundance of public funding, but the stage of development is good, even though many methods became under the umbrella of agriculture. This might be attributed to a unique nature of farm production, which functions as an open system whereby energy and matter are exchanged freely. The scale of demand of input materials is always being large in contrast with industrial nanoproducts with the absence of control over the input of the nanomaterials in contrast with industrial nanoproducts [6]. Nanotechnology provides new agrochemical agents and new delivery mechanisms to improve crop productivity, and it promises to reduce pesticide applications. Nanotechnology can increase agricultural production, and its applications include: (1) nanoformulations of agrochemicals for applying pesticides and fertilizers for crop improvement; (2) the application of nanosensors in crop protection for the identification of diseases and residues of agrochemicals; (3) nanodevices for the genetic engineering of plants; (4) plant disease diagnostics; (5) animal health, animal breeding, poultry production; and (6) postharvest management. Precision farming techniques might be used to further improve the crop yields but not damage soil and water. In addition, it can reduce nitrogen loss due to leaching and emissions, and soil microorganisms. Nanotechnology applications include nanoparticle-mediated gene or DNA transfer in plants for the development of insect-resistant varieties, food processing and storage and increased product shelf life. Nanotechnology may increase the development of biomass-to-fuel production. Experts feel that the potential benefits of nanotechnology for agriculture, food, fisheries and aquaculture need to be balanced against concerns for the soil, water and environment and the occupational health of workers [7]. Nanotechnology uses are currently being researched, tested and in some cases already applied in food technology [8]. Nanomaterials are considered with specific chemical, physical and mechanical properties. In recent years, agricultural waste products have attracted attention as source of renewable raw materials to be processed in substitution of several different applications as well as a raw material for nonmaterial production. Insecticide resistance is one of the best examples of evolution occurring on an ecological time scale. The study of insecticide resistance is needed, both because it leads to understanding mechanisms operating in real time and because of its economic importance. It has become in insects an increasing problem for agriculture and public health. Agricultural practices could include wide range of selective regimes [1]. Nanotechnology applications are being tested in food technology and agriculture. The applications of nanomaterials in agriculture aim to reduce spraying of plant protection products and to increase plant yields. Nanotechnology means like nanocapsules, and nanoparticles are examples of uses for the detection and treatment of diseases. Nanotechnology derived devices are also explored in the field of plant breeding and genetic transformation. The potential of nanotechnology in agriculture is large, but a few issues are still to be addressed as the risk assessment. In this respect, some nanoparticle attractants are derived from biopolymers such as proteins and carbohydrates with low effect on human health and the environment. Nanotechnology has many uses in all stages of production, processing, storing, packaging and transport of agricultural products. Nanotechnology will revolutionize agriculture and food industry such as in case of farming techniques, enhancing the ability of plants to absorb nutrients, disease detection and control pests.[5,7,8]

DISCUSSION

The poor awareness of the farmers in general and the excessive use of chemicals has severely affected the agricultural land as the toxic agrochemicals pollute the surface and groundwater. The increased use of chemical pesticides also eliminates beneficial microbes, insects, and other wildlife from the soil. The cumulative effect of all of the above results in major degradation of the ecosystem.

Nanoparticles Commonly Used in the Agricultural Sector

Several nanoparticles are commercially used in agriculture. Some of the commonly used nanoparticles are mentioned below:

Polymeric nanoparticles

In the agricultural sector, polymeric nanoparticles are used in the delivery of agrochemicals in a slow and controlled manner. Some of the advantages of polymeric nanoparticles are their superior biocompatibility and minimal impact on non-targeted organisms.

Some of the polymeric nanomaterials used in agriculture are polyethylene glycol, poly(epsilon-caprolactone), poly(lactide-co-glycolides), and poly (γ-glutamic acid).

Silver nanoparticles

Silver nanoparticles are extensively used for their antimicrobial property against a wide range of phytopathogens. Scientists have also reported that silver nanoparticles enhance plant growth.

Nano alumino-silicates

Many chemical companies use nano alumino-silicate formulations as an efficient pesticide.

Titanium dioxide nanoparticles

These nanoparticles are biocompatible and are used as a disinfecting agent for water.

Carbon nanomaterials

Carbon nanoparticles such as graphene, graphene oxide, carbon dots, and fullerenes, are used for improved seed germination.

Some of the other nanoparticles that are used in agriculture are zinc oxide, copper oxide nanoparticles, and magnetic nanoparticles.[9,10,11]

Agricultural Nanotechnology for the Enhancement of Crop Productivity

Nanopesticides and nanoherbicides

The application of nanoherbicides and nanopesticides for the management of weed and pests have significantly increased crop productivity. Different types of nanoparticles such as polymeric nanoparticles and inorganic nanoparticles are utilized for the nanoherbicide formulations.

Scientists have developed various routes for the efficient delivery of herbicides. For example, poly (epsiloncaprolactone) nanoparticles encapsulate atrazine, a herbicide. This nanocapsule showed strong control of the targeted species, reduced genotoxicity level, and could also significantly decrease the atrazine mobility in the soil.

Nanomaterials for disease management

Huge agricultural losses are incurred annually owing to microbial (virus, fungus, and bacteria) infections.

Nanomaterials with specific antimicrobial properties help prevent microbial infestations. Some of the common pathogenic fungi that cause diseases are Colletotrichum gloeosporioides, Fusarium oxysporum, Fusarium solani, and Dematophora necatrix.

Several nanoparticles such as nickel ferrite nanoparticles and copper nanoparticles, have a strong antifungal property and are effectively used in disease management. In the case of viral infection treatment, chitosan nanoparticles, zinc oxide nanoparticles, and silica nanoparticles are effective against viral diseases such as mosaic virus for tobacco, potato, and alfalfa.

Nanofertilizers

Scientists have used nanotechnology to design a smart delivery system that would release nutrients in a slow and controlled manner to the targeted site to tackle nutrient deficiency in plants.

Nanofertilizers increase crop productivity by enhancing the availability of essential nutrients to the plant.

A significant increase in the yields of millet and cluster beans was found after the application of nanophosphorus fertilizers in arid conditions. Chitosan nanoparticles suspensions containing nitrogen, phosphorus, and sodium have also increased crop production. [12,13,15]

Nanotechnology in seed development

Seed quality is an important factor which crop productivity depends on.

It has been observed that carbon nanotubes can enter the hard seed coat of tomatoes and significantly improve the germination index and plant growth.

Similarly, the germination percentage increased when soybean and corn seeds were sprayed with a multiwall carbon nanotube. Various nano treatments are available to enhance the germination index of plants.

Nanobiosensors

Nanobiosensors are highly sensitive and specific when compared to conventional biosensors. These devices convert biological responses to electrical responses via a microprocessor.

Nanobiosensors offer a real-time signal monitoring and are involved in direct or indirect detection of pathogenic microorganisms, antibiotic resistance, pesticides, toxin, and heavy metal contaminants. This technology is also used to monitor crop stress, soil health, plant growth, nutrient content, and food quality.

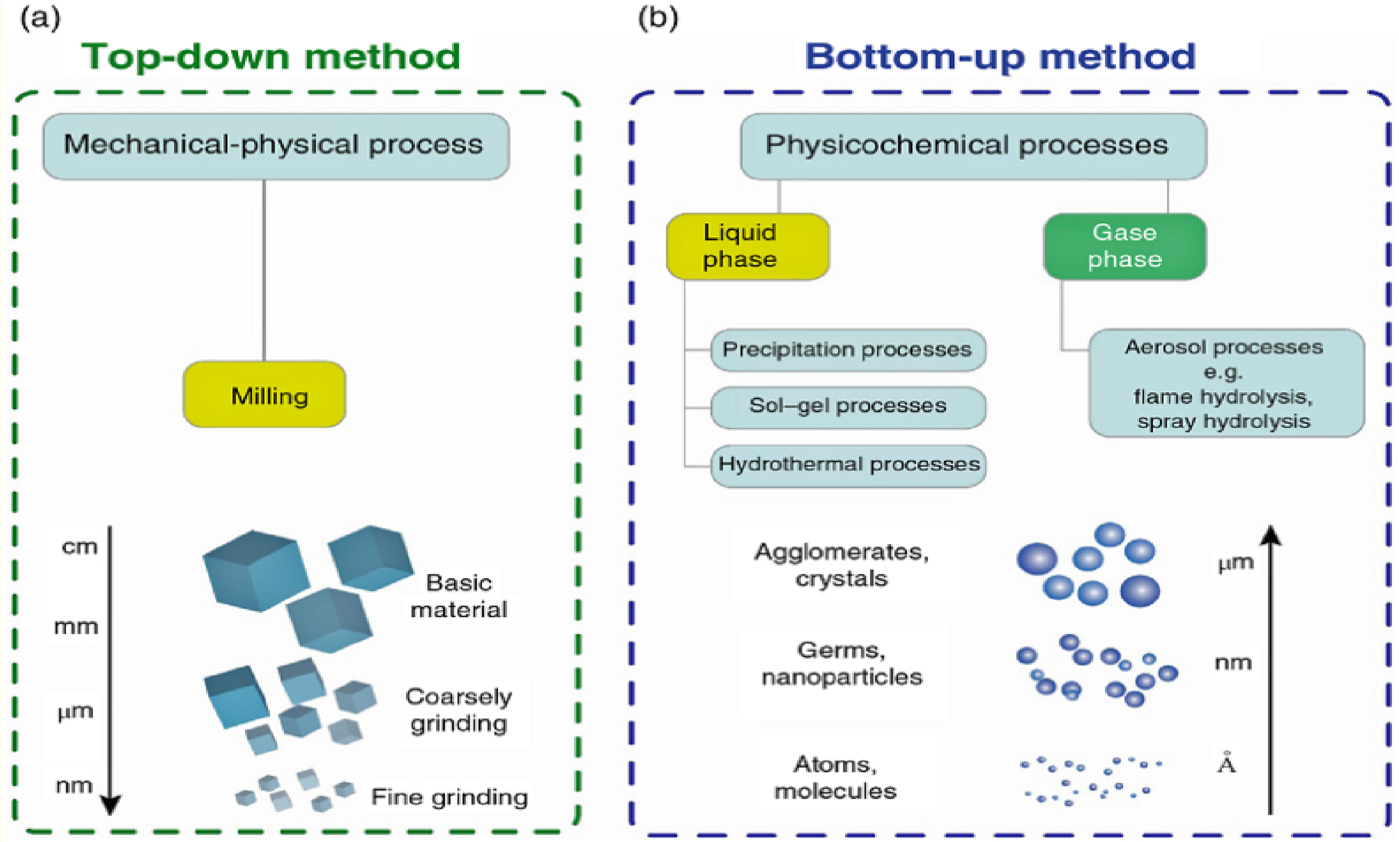
Futuristic Strategies and Policy Options for Sustainable Farming Using Agricultural Nanotechnology

The following are some of the strategies devised for sustainable farming using agricultural nanotechnology:

- Controlled green synthesis of nanoparticles
- Understanding of nanoparticles produced by root endophytes and mycorrhizal fungi, which play an important role in plant productivity and disease management
- Interaction of nanoparticles with plant system such as transport mechanism of nanoparticles inside plant body
- Critical evaluation of the negative side effects of nanoparticles on different environmental conditions
- Development of portable and user-friendly nanobiosensors for rapid analysis of soil, plants, water, and pesticides[17,18,19]
- Some of the policy options for the application of nanotechnology for sustainable development of agriculture are listed below:
- Development of special institutions with expertise for the proper evaluation for biosafety of nanoparticles
- Formation of clear guidelines following Food Safety and Standards Authority (WHO standards) for monitoring and evaluation of nanoparticle-based systems
- Proper documentation of nanomaterials-based toxicity to the aquatic organisms
- More collaborative research and sharing of resources for the development of a better research system
- For effective use of nano-based products, farmers should be educated by skilled professionals to minimize field problems.[20,21]

RESULTS

Nanotechnology can be applied via two opposite approaches that are “bottom-up” or “top-down” approach even in food technology. The top-down approach can be employed via the physical method undertaken for food and agriculturally based materials. Production of nanomaterials at a commercial scale presently employs mainly the ‘‘top-down” approach, where nanoscale materials are synthesized by size decrease of bulk precursors, via milling technique, nanolithography, or using precision engineering (De Azeredo, 2009; Sozer and Kokini, 2009). Dry milling protocol is employed to get grain flour with reduced size and hence more water-retaining ability. The top-down approach can enhance the antioxidant properties of green tea via size decreasing procedure (Shibata, 2002). According to a report, powdered green tea with 1000 nm size has higher digestion of nutrients and results in the enhanced ability for dismutase enzyme with enhanced removal of oxygen and hence elevated antioxidant activity (Sanguansri and Augustin, 2006). Another procedure called homogenization broadly used for dairy work regarding size reduction in case of globules, vaporization, and laser application associated with cooling is also supposed to be top-down protocol (Roohinejad and Greiner, 2017). The functionality of food material for the required purpose is a surface area with better properties. Top-down and bottom-up approaches are exhibited inFigure and dependent upon size reduction as finer size material possesses bigger.[22,23,25]



Schematic of the (a) top-down and (b) bottom-up approaches for making nanoparticles. Adapted from Roohinejad and Greiner (2017) with permission copyright © 2017 John Wiley and Sons.

The top-down protocol is associated with nanotechnology-based devices are monitored with external power to yield the preferred parameters and specific initiation from larger dimensions having stuff with cutting to obtain the desired size (Sangeetha et al., 2017). Using the bottom-up protocol, atoms are converted into nanoscale materials or fixed self-assemblies using complex processes. Self-assembly depends on matching attractive and repulsive forces between molecule pairs used as building blocks for manufacturing efficient supramolecular assemblies (Sanguansri and Augustin, 2006). For example, self-assemblage or grouping of casein micelle gives rise to the formation of carbohydrate-Examples of self-assembled nanostructures in food include the organization of the casein micelle, the structures formed in protein-polysaccharide liposomes, and aggregates. According to a report, the bottom-up method provides a better opportunity for the synthesis of nanostructures with fewer flaws, enhanced identical chemical arrangement, and improved organization (Pathakoti et al., 2017).[27,28,29]

Agriculture is practiced for food production via the cultivation of varied crops and raising of livestock. It is considered the backbone economy for most developing countries as a vital role in progress and development. The rising population in the world results in high demand for more food supply, and scientists and engineers are now practicing new methods to increase agricultural production (Baruah and Dutta, 2009). For the last several years, agriculture nanotechnology has focused on research and application to resolve agriculture and environmental issues sustainability, crop improvement, and enhanced productivity. Agricultural nanotechnology seems to be highly interesting for developing countries, regarding the decrease in hunger, underfeeding, and mortality rate in children (Gogos et al., 2012). Developed and emerging countries like Germany, the United States of America (USA), Brazil, China, India, France, and Korea show increased curiosity for using nanomaterials for agriculture uses as revealed via a more producing high number of publications and patents (Gogos et al., 2012).

As a potential device, nanotechnology can be applied to renovate agricultural divisions; it helps in learning the biochemical pathways of crops via modifying the conservative methods for evaluating environmental issues and its application to production improvements (Prasad et al., 2017b). Comparisons of nanotechnology with environmentally friendly technologies and agricultural biotechnology show an opportunity for enhanced and quicker influence upon all constituents of the agricultural-value linkage for synchronized public benefits, legal, moral, and environmental effects (Sastry et al., 2011). The prospective use of nanoscale agrochemicals such as nanofertilizers, nanopesticides, nanosensors, and nanoformulations in agriculture has transformed traditional agro-practices, making them more sustainable and efficient (Figure 3). Multiple applications of nanotechnology exist in agriculture including wastewater treatment, reducing the quality of polluted soil, enhance the productivity of crops via security in terms of sensors to detect pathogens (Singh et al., 2021; Axelos and Van De Voorde, 2017). For instance, nanobiosensors is the wide ranging nanotools, scaffold the growth of high-tech agricultural farms and also stand proof for the practical and proposed applications of the nanotools in terms of agricultural inputs control and their management precision (Sivarethinamohan and Sujatha, 2021; Duhan et al., 2017). The application of nanopore bearing zeolite for slow discharge and improved efficacy of enrichers, nanosensors for measuring soil quality and smooth supply mechanisms for herbicides are among positive impact of nanotechnology in agriculture (Chinnamuthu and Boopathi, 2009). Several nanoparticles used for monitoring plant diseases are nanoforms of carbon, silica, silver, and alumino-silicates. The use of nanomaterials for agriculture is proposed to reduce spraying chemicals via the smooth supply of energetic compounds. It can minimize nutrient wastage during applying fertilizer and promote the harvests by enhancing the water and ingredient management (Gogos et al., 2012). The responses of different rice cultivars exposed to engineered nanoparticles at different growth stages and under different conditions were also reported (Wang et al., 2021).[30,31,32]

About 20–40% of crops are lost due to plant pests and pathogens each year worldwide (Flood, 2010). In modern farming practices, pest management relies heavily on the application of pesticides, such as insecticides, fungicides, and herbicides. The development of cost-efficient, high-performing pesticides that are less harmful to the environment is crucial. The new concepts such as nanotechnology can offer advantages to pesticides, like reducing toxicity, improving the shelf-life, and increasing the solubility of poorly water-soluble pesticides, all of which could have positive environmental impacts (Mali et al., 2020; Worrall et al., 2018). The significance of agricultural nanotechnology, mainly for controlling diseases and safety has been reported elsewhere (Gogos et al., 2012; Rehmanullah et al., 2020; Sastry et al., 2010). Nano-based conventional herbicides and pesticides assist in the slow and continued supply of nutrients and agricultural chemicals in a controlled amount to the plants (Duhan et al., 2017). Nanoparticles may have also a key role in the control of insect pests and host pathogens (Khota et al., 2012). Type of polysaccharides such as chitosan, alginates, starch, and polyesters have been considered for the synthesis of nano-insecticides (Mali et al., 2020). In general, the use of nanoparticles to protect plants can occur via two different mechanisms: (a) nanoparticles themselves providing crop protection, or (b) nanoparticles as carriers for existing pesticides and can be applied by spray (Worrall et al., 2018). However, the use of nanomaterials in plant protection and production of food is under-explored (Prasad et al., 2017a).

Nanotechnology for the management of crops is used as an essential technology for enhancing crop productivity. Nanomaterials and nanostructures, such as carbon nanotubes, nanofibers, and quantum dots are now exploited in agriculture research as biosensors for evaluating the quality of soil and fertilizer distribution. The purpose of nanoparticles is to minimize the spread of chemicals amount, reduce the nutrient loss during fertilization, and increase the quality and yield with proper nutrient (Sangeetha et al., 2021). The development and use of vermiculite, nanoclay, and zeolite could improve fertilizer efficacy and crop production for ecological agriculture in coarse-textured (Sivarethinamohan and Sujatha, 2021). Amending sandy loam soils with inorganic amendments reduce NH_4–N passage and increasing the yield of N fertilizer in ecological agriculture systems (Mazloomi and Jalali, 2019). Nanoclay is systematized into a number of modules such as montmorillonite, bentonite, kaolinite, hectorite, and halloysite on the basis of chemical composition and nanoparticle morphology (Sivarethinamohan and Sujatha, 2021).[33,35,37]

Most of the productivity of agricultural practices is heavily dependent on fertilizer use. Studies show that crop production is linearly determined by exhaustive application of fertilizers to increase soil fertility (Rehmanullah et al., 2020). The use of nano fertilizer is crucial to enhance crop production. Nano fertilizer is a material with nanometer-size which improves the delivery to plants and managed the slow release of nutrients into the soil gradually in a highly controlled way, hence stopping eutrophication and contamination of water (Davari et al., 2017). Nanotechnology makes the exploitation of nanostructured or nanomaterials for fertilizer transport or limited release routes to construct smooth fertilizer as new opportunities to modify nutrient usage efficacy and reduce charges for environmental safety (Hai-Xin et al., 2011). Nano-fertilizer could improve nutrient efficiency through encapsulation within nanoparticles which is conducted by three methods. (a) Nutrient encapsulation within nanoporous structures, (b) Coating of thin polymeric film, or (c) Delivery in the form of particle or suspensions with nanoscale sizes (Davari et al., 2017; Rai et al., 2012). Nanoscale fertilizers could lead to the more effective delivery of nutrients as their small size may allow them access to plant surfaces and transport channels (Mastronardi et al., 2015). Nano-fertilizer extracted and prepared from banana peels were used in the growth of tomatoes, peppers, or flowers (Sivarethinamohan and Sujatha, 2021).[38,39] Nano fertilizers were used for the growth and improvement of different crops, for instance, nanoparticles of ZnO for chickpea, silicon dioxide and iron slag powder for maize, colloidal silica and NPK for tomato, TiO_2 for spinach, gold and sulfur fertilizers were used for the growth of grapes (Sivarethinamohan and Sujatha, 2021). Fertilizer usage with nanoscale transporters may be subjected in a way so that they anchor the roots of the plant with the surrounding soil contents and organic material hence decreasing chemical loss and lessening environmental issues (Dasgupta et al., 2015). Nanoscale fertilizers can decrease the toxicity of soil and hence the potential undesirable impacts accompanied by high dosage are reduced (Davari et al., 2017). Such nano fertilizers slow down the nutrients release and extend the duration of fertilizer impact (Naderi and Danesh-Shahraki, 2013). TiO_2 nanoparticles have shown a major effect on the growth of maize crop; moreover, SiO_2 plus TiO_2 nanoparticles elevated the action of nitrate and increased plant absorption potential, by controlled use of water and fertilizer with the efficient outcome (Abobatta, 2018; Sekhon, 2014).

The use of nanotechnology also facilitated gene sequencing that contributed to the improved identification and use of plant trait means, modifying their potential to respond against environmental pressures and ailments. Quantum dots and nanoparticles have proved to a biological marker associated with outstanding accuracy (Sharon et al., 2010). Optical mapping of DNA in the age of nanotechnology and nanoscopy also reported (Levy-Sakin and Ebenstein, 2013). Optical mapping of DNA grants accesses to genetic and epigenetic information on individual DNA molecules. Nanopore sequencing could allow sequencing of single DNA molecules spanning tens of kbp (perhaps up to 100 kbp) thus lifting the limitations of short-read data (Levy-Sakin and Ebenstein, 2013). In general, nanotechnologies have been applied in a variety of contexts, including genome sequencing, targeted resequencing and discovery of transcription factor binding sites, noncoding RNA expression profiling, and molecular diagnostics (Elingarami et al., 2013).

In developed countries, greater than 40% losses of food (cereals, roots and tubers, pulses and oil crops, vegetables and fruit, fish meat, and dairy) occurs at trade and customer stages, while in the case of developing countries, greater than 40% losses of food occur at post-harvest stage and processing point (FAO, 2019; Gustavsson et al., 2011). Newly harvested high moisture unpreserved yields may quickly deteriorate owing to microorganism's attack. Newer and advanced technologies such as nanotechnology can help for decreasing post-harvest losses. Nanotechnology application can minimize post-harvest losses by designing functional packing ingredients with the least quantities of bioactive constituents, improved gas and mechanical properties with a reduced effect on sensor qualities of vegetables and fruits (Flores-López et al., 2016).

Edible coatings are used as a liquid on food, generally by dipping the product in a solution-providing substance made by the structural medium (carbohydrate, lipid, protein, or mixture). They protect untreated foods from worsening via hindering dehydration, overturning respiration, refining textural features, aiding to preserve volatile aroma compounds, and decreasing the growth of microbes. Nano-coatings with edible quality deposited on different foodstuff provides a fence to gas and moisture exchange and delivering flavors, colors, enzymes, antioxidants, and browning resistant agents that may enhance the shelf life of synthetic foods (Zambrano-Zaragoza et al., 2018). The technology enables the formation of nanoscale coatings up to five nano meter thickness (Sekhon, 2010). The use of edible coatings and thin films are common for horticultural commodities. The use depends on properties like cost, availability, functional qualities, mechanical properties (elasticity, tension), photosensitive properties (brilliance and opacity), the fencing effect versus gas flow, structural hindrance to water migration, microbes and sensory suitability (Zambrano-Zaragoza et al., 2018; Falguera et al., 2011).

CONCLUSIONS

Various nanoscale edible coatings are applied to food to control the post-harvest excellence of new harvested products. Silver nanoparticles are of increasing attention recently owing to their antimicrobial properties essential for processing food. The use of PVP-based silver nanoparticles on asparagus, considerably delayed the growth of microbes, slowing the loss of weight and decreased changes in skin color (An et al., 2008). In another report, gelatin-derived edible coatings with cellulose nanocrystal considerably improved the shelf life of strawberries (Fakhouri et al., 2014). Chitosan-assisted nano-silica coating beneficially improved the physicochemical and physiological value regarding longan fruit within ambient temperature as compared to other treatments via proficiently providing an outstanding semi-permeable film (Shi et al., 2013). Moreover, chitosan film-based nano-SiO_2 (Yu et al., 2012) and alginate or lysozyme-based nanolaminate coatings (Medeiros et al., 2014) investigated to reserve the value of fresh diets during prolonged storage. Nano-ZnO coating also reduced the microbial damage and kept the post-harvest value of some fruits during storing (Sogvar et al., 2016).

Nanotechnology can also be applied in grain quality control using nanosensors (Bouwmeester et al., 2009). The sensors are capable to respond to changes in the environment during storage (temperature, oxygen exposure, and relative humidity), degradation products, or contamination by microbes. They are also applied to respond to the presence of fungus or insects in the stored grain (Axelos and Van De Voorde, 2017). Nanosensors for grain quality observing have also been developed by using polymer nanoparticles that respond to volatile agents and other analytes in an environment of stored foods and hence detect the cause and the kind of decomposition involved (Neethirajan and Jayas, 2011).[50]

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