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Recent Advancement and Impact of Nanoparticles in Sustainable Farming Practices

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Abstract

In this era of rapid urbanization and increasing population traditional-farming activities are facing various unforeseen hurdles. Due to some major drawbacks, traditional farming activities are unable to meet global food demand, necessitating the use of advanced technology to achieve food security. In this aspect, nanoparticles mediated advanced technology is an alternative tool to boost up crop production in a feasible way. Nanotechnology has a pronounced perspective to boost the status of precision farming techniques by increasing the plant-nutrient absorption level, disease detection capability, pest and pathogen control, food storage and packing, etc. Nanotechnology offers varied types of new tools for agriculture like nano-fertilizer, nano-herbicides, nano-pesticides formulations, nano-based antimicrobial solutions, and nano-sensors. Nanoparticles are considered a good carrier platform for various nano-based agrochemical formulations. It can enrich the efficacy of the site-directed delivery of nano encapsulated active ingredients. Moreover, nanoencapsulation also provides the slow and sustained release of active ingredients. In this review content, we attempt to describe the modern advancement of nanotechnologies and their application in farming to meet the increasing food demand in an eco-friendly manner.

Keywords: Traditional farming activities; Nanoparticles; Nano-fertilizer; Nanoencapsulation.

Introduction

To meet the food requirements of a large population, food grain production must be increased. In recent years, significant technological advances and innovations in the field of agriculture have been made to address the increasing challenges of sustainable production and food security (Fróna et al., 2019; Shang et al., 2019). Nanotechnology in particular can deliver effective solutions to multiple problems in agriculture. Nanotechnology has the ability to improve farming and play a crucial role in increased agricultural production. Nanotechnology can revolutionize agriculture and play an important part in the production of food and crops (Shang et al., 2019). A nanoparticle is a tiny particle (1-100 nm diameter). Nanoparticles were different from their bulk counter-part in terms of their physical, chemical and biological properties. The interest regarding nanoparticles was developed due to their unique properties like greater surface to volume ratio, better biocompatibility, etc. which makes it a 'magic bullet' (Gumber K, 2019). There are different methods to synthesize the nanoparticles, such as chemical, physical and biological (green) methods (Fig.1).

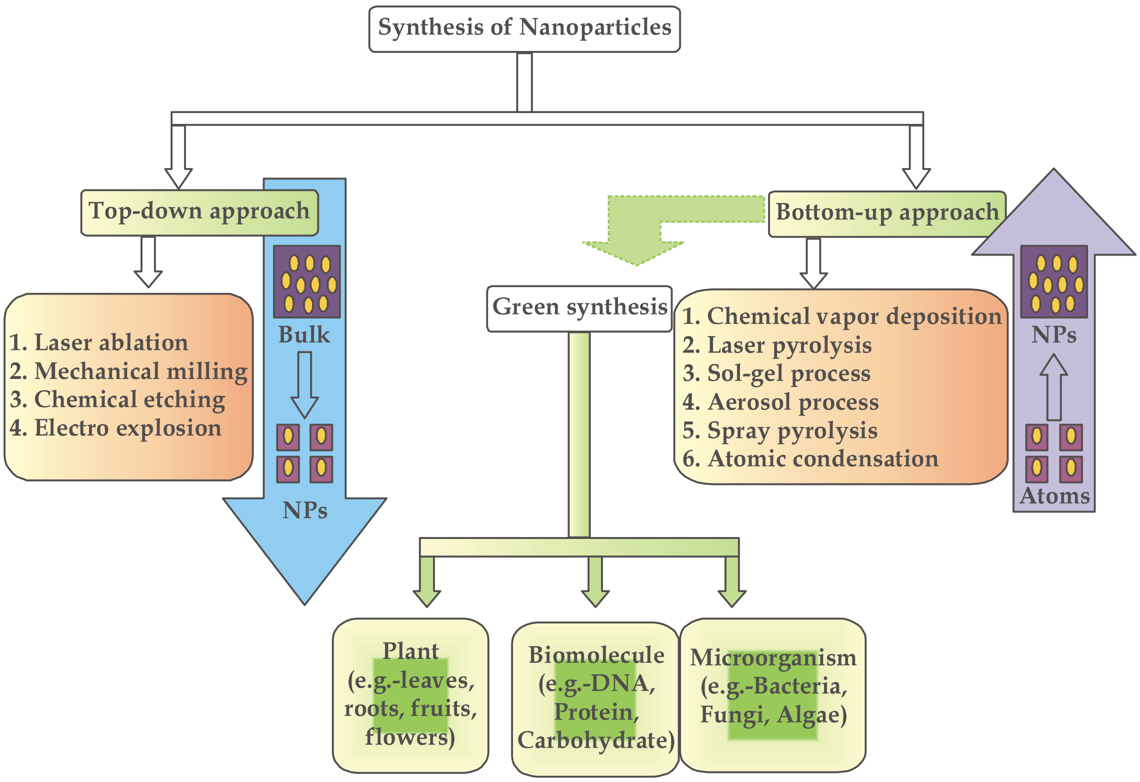

Fig.1. Different approach of the nanoparticles synthesis.

Among them, the biological synthesis is more eco-friendly and less toxic.

The synthesized nanoparticles are characterized by the help of different types of tools and techniques. The UV–Visible spectroscopy, used to determine the optical properties of nanoparticles. To know the presence of functional groups on the surface of nanoparticles, FTIR spectroscopy was used. XRD analysis was employed to know the nanoparticle crystal structure. The electron microscopy was performed to check the nanoparticle size, shape, structure, etc. (Mondal et al., 2021; Some et al., 2020).

In agricultural practices, various types of nanoparticles are used like silver nanoparticles, silicon nanoparticles, gold nanoparticles, zinc nanoparticles, copper nanoparticles, carbon-based nanostructures, etc. in the form of nano-pesticides, nano fertilizers, nano-sensors (Paramo et al., 2020; Rastogi et al., 2019). Plants can uptake the different-sized nanoparticles through their different areas (like 4-100nm-sized nanoparticles can enter into the plant system through the cuticle, plant stomata can uptake the polymeric nanoparticles (diameter 43nm), <5nm-sized nanoparticles enter the cell through the cell wall, etc.) (Mittal et al., 2020; Larue et al., 2014; Eichert et al., 2008). Moreover, different types of NPs (e.g. silver nanoparticles, zinc nanoparticles, copper nanoparticles, gold nanoparticles, carbon nanotube etc.) were used in agriculture as nanoscale delivery systems. The main role of these types of delivery systems was to slow the release of the active ingredients (e.g. pesticides, plant growth regulators, fertilizers, herbicides etc.) on their target site (Fig.2). The value of nanoscale delivery systems in agriculture is because of their increased solubility and stability against deterioration in environmental factors. The nanoscale delivery vehicles improve efficacy by attaching strongly to the plant surface and lowers the number of agrochemicals by stopping runoff into the atmosphere (Wu et al., 2008).

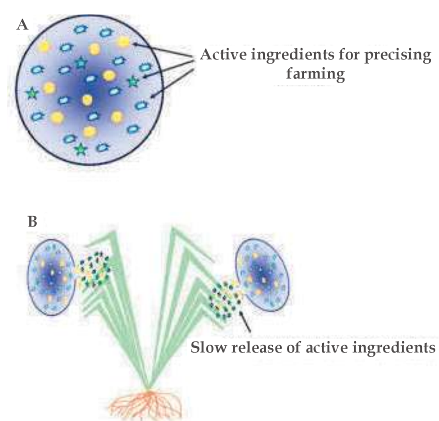

Fig. 2: (A) Nanoencapsulated active ingredients required for sustainable farming (B) Sustainable and controlled release of these Nanoencapsulated active ingredients.

Due to the unique properties of NPs, the interaction between plant and nanoparticles creates different types of alterations in plant physiological systems. The efficiency of nanoparticles depends on some factors like concentration, size, composition etc. Different types of nanoparticles show different types of plant growth-promoting attributes as well as performs their role as nano-fertilizer, nano-herbicides, nano-pesticides formulations, nano-based antimicrobial solutions, nano-sensors.

To combat nutrient deficiency in plants, scientists used nanotechnology to develop a smart transport platform that would release nutrients in a gradual and regulated manner to the target point. Nanofertilizers are considered as the nanomaterial encapsulated or covered plant nutrient, that helps to enhance plant growth and productivity (DeRosa et al., 2010). By regulating the number of vital nutrients to the plant, nanofertilizers boost crop productivity. Nanofertilizer has provided various benefits (like a) Production cost is low, maximum profit, b) Controlled and slow release of nutrients, c) Low toxicity than other chemical fertilizers, d) Optimum and sustainable production of plant yield) in agriculture. The nanofertilizers contain silver, gold, iron, silica, nano zinc, titanium dioxide, Mn/ZnSe QDs, gold nanorods, InP/ZnS core-shell QDs, ZnCdSe/ZnS core-shell QDs, core-shell QDs, etc.Silver nanoparticles (AgNPs) are the utmostextensively used commercialized nanomaterials, used in farming (Gumber K, 2019). Fungal extract (*Aspergillus fumigatus and Trichoderma harzianum*) mediated biogenic synthesized AgNPs acts as a plant growth-promoting agent. Helps to increase the tomato plant height (cm), fresh and dry biomass (g), the number of shoots per plant, yield of tomato per plant (g), the weight of root (g) (Noshad et al., 2019). It is reported that biogenic AgNPs can also increase some growth parameters (e.g. root & shoot growth, seed biomass & length) as well as biochemical properties (enhance the level of carotenoid, chlorophyll) (Gupta et al., 2018). Green synthesized AgNPs & AuNPs both have an impact on onion, helps to increase the plant height, seed germination, leaf diameter & length (Acharya et al., 2019). In the phosphorous amended soil, the TiO_2 NPs helps to improve the wheat quality by altering shoot & root length, nutrient level, protein percentages (Ullah et al., 2020). Carbon nanotubes (CNTs) were vital nanoparticles due to their distinctive mechanical, electrical, properties. The nanocarbon-based multi-walled carbon nanotubes show some growth-promoting activities (like area of the leaf, plant height, chlorophyll level) on onion (Abdul-Ameer et al., 2019).

Along with this nanofertilizer, crop production has also improved dramatically as a result of the use of nanopesticides, bactericide, nanofungicide, nanoherbicides to regulate pests and weeds. The nanoherbicide formulations use a variety of nanoparticles, including inorganic nanoparticles and polymeric. Nanopesticides allow the application of active substances to plants, distribute them evenly, and keep them stable after application. Nanopesticides have provided various benefits like a) an increase in efficiency towards pests, pathogens, b) high solubility and site-directed controlled release, c) less hazardous. Silver nanoparticles were the most used antimicrobial agents, due to their less toxic effect, higher biocompatibility, strong inhibitory and antimicrobial activities. *Phyllanthus emblica* extract mediated green AgNPs has a strong antibacterial property against rice pathogenic organism viz. *Acidovorax oryzae* strain RS-2, that causes bacterial brown stripe (Masum et al., 2019). Fungal extract (*A. fumigatus* and *T.harzianum*) mediated biogenic synthesized AgNPs can also show antibacterial activity against *Clavibacter michiganensis subsp. michiganensis* (*cmm*), which causes bacterial canker disease in the tomato plant (Noshad et al., 2019).The copper oxide nanoparticles (CuO-NPs) have antifungal activity against a plant pathogen viz. *Colletotrichum gloeoesporioides* (Oussou-Azo et al., 2020). ZnO NPs show antifungal actions against foodborne pathogenic organisms *A.fumigatus*, which can causes diseases in horticultural crops (Patra and Goswami 2012).

Nanobiosensors have real-time signal control and are used to track pesticides, disease-causing microorganisms, pollutants, soil health, nutrient content, plant growth, etc. all are monitored through this technology. The nanobiosensors are exceptionally precise and sensitive. These instruments use a microprocessor to convert the biological responses to electrical responses. Silica nanoparticles (fluorescent nano-probes) based biosensor was used to detect the Solanaceous plant pathogen, known as Xanthomonas axonopdis that can cause bacterial spot disease. Baek and his team (2017) developed an AuNPs (detection probe) based detection tool, that can easily detect the insecticide (organophosphorus) and fungicide (triazole). As per Sharon and Sharon (2008), pesticide residues can easily detect by using a carbon nanoparticles-based sensor.

Some future policy is required for the use of nanotechnology to maintain sustainable farming practices like properly maintain the standard guidelines, safety protocols, proper documentation for the use of nanoparticle-based platforms in agriculture, skilled professionals are required to minimize the hazards that can evolve during the application of nanoparticles in agricultural land etc.

Conclusion

Traditional farming activities are experiencing a number of unexpected challenges in this period of rapid urbanization and population growth. Due to numerous major restrictions, traditional farming activities are insufficient to supply global food demand, necessitating the use of modern technology to achieve food security. In this regard, nanoparticle-mediated advanced technology is a viable alternative tool for increasing crop production. Nanotechnology could be used as sensors to monitor the soil quality in agricultural fields, ensuring the health of the plants. This review outlines the current difficulties of sustainability, food security, and climate change, as well as how technological progress nanotechnology is addressing these difficulties for a more sustainable environment in order to improve agriculture.

Conflict of Interests

The authors have declared no conflict of interest.

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