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Applications of Nanotechnology in Modern Agriculture: A Review

Tanushka Mantri[1], Purushottam M. Dewang[1]

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ABSTRACT

Agriculture is the most important foundation for human civilization as it forms the basis of our food and the raw materials for several other products. Most of the people globally depend on agriculture for their survival and livelihood. Nanotechnology is finding its applications in all realms of life, thus invariably this technology is also playing a profound role in modern agriculture. This article explores how nanotechnology holds potential to revolutionize modern agriculture and provide a new approach towards effective crop management. Methods of improving crop nutrition, protection and production have also been discussed. Furthermore, it describe the uses of different nanoparticles (NP) such as silver nanoparticles (AgNP), Titanium dioxide nanoparticles (TiO_2 NP), Chitosan NP, Carbon Nanotubes, Silicon nanoparticles (SiNP) *etc.* for their various applications in wastewater management, plant growth mechanisms, food packaging, antimicrobial agents and nanosensors *etc.*

Key words: Agriculture, Antimicrobial agents, Conventional chemicals, Crop yield, Growing population, Nanoparticles, Nanosensors, Nanotechnology.

The world's population has been increasing drastically day by day and there is a need to boost the production of food by double the quantity in order to fulfill the requirements of the growing population (Acharya *et al*., 2023). This results in indiscriminate use of fertilizers and pesticides, environmental pollution, climate changeand increased energy and water demands creating significant pressure on the world's ecosystem, agricultural sector and distribution systems. For example, the yearly grain production worldwide is more than three billion tons, necessitating 187 million tonnes of 2.7 trillion cubic meters of water, 4 million tonnes of pesticides, fertilizerand more than two quadrillion British thermal units (BTU) of energy (Usman *et al*., 2020). As the world's population is predicted to reach 9.6 billion people by 2050, the demand for food is predicted to rise by 70% to 100%. In order to fulfill the rising need for food, the majority of the water utilized globally now is devoted to food production. By 2050, this percentage is expected to increase by approximately 83% (Rodrigues *et al*., 2017). Thus there is a need to optimize the use of agricultural inputs such as water, pesticides, fertilizers *etc.*

Modern science and technology have made it possible to transform the situation for the better. Scientists are exploring nanotechnology as a new source of innovation for improvement in agriculture (Pattanayak and Das, 2022). It encompasses the creation, control and utilization of materials with dimensions ranging from smaller than a micron to the scale of individual bulk atoms (Singh and Prasad, 2017). Due to their extremely small size and high surface to volume ratio, nanoparticles have distinct chemical and physical properties than the original particles. These characteristics make them suitable to use as chemical sensors, fertilizers and pesticides, biosensors, antimicrobial agents, detectorsand nanocomposites.

[1]Department of Research and Development, CropG1 Agro Research and Development Pvt. Ltd, Bengaluru-562 123, Karnataka, India.

Corresponding Author: Purushottam M. Dewang, Department of Research and Development, CropG1 Agro Research & Development Pvt. Ltd, Bengaluru-562 123, Karnataka, India.
Email: dr.purushottam@cropg1.com

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These nanoparticles hence can be used to enhance the crop yield, nutrition and protection (Kaushik and Djiwanti, 2017). While substantial research exists within this domain, a comprehensive literature review addressing the diverse applications of nanotechnology across various agricultural sectors becomes of paramount importance. This article demonstrates the uses of nanotechnology in different fields of agriculture such as fertilizers, pesticides, plant growth mechanisms, wastewater treatment and food packaging. Different types of nanoparticles along with their applications are highlighted. This review is aimed to provide a clear understanding and scope of nanotechnology in modern agriculture for scientists and researchers.

Nanotechnology in agriculture

Nanotechnology is a set of procedures and technologies used to create engineered nanoparticles and devices with minimum dimensions of less than 100 nm. Applications for nanomaterials are distinct due to their size-dependent properties (Kale *et al*., 2021). Properties such as the chemical composition, morphology, surface characteristics, surface charge, behavior, extent of particle aggregation, or dispersion

play a pivotal role in influencing the toxicity of nanomaterials, alongside their size. Interdisciplinary research in nanotechnology is a vast area. It possesses a wide range of potential in fields like agriculture, pharmaceuticalsand electronics. With new instruments for the molecular management of diseases, quick disease diagnosis, improving the capacity of plants to absorb nutrients, *etc.* nanotechnology has the potential to change agricultural practices significantly. The nanoparticles can be synthesized by physical, chemical or biological methods (top-down or bottom-up approach) (Singh and Prasad, 2017).

Nanoparticles (NPs) interact with plant cell walls, where functional compounds like carboxylate, phosphateand others form complex molecules, facilitating selective NP absorption. Cell walls act as semipermeable barriers, allowing smaller NPs to pass while sieving out larger ones. NPs can penetrate through cell wall pores, increasing wall permeability and promoting absorption. After breaking through the cell wall, NPs enter the plant via endocytosis and interact with organelles in the cytoplasm (Mishra *et al*., 2014, Rai *et al*., 2018).

Pros and cons of nanotechnology in agriculture

Nanotechnology offers diverse benefits such as enhancing agricultural yield and the quality of product, treatment of wastewater and enabling sensor applications. Progress in nano sensor development facilitates the detection of disease-causing agents, toxins, nutrients in foodand heavy metals in the environment, making it more accessible and cost-effective (Kumar *et al*., 2019). The use of nanotechnology in agriculture has enormous potential and improves living standards (Chandrika *et al*., 2018). The progress in agriculture owes much to the efficient use of nanomaterials, which require smaller amounts compared to traditional ones. Beyond their direct impact as nanopesticides and targeted delivery systems for active ingredients, some nanomaterials also play a distinct role in enhancing plant functions, developmentand metabolism by acting as artificial organs (Teoh *et al*., 2015). In animal agriculture, nanoparticles may find use as anti-inflammatory, antiviraland anti-cancer medications and also as promising techniques for animal sciences, veterinary medicine, drug delivery, illness detectionand vaccine development, indicating a wide range of potential applications in animal breeding (Wang *et al*., 2022; Kumar *et al*., 2023). Additionally, NPs may lower the requirement for preservatives and remove animal-irritating feed odours (Reddy *et al*., 2020).

The diagnosis and treatment of animal reproductive issues, the identification of estrusand the isolation and freezing of sperm are just a few of the animal breeding and reproduction applications that have made extensive use of nanotechnology (Wang *et al*., 2022). But nanotechnology also has few constraints. Nanomaterials, upon entering the soil system, have the potential to influence both soil quality and plant growth. The composition of the roots was altered by the application of nanoparticles and uptake through the root apertures, which had an impact on the uptake of nutrients into plant roots (Chandrika *et al*., 2018). Animal health is also impacted by nanoparticles because they can contaminate food chains and drinking water sources. Current *in vitro* and animal research has demonstrated that an excessive build-up of NPs causes harm to cellular organs, including the liver, spleen, kidneys and respiratory system and the reproductive system which can be hazardous (Surendhiran *et al*., 2020). The accumulation of NMs and toxins in edible animal products, such as eggs or meats, may have an indirect negative impact on human health, is another significant concern (Hill and Li, 2017).

Different nanoparticles in agriculture

Depending on the physiochemical properties, many nanoparticles (NP's) are finding interesting applications in agriculture (Fig 1). Some of the recent developments are discussed as follows.

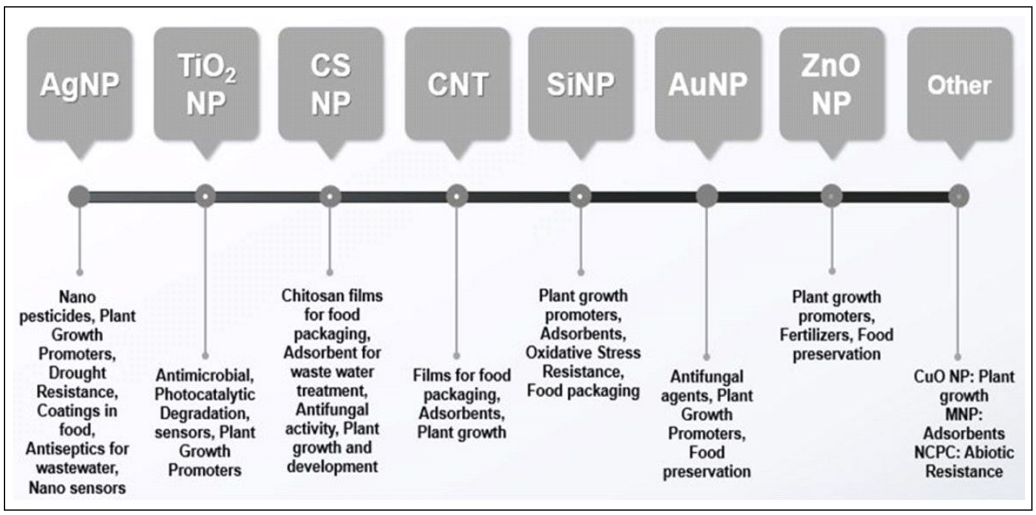

Fig 1: Applications of different nanoparticles in agriculture.

Silver nanoparticles (AgNP)

Researchers have been investigating the applications of silver nanoparticles in agriculture (Kale *et al*., 2021, Panpatte and Jhala, 2019). AgNP's are usually synthesized by chemical method, (utilizing both organic and inorganic dyes), physical methods (such as evaporation-condensation and laser ablation), biological methods and photochemical methods. They possess excellent properties such as antibacterial and antimicrobial efficiencies, photosynthetic activities, slow release of nutrients *etc.* (Khan *et al*., 2023). They find several potential applications like antimicrobial agents, food packaging, plant protection, growth and development along wastewater treatment (Javad, 2020). AS Alif Alisha and S Thangapandiyan found out that the malathion-based AgNPs showed the maximal pesticidal activity against *Tribolium castaneum*, according to the results of the mortality tests, repellent action, antifeedant testsand ovipositional deterrency (Alisha Alif and Thangapandiyan, 2019). AgNPs may adhere to cell walls and membranes of the pest and cause damage to intracellular organelles like mitochondria and ribosomes as well as biomolecules like proteins, lipidsand DNA. They also modify the signal transduction pathway and hence kill the pests (Mostafa *et al*., 2018). In the case of fenugreek, very promising results were observed as plant growth promoters. It was found out that shoot dry weight, number of plants/leavesand shoot length along with the other biochemical features, like the content of indole acetic acid (IAA) and photosynthetic pigments (chlorophyll a, chlorophyll band carotenoids) have been improved by foliar AgNPs treatment at 20, 40 and 60 mg/l (Sadak, 2019). In another example, AgNPs enhanced growth parameters like shoot length and fresh and dry weight, which helped lentils maintain water balance under drought stress. Based on the findings of these tests, it was determined that using AgNPs improved lentil germination in drought-like conditions (Hojjat and Ganjali, 2016). AgNP has also shown effective treatment against abiotic stresses like salt and drought stress. Wahid *et al*. (2020) showed that by applying AgNP and NaCl together reduced the amount of electrolyte leakages (EL), thiobarbituric acid reactive compounds (TBARS)and hydrogen peroxide (H_2O_2). In reaction to the detrimental effects of salt, *Glycine max* (L.) strengthens their antioxidant defenses (Wahid *et al*., 2020). An *et al*. (2008) also showed the application of AgNPs-PVP coating on the preservation of green asparagus. Asparagus skin color changes were reduced, ascorbic acid and total chlorophyll levels were held steady, the growth of microorganisms was inhibitedand the asparagus's shelf life at 2 degrees Celsius was extended by about 10 days because of to the coating of AgNPs PVP (An *et al*., 2008). They are also used as excellent biocides which are widely employed as antiseptics to eliminate wastewater's microbiological and pathogens infections. Additionally, they can be employed in the process of purifying water as decontaminating agents. Silver Nanoparticle-Based chemiluminescent (CL) sensors are used for the identification of pesticides. The basis of this CL sensor array is the simultaneous use of the triple-channel characteristics of the H_2O_2 CL system and luminol-functionalized silver nanoparticle (Lum-AgNP), which include the CL peak value, emission durationand intensity, all of which can be determined by a solitary experiment. At a dosage of 24 μg/ml, five organophosphate and carbamate pesticides-dimethoate, dipterex, carbaryl, chlorpyrifosand carbofuran have been clearly identified with this sensor array. With a 95% accuracy rate, 20 samples of unidentified pesticides have been successfully identified (He *et al*., 2015). From the above examples it is evident that AgNP's are gaining substantial importance in a wide range of aspects in agriculture.

Titanium dioxide nanoparticles (TiO_2 NP)

Titanium dioxide nanoparticles, referred to as TiO_2 NP's, find versatile applications in agriculture, with their photocatalytic properties playing a major role in the reduction of various microorganisms by reacting with H_2O or hydroxide ions deposited on the surface upon activation from UV radiation to form hydroxyl radicals (OH) or decrease O_2 to generate ions of superoxide. In the presence of UV radiation and TiO_2, other reactive oxygen species (ROS) have also been discovered, including hydrogen peroxide (H_2O_2) and singlet oxygen and hence decrease the microbial population (Javad, 2020; Long *et al*., 2014). These nanoparticles have several properties that include antimicrobial activity, higher refractive index and their ability to absorb ultraviolet light and have the ability to accomplish the mineralization of organic chemicals, insecticidesand other contaminants in hydroponic cultures and in simulated environments (Kaningini *et al*., 2022). They can be synthesized by several methods including electrochemical method, biological method (plants), chemical (sol gel method) (Anandgaonker *et al*., 2019; Al-Taweel and Saud; 2016; Subhapriya and Gomathipriya, 2018). In agriculture they find applications in several fields such as antimicrobial agents, plant growth promoters, sensors *etc.* Waghmode *et al*. (2019); Akbari Shorgoli and Shokri, (2017) determined the effect of TiO_2 NP on imidacloprid pesticide in an aqueous solution and checked for the photocatalytic degradation of the pesticide. TiO_2 nanoparticles mounted on a glass plate and exposed to UV light were used to break down imidacloprid. The results obtained proved that TiO_2 had remarkable photocatalytic efficiency for the elimination of imidacloprid from the aqueous solution in the presence of UV-C light irradiation. The starting concentration of 20 mg/l imidacloprid, pH = 5 and light intensity of 17 W m^2 produced the best functionality for imidacloprid removal (R%=90.24) after 180 min. TiO_2 NP can be used as sensors. Pang *et al*. (2016) created a cellulose/TiO_2-polyaniline (PANI) hybrid composite through P-N heterojunctions to enhance ammonia-sending properties in a home-made test system at room

temperature. They reported that the P-N heterojunction at the interface of PANI and TiO_2 nanoparticles gave the cellulose-TiO_2-PANI sensor a higher gas sensitivity performance than the cellulose-PANI sensor. In an experiment on mung 2 bean (*Vigna radiata L*.) and showed that 14-day-old mung bean plants were sprayed with 10 mg/l of TiO_2 NPs via foliar application. The treatment of TiO_2 NPs resulted in a considerable improvement in the following parameters: length of the shoot (17.02%), root length (49.6%), root area (43%), root nodule (67.5%), chlorophyll content (46.4%)and total soluble leaf protein (94%). Due to the application of TiO_2 NPs, the microbial population in the rhizosphere rose by 21.4-48.1%and activity of the enzymes acid phosphatase (67.3%), alkaline phosphatase (72%), phytase (64%) and dehydrogenase (108.7%) was detected over control in plants that were six weeks old (Raliya *et al*., 2015). To sum up, the use of TiO2 NPs in agriculture is extensive and has many uses.

Chitosan nanoparticle (CS NP)

Chitosan is a naturally occurring biopolymer that is non-hazardous and biodegradable, which is obtained when chitin is deacetylated. The degree of deacetylation and molecular weight of chitosan are the primary indicators of its chemical and physical characteristics (Al-Dhabaan *et al*., 2018). In a study where banana puree films with chitosan nanoparticles (89 nm) and pectin (used as a plasticizer) were compared with the control (films without any pectin and nanoparticle additions). The incorporation of nanoparticles significantly improved the mechanical properties and acted to reduce the water vapor permeation rate by 21% for films processed with pectin and up to 38% for films processed without pectin (Martelli *et al*., 2013). Chitosan nanoparticles have been found as a potentially effective adsorbent for the removal of hazardous pollutants from wastewater due to its characteristics Shukla *et al*. (2013); Naim *et al*. (2016) showed that in contrast to $CuSO_4$, the biosorption of the CS NPs membrane was 59.8 from a 12.5 g/l solution because of the existence of many functional groups other than amino and hydroxyl groups, was able to biosorb 70.68 and 42.1 proportion of NaCl from 9.38 and 15.2 g/l salt solutions, respectively. The antifungal activity of oleoyl-chitosan (O-chitosan) nanoparticles in a dispersion system against numerous plant pathogenic fungi was examined. *Nigrospora sphaerica*, *Botryosphaeria dothidea*, *Nigrospora oryzae*and *Alternaria tenuissima* were chitosan-sensitive, whereas *Gibberella zeae* and *Fusarium culmorum* were chitosan-resistant hence proving the antifungal property (Xing *et al*., 2016). They are also used for plant growth and development. (Li *et al*., 2019) conducted a systematic study with varied concentrations (1-100 g/ml) of CS NPs and chitosan (CS) to examine the effect and mechanism of chitosan nanoparticles (CS NPs) on wheat (*Triticum aestivum L*.) germination and seedling growth. At a lower dose (5 g/ml), CS NPs promoted growth more than CS (50 g/ml). Furthermore, the application of 5 g/ml CS NPs increased the expression of auxin-related genes, accelerated indole-3-acetic acid (IAA) production and transportand decreased IAA oxidase activity, resulting in an increase in IAA concentration in wheat shoots and roots. To summarize, the exceptional adaptability of chitosan nanoparticles across a range of applications underscores their potential as environmentally friendly remedies for a sustainable agriculture.

Carbon nanotubes (CNT)

Carbon nanotubes (CNTs) are carbon allotropes with a cylindrical nanostructure. Carbon atoms derived from hydrocarbons or graphite are used to structure them. CNTs can be 100 times stronger than steel yet only one-sixth the weight, making them capable of reinforcing any material (Vithanage *et al*., 2017). They can be synthesized by various methods including arc discharge, laser ablationand chemical vapor deposition (Prasek *et al*., 2011). Because of their appealing physiochemical properties such as small size, high surface areaand excellent mechanical and thermal strength, carbon nanotubes (CNTs) are one of the most promising carbon-based nanomaterials, providing improved potential for agriculture sector applications (Safdar *et al*., 2022). It was shown that PVA (poly vinyl alcohol) nanocomposite films were produced with different quantities of zinc oxide-doped multiwalled carbon nanotubes (MWCNTs-ZnO). The nanocomposite film's tensile strength was 116% greater than that of the PVA film. The nanocomposite films outperformed pure PVA in terms of thermal stability, water vapour transmission rate, hydrophobicity and antibacterial activity. Water loss tests conducted on vegetables at room temperature indicated that vegetables packed in these films could retain more water for up to four days. Tests on the shelf life of chicken meat packed in films revealed that the growth of natural microorganisms in raw chicken stored in the refrigerator′s storage may be suppressed for at least 36 hours with the use of these films (Wen *et al*., 2022). One of the well-researched nanomaterials utilized for the purification of wastewater is carbon-based nano adsorbents. CNTs have a wide variety of distinctive characteristics, including a highly reactive surface chemistry and multiple adsorption sites. These CNTs can be utilized to find and get rid of a number of non-biodegradable contaminants, helping eco-friendly agricultural practices and can also be used to locate and remove a variety of non-biodegradable pollutants. Javad (2020); Yang *et al*. (2013) reported the production of plasma-modified ultra-long CNTs, which had better salt adsorption properties than conventional decontamination techniques. Khodakovskaya *et al*. (2013) showed that Tomato plants cultivated in CNT-enriched soil generated twice as many blossoms and fruits as those produced in control soil. With rising CNT concentrations, the relative abundances of Bacteroidetes and Firmicutes grow, whereas Proteobacteria and Verrucomicorbia diminish. As a result of their exceptional chemical and physical characteristics, carbon nanotubes (CNTs) are extremely sought after material for a variety of uses in agriculture.

Silicon nanoparticles (Si NP)

Silicon nanoparticles have unique physiological properties that allow them to penetrate plants and alter plant metabolism. Because of their mesoporous nature, silicon nanoparticles are also good prospects as suitable nanocarriers for various compounds that may aid in agriculture (Rastogi *et al*., 2019). These nanoparticles can be synthesized using sol gel method through a simple acid pretreatment (chemical method), silica nanopowders can also be produced from various types of rice husk ashes (Rahman and Padavettan, 2012; Sankar *et al*., 2016). They are used for plant growth, as antimicrobial agents, sensors, slow releasing agents, in food packagingand also against abiotic stresses (Rastogi *et al*., 2019). Mesoporous SiO_2 NPs were applied to wheat plants at concentrations of 500 and 1000 mg/l, which enhanced the germination of the seeds and increased biomass volume, total protein contentand the content of chlorophyll along with enhancing the seedling photosynthetic activity (Sun *et al*., 2016). These nanoparticles can be used as adsorbents to remove harmful dyes from aqueous solutions. Methyl green was extracted from aqueous solutions using the sulfonic acid-functionalized KIT-6 magnetite mesoporous silica nanoparticles ($Fe3O_4$ @ SiO_2 @ KIT-6-SO_3H NPs) as an adsorbent. Based on the experimental findings, approximately 96.4% of the dye had been eliminated from aqueous solutions in 10 minutes at an adsorbent quantity of 3.2 g/l, pH = 3 and ionic strength = 0 (Danesh *et al*., 2018). They are also used as fertilizers. Oxidative stress or cell membrane damage was not seen even at 2000 mg/l. *Zea mays* L. plants grew taller and produced more leaves, as well as more wet and dry weight, when NPK fertilizer and NanoChisil (fertilizer CS NPs and SiO_2 NPs) were applied together. The best results were seen when the ratio of 25% NanoChisil to 75% NPK was used Pertaminingsih *et al*. (2018); Dong *et al*. (2022) by covalently grafting gallic acid onto silica nanoparticles, two modified silica nanoparticles (SiO_2-GA NPs) were successfully synthesized. The mechanical capabilities, water vapor barrier propertyand UV light barrier capabilities of the hybrid films were greatly improved as compared to the chitosan film. Furthermore, the incorporation of the two modified silica nanoparticles boosted the antioxidant activity of the composite films substantially. As a result, 1-SiO_2-GA NPs can be employed to create innovative antioxidant food packaging composite films. In conclusion, silicon nanoparticles, particularly those with mesoporous characteristics, exhibit unique physiological properties that make them versatile in agricultural applications.

Gold nanoparticles (Au NP)

AuNPs are one of the most important nanoparticlesand they have been widely employed as suitable material for agricultural applications due to their unique characteristic features such as inertness, biocompatibilityand especially low toxicity (Hammami and Alabdallah, 2021). Gold nanoparticles can be synthesized by biological methods (microbes) (Menon *et al*., 2017), radiation technologies and chemicals (Freitas de Freitas *et al*., 2018). They can be used as antifungal agents, plant growth promoting agents (Graily-Moradi *et al*., 2020), food packaging materials (Chowdhury *et al*., 2020). Numerous investigations assessed the antifungal properties of AuNPs produced using chemical and environmentally friendly methods against *Candida albicans*. Strong antifungal effects of AuNPs have been demonstrated with size, shapeand concentration serving as the main factors of fungicidal activities (Paidari and Ibrahim, 2021). The produced polyhedrons and disks of gold nanoparticles (25-30 nm) were studied by Wani Ahmad and the outcomes demonstrated strong antifungal action against *Candida albicans* (Wani and Ahmad, 2013). Under field conditions, experiments were conducted to find out how Gold nanoparticles affected Brassica juncea's growth profile and yield. Through foliar spraying, five distinct doses of gold nanoparticles (0, 10, 25, 50 and 100 ppm) were sprayed. The nanoparticle treatment had positive impacts on growth and yield-related metrics, such as height of the plant, diameter of the stem, branches number, number of pods, seed production, *etc.* (Arora *et al*., 2012). Chowdhury *et al*. (2020) reported the successful independent incorporation of graphene oxide (GO) and gold nanoparticles (AuNPs) into the poly (vinyl) alcohol (PVA) cross linked composite films. With PVA-glyoxal-AuNPs composite film for food preservation, banana shelf life has enhanced significantly and its applicability in food packaging have been confirmed (Chowdhury *et al*., 2020). Due to their distinctive characteristics, AuNPs are one of the most significant nanoparticles and have been used extensively as a suitable material for agricultural purposes.

Zinc oxide nanoparticles (ZnO NP)

Zinc oxide is a necessary component of several enzymes. The broad band gap of its microcrystals makes them highly effective light absorbers in the ultraviolet (UV) portions of the spectrum. The shape, particle size, exposure duration, concentration, pHand biocompatibility of zinc oxide all affect biological processes. They are also known to exhibit strong antimicrobial capacity (Siddiqi *et al*., 2018). ZnO NPs can be produced chemically using a variety of techniques, including the hydrothermal process, vapor transfer methodand precipitation method, biogenic synthesis utilizing various plant extracts (Sabir *et al*., 2014). Prasad *et al*. (2012) carried out an experiment where different zinc oxide nanoparticle concentrations were applied to peanut seeds. ZnO at a concentration of 1000 parts per million (nanoscale; 25 nm is the typical particle size) was treated to increase seed germination and seedling vigor. This resulted in early soil establishment, as seen by early blooming and higher leaf chlorophyll content. The growth of roots and stems was effectively enhanced by these particles. When compared the pod yield per plant to chelated bulk $ZnSO_4$, it was 34% higher. It can also be used as a fertilizer, (Raliya and Tarafdar, 2013) in order to increase native

phosphorus-mobilizing enzymes and nano induced gum synthesis, ZnO nanoparticles were examined on clusterbean (*Cyamopsis tetragonoloba* L.). The 14-day-old cluster bean plants were treated foliarly with 10 ppm concentration of the specified ZnO nanoparticles. Significant increases in plant biomass (27.1%), total soluble leaf protein (27.1%), shoot length (31.5%), root length (66.3%), root area (73.5%) and chlorophyll content (276.2%). After reaching maturity, the gum content of clusterbean seeds increased by 7.5%, indicating the presence of ZnO in nano form. It was found that by using a Trojan-horse tactic and reactive oxygen mechanism, ZnO NPs added to biopolymer packaging materials significantly increased the antibacterial activity against foodborne pathogens and extended food shelf life. By reducing the amount of oxygen in the headspace, ZnO NPs enhance the antioxidant activity of the packing materials in addition to their antibacterial properties (Zare *et al*., 2022). Thus, zinc nanoparticles are used because of their wide spectrum of potential in order to achieve sustainable agriculture.

Miscellaneous

Besides the above mentioned nanoparticles, there are several other nanoparticles that have application in agriculture, some of them include CuO NP, Magnetic Iron Oxide Nanoparticles (MNP), Nanoclay *etc*. A study showed that CuO NPs (<50 nm) supplied in solution culture as well as in the form of spray enhanced the growth of *Z. mays* plant by 51% compared to the control and significantly affected the activity of glucose 6-phosphate dehydrogenase and the pentose phosphate pathway of maize plant Adhikari *et al*. (2016); Xu *et al*. (2019) experimented with magnetically recoverable carboxylated magnetic iron oxide nanoparticles (MNPs-COOH) with a well-formed nanostructure. The strongest binding with the carboxyl groups on the MNPs-COOH surface was shown by the adsorption of the metal cadmium (Cd^{2+}), which showed the strongest resistance to the impacts of external influences. The bacterial cellulose used to make the packaging films was synthesized from cashew apple juice, together with lignin (up to 15% (w/w) and cellulose nanocrystals (up to 8% (w/w) all of which were derived from waste cashew tree pruning fibers. The films that were created had improved tensile characteristics and had a lower water vapor permeability. The films improved antioxidant and UV-absorbing properties made them desirable for food packaging that is vulnerable to lipid oxidation (Sá *et al*., 2020). In a study, it was observed that Nanoclay Polymer Composite (NCPC) offers potential agro-biotechnological applications for improving the efficiency of input utilization, particularly for water and fertilizer in the presence of abiotic stress. The study also discussed how different bioagents, such as *Trichoderma harzianum* and *Pseudomonas fluorescens*, can be encapsulated and loaded through NCPC to control fungal-nematode disease complexes (Mukhopadhyay and De, 2014).

CONCLUSION

This article gives a glimpse of all the nanoparticles that can be used in the agricultural sector such as AgNP, TiO_2 NP, ZnO NP, Chitosan NP, Carbon NT *etc.* that have proved to have potential applications as nanofertilizers, nanopesticides, as adsorbents for heavy metals in the treatment of wastewater, as films for packaging in the food industry and as plant growth promoters. Hence from all the above examples, it is confirmed that nanotechnology plays a vital role in the agricultural sector. The use of the conventional chemicals, pesticides and fertilizers can be reduced by the nanoparticles which enhance the efficiencies, yields and production of the crop with minimum toxicity and reduced amounts. The use of nanotechnology is vast in agriculture such as antimicrobial agents, wastewater treatment, food industry *etc.* Because of such new innovations, it is possible and hence it is possible to overcome the biological limitations of traditional farming by combining cutting-edge technologies with innovative sustainable farming systems.

Conflict of interest

The authors declare that they have no conflict of interest.

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