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Role of Metallic Nanoparticles as Plant Growth Promoter

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ABSTRACT

Nanotechnology does have a vast range of scientific and agricultural applications. Agriculture both directly and indirectly produces food for mankind. With the world's population booming, it's more imperative than ever to adopt cutting-edge agricultural technologies like nanotechnology. Nanotechnology allows plants to make better use of water, insecticides, and fertilizers. Nanotechnology is described as materials that work at a scale of 100 nanometers or smaller. NPs can be employed as a "thrilling shot, containing herbicides, nano-pesticide fertilizers, or genes" that target certain plant organelles and disseminate their contents. The processes by which nanoparticles influence plant growth and development have received considerable attention. As a corollary, the current research concentrates on the effects of nanoparticles on plants. Nanotechnology will modernize agriculture and food engineering by introducing the latest course of actions such as precision farming, improving plants' aptness to absorb nutrients, more efficient and cost-effective input maneuvers, disease control and prevention, resistance to environmental pressures, and appropriate dispensing, storage, and packaging systems. In this review, we highlight the importance of nanoparticles and their applicability in the agriculture region as an enhancer for plant growth and development.

INTRODUCTION

Nanotechnology is fetching and a prompt promising field that emphasizes the production and use of particles at 1-100nm size. Because of their precise peculiarities such as dimension, form, and deployment, these nanomaterials have grabbed more attention from researchers across the deck (Zargar et al., 2011).

Different physical and chemical approaches are established aimed at nanoparticle (NPs) fabrication. Nevertheless, these procedures have certain pitfalls and pollute the surrounding region. Therefore, biological synthesis of NPs through bacteria, algae, fungi, and higher plants has begun as cost competent and milieu pleasant substitute technology (Makarov *et al.*, 2014);(Siddiqi, ur Rahman, & Husen, 2016). Because of the inclusion of phytochemicals (bioactive compounds) in plant extracts, no additional capping mediator is required for the assembly of MONPs. For human life, plants always show a crucial part. 25% of the pharmaceutical drugs are plant-based and its application accounts for almost 70% of disease treatments such as cancer or other infectious diseases (Perassolo *et al.*, 2017). Because medicinal plants are the cornerstone of traditional prescriptions, modern medicines are also based on them. Herbal medicines, according to the WHO, meet 80% of human healthcare prerequisites in remote areas, where many people have been disillusioned by conventional practice and are looking for alternatives (Hosseinzadeh, Jafarikukhdan, Hosseini, & Armand, 2015).

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Phytochemicals e.g., flavonoids and phenolic have a great effect on cancer inhibition and health. Plants are a rich source of phytochemicals. In the Okinawan population, the life span can be prolonged by phytochemical-rich vegetables and fruits, according to Dietary Approaches Stop Hypertension. Additionally, these compounds have high antioxidant activities. Secondary metabolites are plant active components that serve a variety of roles around the planet. The use of phytochemicals in pharmacological and cosmeceutical products, as well as medications, is a current research topic (Azwanida, 2015). Medicinal herbs were being used for flavor, food preservation, and the treatment of specific diseases since ancient times. Modern research focused on the use of nanotechnology to escalate the yield of plants and enhance their nutritional components to complete the food requirement of populations.

LITERATURE

Nanotechnology analyzes nanomaterials in a variety of different ways. Nanomaterials provide innovative concepts and objectives for the agriculture sector. The use of nanomaterials in nanotechnology has changed farm output. Nanoparticles have a variety of uses in areas such as medicine delivery, the environment, energy, pharmaceuticals, cosmetics, and agriculture, among others, due to their unique features. Nanoparticles have attracted considerable attention in recent decades (Okuyama, Lenggoro, & Iwaki, 2004).

Nanoparticles are made using a variety of processes, including physical, chemical, and biological ones. Nonetheless, the biological or green approach of producing nanomaterials is significant. The most suitable, appropriate, and environmentally beneficial approach to nanomaterial or nanoparticle synthesis is biological synthesis. Physical and chemical methods of nanoparticle manufacturing are both detrimental to the environment and pricy. Plant extracts are being used for biosynthesis of nanoparticles, which is garnering greater attention concerning other materials (Basavegowda *et al.,* 2013).

Depiction of nanoparticles is a necessary stride after synthesis. Nanoparticle characterization encompasses a series of microscopic and spectroscopic techniques. Microscopically based approaches, such as Scanning Electron microscopy (SEM) and Transmission Electron Microscopy (TEM), are being used to define the size and morphological configuration (Poinern, 2014). Similarly, spectroscopic methods such as XRD, FT-IR, and UV-vis are extensively conducted to analyze the organization, conformation, crystal phase, and assembly of nanoparticles. In addition, XRD observations indicate the crystalline size and alignment of nanoparticles. The FT-IR technique is used to confirm functional groups such as hydroxyls and carbonyls. FT-IR can also be employed to quantify surface morphology and residues because these constituents are fastened to the surface via nanoparticle formation (M. Shah, Fawcett, Sharma, Tripathy, & Poinern, 2015).

Nanotechnology draws a major effect on the food and agriculture industries. Distinct nanoparticles have unique characteristics and are applicable in ample domains. Nanoparticles like copper, zinc, as well as silver, and gold are frequently employed. Different nanoparticles are employed in growth mediums to minimize bacterial contamination as they have greater antimicrobial properties. Nanosensors are typically utilized in agribusiness to detect plant viruses and identify underground rail. These renewable agricultural resources, such as chemicals, minerals, and water, are user-friendly as nanosensors. To check the outcome, these petite sensors are disseminated across the desired dome (Ingale & Chaudhari, 2013). Nanosensors can help to diminish pollution and fertilizer consumption in the environment. Nano-fertilizers with a gradual release rate are commonly employed (DeRosa, Monreal, Schnitzer, Walsh, & Sultan, 2010).

Scientists are engrossed and leaning toward auxin evaluation as it aids them to cognize how plants respond to their environs. Auxin-based nanosensors have moreover, been discovered to play a foremost role in agriculture (McLamore et al., 2010). Formers will profit more from these revolutionary technologies, particularly nanotechnology, in zones where industries are less developed and in fully developed countries. Nanoparticles have a variety of commercial applications, including the Food and Cosmetics industries , as well as water treatment where nanomaterials contribute significantly and are cost-effective. Nanoporous ceramics, membrane-based carbon nanotubes, and magnetic nanoparticles are employed extensively in water purification systems, despite the inclusion of UV and chemicals. Carbon nanotubes, according to researchers, have eliminated heavy metals such as arsenic, lead, uranium, and water pathogens. Endosulfan, chlorpyrifos, and Malathion are pesticides, viruses, and pesticides that can be eradicated with nanoparticles. In bioremediation, nanotechnology plays a crucial role (Karn, Kuiken, & Otto, 2009).

Nano-encapsulation is the varnish of various nanomaterials within an additional material, such as a matrix or shell, at a nano-scale scale. In the agricultural industry, nano-encapsulation is a typical procedure for releasing insecticides slowly and efficiently into a specific host plant. It permits herbicides to be absorbed properly in plants. Nano-encapsulation is also a viable option for DNA delivery. Nano-encapsulation has changed the way plants interact with infectious agents and effectively defends plants from insects (Torney, 2009). Nano-fertilizers are more proficient than regular stimulants, according to (Liu, Feng, Zhang, Zhang, & He, 2006). Nano-fertilizers can help agricultural products flourish faster (35 to 40 percent). Nano-fertilizers are significant in the agriculture business for increasing nutrient efficiency and controlling eutrophication challenges. Nano-fertilizers are a new and effective technique to address organic fertilizer deficits. Many more studies about the use of nanoparticles as nano-fertilizers are required (Rout & Sahoo, 2015).

Urgency of Study

The impacts and applications of NPs on plant development and enlargement are highlighted in this review. Plant proliferation can also be boosted by nanoparticles because they can improve soil quality by degrading pesticide residues. Furthermore, it demonstrates how nanoparticles are the best alternative for agricultural production sustainability because they pose fewer environmental risks such as single-walled carbon nanotubes, for example, could pierce the cell wall, act as a transporter, and are cost-efficient. As a result, for nanoparticles synthesis that is safe to the environment, non-toxic, cheap, effective, and acceptable technology is required.

Research Purpose

The current appraisal is designed to keep in view the importance of metallic nanoparticles for the germination and burgeoning of plants. The main objective of the study includes the environmentally friendly amalgamation of nanoparticles and the effect of metallic nanoparticles on plant escalation as well as on plant development. This review also highlights the applications of nano-scale particles in various arenas.

Interaction of Nanoparticles with Plants

Nanomaterials must be incorporated by the plant cell and transit the plasma membrane to enter the symplastic path (Pérez-de-Luque, 2017).

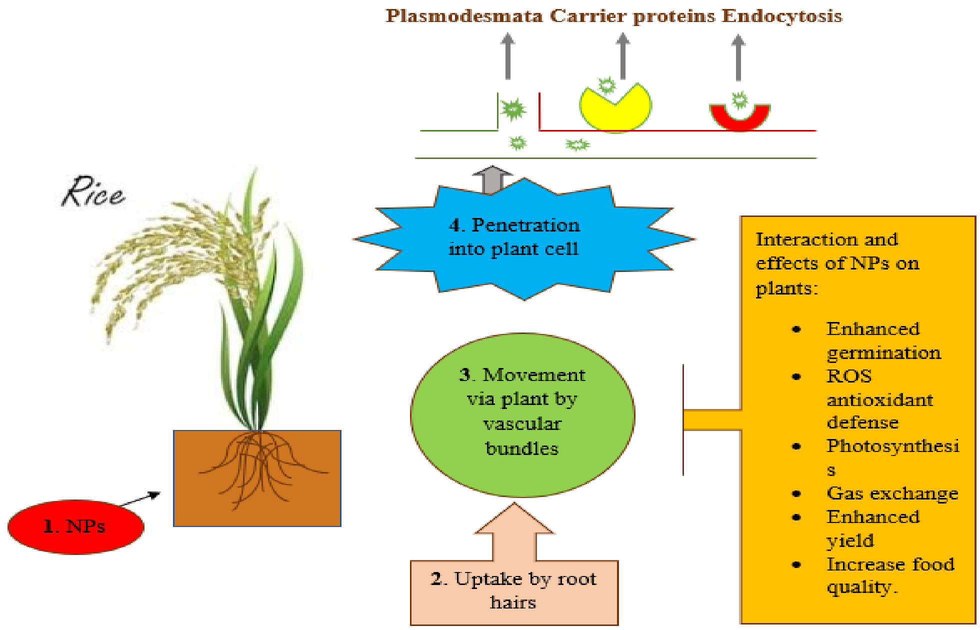

Figure 1: General schematic approach of nanoparticle incorporation in rice plants.

There are numerous ways for nanoparticles to penetrate the plant cell (Schwab et al., 2016). How nanoparticles are stewed in the cells is one more important query as it will over manipulate the useful function of the nanomaterials. If we intend to distribute chemicals within organelles, then endocytosis emerges as the mainly appropriate method. Resting on the converse, for liberation in the cytosol, pore development ought to be the most obvious approach for it. Furthermore, we could be fascinated in nano-materials that do not go within the cells of plants although in other creatures, such as bacteria or fungi in array to indulgence crop systemic ailments and toxicities (Rispail et al., 2014).

Impact of metallic NPs in Plant Escalation and Growth

Each MONPs has the capacity of affecting the development and growth of floras. Seed growth, shoot/root development, biomass assembly, and physiological/biochemical responses all indicate both beneficial and harmful properties (Mohamed & Kumar, 2016). With changing morphological, structural, physiological, and hereditary factors of plants, metallic ENMs induce noxiousness at increasing concentrations (Rico, Peralta-Videa, & Gardea-Torresdey, 2015). A small number of booms are also available on the deleterious effects of engineered metallic NPs on seeds and seed-renown in wheat (Rico et al., 2014) and ordinary bean (Majumdar et al., 2015).
Even while significant differences in antioxidant enzyme functioning and up-regulation of heat shock proteins have been documented intermittently, some plant species may not show any physiological alterations (Siddiqi & Husen, 2016). Plants have a sumptuous antioxidant resistance arsenal, concerning enzymatic as well as non-enzymatic constituents, to avoid oxidative

detriment and concurrently amplify confrontation contrary to metal oxide noxiousness (Kumari, Singh, Singh, & Biochemistry, 2017). Metallic nanoparticles increase antioxidant actions in plants (Table1).

Metallic Nanoparticles	Enhanced Antioxidant Activity	Plants	References
Fe3O4 NPs	Superoxide dismutase (SOD), Peroxidase (POX) Catalase (CAT)	Wheat plants	(Iannone *et al.*, 2016)
TiO2 NP	Catalase (CAT), Glutathione Reductase (GR) activities	Water thyme plants	(Okupnik & Pflugmacher, 2016)

The precise method fundamental to the plant protections against the nanoparticles beget harmfulness has not been completely recognized. The bioavailability, absorption, solubility, and disclosure period of metal oxide NPs influence their assimilation and transportation in diverse plant components (Verma et al., 2018).

Nanotechnology Applications

Nanotechnology is a fascinating and promising discipline that allows for new and cutting-edge study in a variety of sectors, and nano-technological discoveries may lead to new and exciting applications in biotechnology and agriculture. Nanotechnology has the potential to accelerate research in fields like "reproductive biology and technology, agricultural and food surplus conversion" to energy, and additional constructive derivatives during enzymatic nano-bio processing, chemical feelers, water cleaning, infection anticipation, and handling in plants using innumerable methods (Nair et al., 2010). The US Department of Agriculture and Clemson University scientists have settled a chicken feed that incorporates multifunctional polystyrene NPs that interact with pathogens to diminish food-borne diseases (Sekhon & applications, 2014). Nanoparticles shows various beneficial effects on palnt development and enlargement as shown in Table 2a, 2b.

The sway of Metallic Nanoparticles in Plants

Scientists from their outcomes demonstrated together constructive and pessimistic effects on plant escalation, progress and the effect of engineered nanoparticles on plants fulcrum on the temperament, attentiveness, dimension, and substantial and biological characteristics of ENPs as well as plant variety (Ma, Geiser-Lee, Deng, & Kolmakov, 2010).
The chemical arrangement, size, shallow casing, reactivity and most crucially the amount at which nanoparticles are treasured all limit their efficiency. Regardless, this exam addresses the important role of NPs in seed sprouting, root development, and growth parameters (Khodakovskaya et al., 2013).

Role of Silicon Dioxide NPs

As the initial emblems of growth and development, plant augmentation and enlargement begin with seed germination, tailed by root extension, and shoot advent. According to the findings of many investigations, the consequence of NPs on seed sprouting was dose-dependent. (Bao et al., 2004)

explore the functional significance of nano-SiO2 on Changbai larch (*Larix olgensis*) plantlets and establish that nano-SiO_2 enhances sprout development and excellence, plus mean elevation, root thickness, foremost root dimension, and the numeral of adjacent roots of saplings and also induce the production of chlorophyll. In abiotic trauma, nano-SiO2 accelerates kernel development. Nano-SiO2 increased seed germination and expedited the antioxidant technique under NaCl pressure (Siddiqui, Al-Whaibi, Faisal, Al Sahli, & chemistry, 2014).
(V. Shah, Belozerova, & pollution, 2009) used "silica, gold, and copper nanoparticles in their research and discovered that all such nanoparticles have a noteworthy impact on lettuce beginnings. The function of nano-SiO_2 and nano-TiO_2" enhance soybean seed propagation by rising nitrate reductase and in addition by boosting the seed's capability to take up and exploit water and minerals (Zheng, Hong, Lu, & Liu, 2005). In salinity tension, "nano-SiO_2" hastens leaf new and desiccated load, chlorophyll substance, and proline gathering. An extend in the gathering of proline, open amino acids, nutrients, antioxidant enzymes action" owing to the nano-SiO2, in this manner improving the lenience of plants to abiotic tension. "Nano-SiO_2 NPs" accelerated the plant development and expansion by mounting "gas exchange and chlorophyll fluorescence constraints, such as residual "photosynthetic grade, transpiration tempo, stomatal conductance, successful photochemical effectiveness, definite photochemical productivity, electron transport rate, and photochemical" douse.

Role of ZnONPs

According to a burgeoning field of knowledge, zinc oxide nanoparticles (ZnONPs) boost plant growth and development." Nevertheless, the elevated quantity of ZnO nanoparticles lessened seed development. The consequence of NPs on growth and plant development differs on engrossment of NPs and diverges among differen typye of plants.
(de la Rosa et al., 2013) utilized various dilutions of ZnO nanoparticles on cucumber, alfalfa, and tomato and observed that isolated cucumber seed propagation was improved. Plantlet roots of "Vigna radiate" and "Cicer arietinum immersed "ZnO nanoparticles" and increased essence and shoot extent, as well as shoot/root biomass, as shown by supplemental light and scanning microscopes, as well as atomic emission spectroscopy. Nano ZnO growth in MS media enhances somatic embryogenesis, shooting, and plantlet restoration, as well as proline generation, superoxide dismutase, catalase, and peroxidase movement, boosting biotic pressure tolerance (Helaly, El-Metwally, El-Hoseiny, Omar, & El-Sheery, 2014).

Role of Carbon Nanotubes

Carbon nanotubes (CNTs) contain a significant position owing to their distinctive perfunctory, electrical, thermal, and chemical characteristics. The accessible information divulges that polls on CNTs have chiefly been based on organisms and human beings (Tiwari et al., 2014). There has been incomplete evidence obtainable on CNTs and their interaction with plant cells and with plant absorption. Though, in different investigations scholars have described that multi-walled CNTs (MWCNTs) have an enchantment aptitude to affect the seed propagation and plant development, and slog as a transfer scheme of DNA and compounds toward plants cells. MWCTs stimulate the H_2O and fundamental Ca and Fe nutrients taking efficacy that could increase the seed propagation and plant enlargement and expansion; (Villagarcia, Dervishi, de Silva, Biris, & Khodakovskaya, 2012). Also, they reported that MWCNTs govern genes assembly controlling a variety of water channel soybean proteins, corn, and barley seeds coat. Different investigations confirmed the constructive function of CNTs in seed growth and plant development and enlargement. On the other hand, a few investigators highlight that MWCNTs do not demonstrate an encouraging effect on

seed germination in various plants even when they acknowledged high absorption of MWCNTs (Husen & Siddiqi, 2014). MWCNTs promote root and stem enlargement as well as peroxidase and dehydrogenase activity, which could be because MWCNTs are taken up and stored by roots, then translocated from roots to leaves, where they stimulate gene expression (Lahiani et al., 2013).
(Tripathi et al., 2015) demonstrate the occurrence of "water-soluble CNTs within the wheat plants through Scanning Electron and Fluorescence Microscopy, and they confirmed that CNTs regulate the Root and Shoot development in nimble and dusky circumstances. Furthermore, MWCNTs enhance water maintenance ability and biomass, flowering and crop harvest, and enhance the therapeutic characteristic of plants. Consequently, the influence of NPs on plants changes from plant to plant, their developmental phases, and the temperament of nanoparticles.

Title Role of Gold NPs

Limited examinations have been concluded on the relationship of "gold nanoparticles (AuNPs) alongside floras. Certain investigations show that AuNPs cause noxiousness in plants by disturbing aquaporin activity (it is a cluster of proteins that expedite the passage of broad series of molecules encompass water. Nonetheless, different scientists reported that in lettuce, cucumber, *Brassica Juncea* and in *Gloriosa superba*," AuNPs enhance seed development (Gopinath, Gowri, Karthika, & Arumugam, 2014). AuNPs increase the mass of leaves, leaf area, plant elevation, chlorophyll component, and sugar matter that direct to the healthier crop harvest (Arora et al., 2012). Consequently, the constructive result of AuNPs requires more research to investigate the functional and molecular methods.

Role of Titanium Dioxide Nanoparticles

Like AgNPs, some researchers examine the effete of "titanium dioxide nanoparticles (TiO2NPs) on bacteria, algae, plankton, fish, mice, and rats although investigation focus on the recognition of the impact of TiO2NPs on plant lingers deficient. Jaberzadeh in 2013 described that TiO2NPs improved wheat plant progression and produced constituents under water divergence hassle requirement. TiO2NPs regulate the action of enzymes elaborate in nitrogen metabolism, like nitrate reductase, glutamine synthase, glutamate dehydrogenase, and glutamic-pyruvic transaminase, that further help plants employ nitrate and also regulate the transfiguration of inorganic nitrogen to organic nitrogen in the arrangement of protein and chlorophyll, which might improve the fresh mass and desiccated weight of plants (Mishra, Mishra, Dikshit, & Pandey, 2014).
TiO2NPs stimulate optical density, quicken the transportation and alteration of the light energy, defend chloroplasts from maturing, and lengthen the photosynthetic duration of the chloroplasts. TiO2NPs may be useful in protecting chloroplasts from undue light absorption by speeding up the work of antioxidant enzymes like catalase, peroxidase, and superoxide dismutase (Hong et al., 2005).

Table (2a): Constructive effect of Metallic NPs on Plant Progression:

Nanoparticles	Plants	Part of plant/ Activity	References
SiO_2 NPs	*Lycopersicon esculentum Mil*	Seed Germination	(Siddiqui and Al-Whaibi 2014)
	Zea mays L.	Seed Germination	(Suriyaprabha *et al.*, 2012)
Zinc Oxide NPs	*Arachis hypogaea*	Seed Germination	(Prasad *et al.*, 2012)
	Glycine max	Seed Germination	(Sedghi *et al.*, 2013)
	Allium cepa	Seed Germination	(Laware, 2014)
	Cyamopsis tetragonoloba	increase root and shoot growth	(Raliya and Tarafdar ,2013)
CNTs	*Hordeum vulgare*	Plant development	(Lahiani *et al.*, 2013)
	Glycine max	Seed Germination	
	Zea mays	Germination and Protein production	
Gold NPs	*Arabidopsis thaliana*	Seed germination, *regulate micro-RNA expression,* antioxidant system	(Kumar *et al.*, 2013)
Silver NPs	*Boswellia ovaliofoliolata*	Germination and seed ling widening	(Savithramma *et al.*, 2012)

Role of Silver Nanoparticles

According to accessible information, a diverse investigation on silver nanoparticles (AgNPs) has been reported on microbial and animal cells. Though a little research was carried out on plants. We are familiar that NPs have both progressive and adverse possessions on plant augmentation and enlargement.

Currently (Krishnaraj et al., 2012) reported the consequence of biologically manufactured silver nanoparticles on hydroponically developed *Bacopa monnieri* growth metabolism and reported that "biosynthesized AgNPs" revealed a considerable impact on seed propagation and stimulate the production of protein and carbohydrate and diminish the entire phenolic components and catalase and peroxidase actions.

Table (2b): Constructive effect of Metallic NPs on Plant Growth:

Nonetheless (Gruyer, Dorais, Bastien, Dassylva, & Triffault-Bouchet, 2013) demonstrated that

Nanoparticles	Plants	Part of plant/ Activity	References
TiO2NPs	Brassica napus	improved seed growth and regulate radicle and plumule growth	(Mahmoodzadeh *et al.* 2013)
	Arabidopsis thaliana	Root length	(Lee *et al.*, 2010)
	Foenicutum vulgare	Germination	(Feizi *et al.*, 2013)
	Lemna minor	Plant development	(Song *et al.*, 2012)
	Triticum aestivum	Increase Chlorophyll content	Mahmoodzadeh *et al.*,2013)
Iron Oxide NPs	*Arachis hypogaea*	Increase root length, plant height and biomass.	(Rui *et al.*, 2016)
Nitrogen NPs	*Pennisetum americanum L*	Increase root area, root length, root perimeter, number of tips, average root diameter and total biomass.	(Thomas *et al.*, 2016)
AlO2NPs	*Arabidopsis thaliana,*	Root span	(Lee *et* al., 2010)
CuO NPs	*Triticum aestivum*	Biomass	(Dimkpa *et al.*, 2012)

AgNPs have both encouraging and damaging influences on root prolongation contingent on the plants' variety. They examined that root dimension was improved in barley though it was decreased in lettuce . AgNP provokes root development by stopping ethylene signals in *Crocus sativus* (Rezvani, Sorooshzadeh, & Farhadi, 2012).

The effect of Ag-NPs on the structure and functioning of plants depends on the dimension and nature of NPs. Furthermore, Ag-NPs stimulated the aminocyclopropane-1-carboxylic acid (ACC) derived reduction of root prolongation in *Arabidopsis* seedlings" as well as decrease the expression of ACC synthase 7 and ACC oxidase2 indicating that Ag NPs function as inhibitors of ethylene sensitivity and could obstruct with thylene biosynthesis.

CONCLUSIONS AND RECOMMENDATIONS

Nanotechnology, without a doubt, is a fast-emerging technology that is attracting greater attention. Nanotechnology opens new possibilities in the areas of "electronics, energy, medicine, and biology". Because of their distinctive characteristics, various studies have been concluded on the toxicological consequence of NPs on plants. However, the investigation of the encouraging effects of NPs on plants remains incomplete. Most plant tech companies are acquainted with metal and metal oxide NPs such as Au, Ag, ZnO, CuO, TiO_2, and CeO_2." Less data shows the affirmative effect of NPs on plant augmentation and growth (Table 2). The interaction of NPs with plants fluctuates from plant to plant. This review indicates that nanoparticles are significant as plant growth regulators, but further important drives are required to recognize the "physiological, biochemical, and molecular phenomenon" of plants concerning nanoparticles. Furthermore, new research work is required to scrutinize the mechanism of the act of nanoparticles, their relations with "biomolecules, and their effect on the stimulation of gene expressions" in plants.

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