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Review: Nanotechnology in Agriculture: Prospects and Problems

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ABSTRACT: Nanoscale expression of distinct particles has led to revolutionary advancements in all key areas such as health, drugs, and agriculture, as compared to their bulk equivalents. Nanotechnology is the science of studying nanoscale particles and their behaviour. Climate change, urbanisation, sustainable resource use, and environmental challenges are all factors that lead to the usage of nanotechnology in agriculture. Nanopesticides, nanofertilizers, nanoherbicides, controlled delivery devices etc are the nanotechnological applications in agriculture. Nanotechnological techniques, like any other technology, offer benefits and drawbacks. Some of the negative aspects of nanotechnology include: entry of nanoparticiles into environment, humans and plants to toxic levels; generation of large amounts of hazardous waste creating environmental threat. Adoption of greener methods for synthesis, as well as the use of green nanomaterials, is a current research trend, and before new nanotechnology advances are implemented, they must be thoroughly investigated.

Keywords: Nanotechnology, Nanoparticle, Nanofertilizer, Nanoherbicide, Sustainability, Environmental Risks.

INTRODUCTION

Global food production and distribution have been severely strained by booming population, climate variability, industrial emissions, and growing fuel and power demands. According to the Food and Agriculture Organization (FAO, 2017), around 2050, the population of the planet would have surpassed 10 billion, resulting in a 50 percent increase in food requirement, predominantly in developing countries. Furthermore, approximately 815 million people are estimated malnourished, with just further 2 billion people around the world anticipated to be malnourished around 2050. (FAO, 2017). In addition, by 2050, energy and food requirements will have surged over 70% from present rate in a sustainable way (Chen and Yada, 2011). Sustainable agriculture offers a feasible solution to the aforementioned issues, yet in India, sustainable agriculture faces serious challenges such as extracting more water from resources than is replenished in traditional irrigation, resulting in water scarcity, subsidisation of urea as the primary nitrogen fertiliser, resulting in nitrate toxicity in water reservoirs, and accumulation of pesticides and insecticides at toxic levels in both crops and the environment. This situation needs major scientific and technological advancements. Nanotechnology, according to recent studies, has the capacity to improve way of farming by improving farm inputs effectiveness and giving solutions to agricultural and challenges posed by nature. Nanotechnology will raise crop productivity based on current ecological parameters, crop disease detection and management, and enhancing crops’ mineral uptake capacity from the soil (Alfadul *et al.*, 2017). With reports from Nanoforum (2006); USDA (2002); Roco (1999), nanotechnology has gained traction in agriculture. All fields of agricultural activity will be overtaken by nanotechnology (Mukhopadhyay, 2014). As a result, research into nanotechnology's agricultural potential has garnered a lot of coverage in past few years (Kah *et al.*, 2019). The goal of this research is to give another resource for academics working in a variety of nano-enabled agriculture sectors, highlighting potential and future work paths for nanotechnology in global food security.

Nanotechnology and nanoparticles

"Nanotechnology is the exploration and management of matter at the nanoscale, where distinct phenomenon permit revolutionary applications," according to the US National Nanotechnology Initiative (NNI) 2004 and entails all of the procedures outlined in Table 1.

Table 1: Primary procedures in nanotech process.

I	Atomic, molecular, and macromolecular research and development with lengths ranging from 1 to 100 nanometers.
II	Because of their tiny and/or intermediate size, systems and equipments with unique features and functions to be build and used.
III	On an atomic scale, the ability to govern or manipulate.

Nanomaterials are defined by the International Organization for Standardization as "substances with just about any outer dimensions in the nanometer range or possessing inner structure or surface morphology in the nano level," while the European Commission's Scientific Committee on Emerging and Newly Identified Health Risks defines them as "components including outer structure, or even an inner structure having novel properties in comparison to the same material without nanostructured features."

Why nanoparticles?

Nanoparticles contain characteristics such as small size (1-100 nm), high activity, and chemical and optical properties particular to this size range (Khan & Rizvi, 2014). The properties of nanoparticles include hydrophilic nature, miscibility, unevenness, morphology, adsorption during synthesis, capacity to yield superoxide radicals, stoichiometry, competiting binding ability with receptor, dispersion, and agglomeration (Somasundaran *et al.,* 2010). The significant fraction of atoms on the surface of these particles suggests that they could be used to build agricultural nanosystems (Maurice and Hochella, 2008) (Table 2). Table 3 lists nanomaterials with possible applications in plant metabolism.

Table 2: Nanoparticles and its application in Agriculture.

Sr. No.	Type of Nanoparticle	Applications	References
1.	Nanopesticides	Crop protection	Krishnaraj *et al.* (2012); Jayaseelan *et al.* 2012
2.	Nanoformulations	Delivery systems	Guan *et al.* (2010)
3.	Nanosensors	Diagnosis of Plant disease	Kang *et al.* (2010); Chartuprayoon *et al.* (2010)
4.	Nanobiosensors	Checking of quality of agricultural products	Van Dyk and Pletschke (2011)
5.	Nanofilters /Nanoabsorbents	Management of water	Hajeh *et al.* (2013)
6.	Nanoremediation	Management of soil	Mohamed and Hairou (2011)

Table 3: Nanomaterials involved in plant metabolism.

Sr. No.	Type of Nanomaterial	Involvement in plants	References
1.	Zinc oxide	In germination, growth of roots, dry weight of shoots, biomass, yield.	Zhao *et al.* (2014)
2.	Graphene oxide	In germination	Anjum *et al.* (2014)
3.	Titanium dioxide	Regulation of photosystem II, Growth of plants, Length of roots, Chlorophyll content, germination, Hill reaction, rate of transpiration, non-cyclic photophosphorylation, protect chloroplasts from aging, net rate of photosynthesis.	Qi *et al.* (2013)
4.	Silver nanoparticles	Antagonize inhibition by 2,4-dichlorophenoxyacetic acid (2,4-D) on plant growth.Germination and growth of seedlings, length of roots, dry weight of root and shoot,	Savithramma *et al.* (2012)
5.	Aluminium oxide	Length of roots	Lee *et al.* (2010)
6.	Silicon dioxide	Growth parameters	Yuvakkumar *et al.* (2011)
7.	Sulphur	Dry weight	Patra *et al.* (2013)
8.	Carbon nanotubes	Root elongation, germination and growth of seedlings.	Miralles *et al.* (2012)

APPLICATIONS OF NANOTECHNOLOGY IN AGRICULTURE

Nanofertilizers. Chemical fertilisers are limited in their application because of fertiliser loss which leads to environmental pollution and increases the cost of manufacturing (FAO, 2017). Around 40-70 percent N (De Rosa, 2010), 50-90 percent K and 80-90 percent P are dispersed in the ecosystem thus unavailable to the crop (Ombodi and Saigusa, 2000), and chemical interaction in soil causes 8–90 percent of standard phosphatic fertilisers to be lost and inaccessible to plants, resulting in long-term and economic losses (Giroto *et al.*, 2017). In this regard, nanotechnology has been used to lessen loss of nutrients, generate gradual fertiliser release, and increase nutrient distribution that aren't readily available (Kah *et al.*, 2018). Nanotechnology has enabled researchers to examine nano range substances as fertiliser transporters or managed vectors for the development of smart fertilisers as emergent means to increase nutrient usage productivity and lowering pollution costs (Chinnamuthu and Boopathi, 2009). Nano-fertilizers can release nutrients, particularly NO_3-N, for up to 50 days, whereas urea-based fertilisers only release nutrients for 10-12 days. The nanofertilizer had 82 percent N-use efficiency whereas the conventional fertiliser (urea) had a 42 percent N-use efficiency, resulting in increase in nitrogen-usage of 40 percent, which is impossible to obtain in the traditional system (Subramanium *et al.*, 2009).

Nanotechnological applications to enhance NUE

(A) *Nanobiosensors*

A biosensor is a tool that includes a biological recognition element with a physical or chemical detector to detect something. Wheat roots and rhizosphere microbes have been found to communicate with each other as a key component of chemical signalling networks (Monreal *et al.*, 2015) via nonobiosensors (Fig. 1).

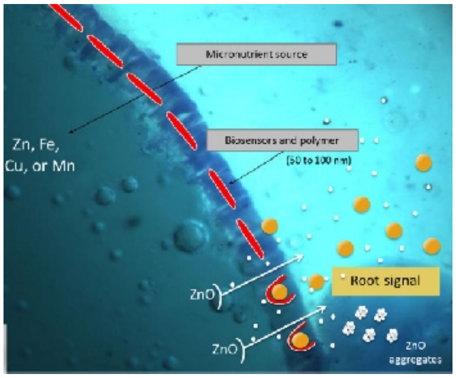

Fig. 1. (yellow): Specific root chemical signals that are bound to (red): a nanobiosensor placed in (blue): a polymer film coating (dark grey): ZnO-fertilizer nanoparticles (white spheres): the consequences of biosensor and signal binding process (Monreal *et al.*, 2015).

(B) *Encapsulation*

Encapsulation reduces the solubility of active ingredients, runoff rates, and interactions with agricultural workers. Due to higher friction on the surface, nanomaterial's coatings on fertiliser granules keeps the material in place with higher effectiveness than standard surfaces, allowing for more controlled release. De Rosa. (2010) suggested that nutrients may be encapsulated inside nanomaterials to create nanofertilizers (Fig. 2). One of these novel facilities is the encapsulation of fertilisers in nanoparticles, which can be accomplished in three ways:

1. Nutrients can be encased within nanosized substances.
2. Placed in polymer coatings.
3. Nanoparticles or emulsions are used to deliver the product. (Rai *et al.*, 2012).

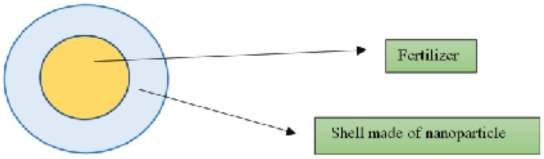

Fig. 2. Encapsulation of fertilizer in nano-particulate polymeric shell.

Encapsulation allows targeted release of fertilizer (Fig. 3). Fertilisers incorporated inside nanoparticles will boost nutrient uptake (Chinnamuthu and Boopathi, 2009). By placing and cementing fertiliser capsules, nano or sub nanocomposites could enable the gradual release of nutrients (Lui *et al.*, 2006) (Fig. 4). It is claimed that a patented nanoparticle of N, P, K, micronutrients, and amino acids improves grain and crop nutrient uptake (Jinghua, 2004).

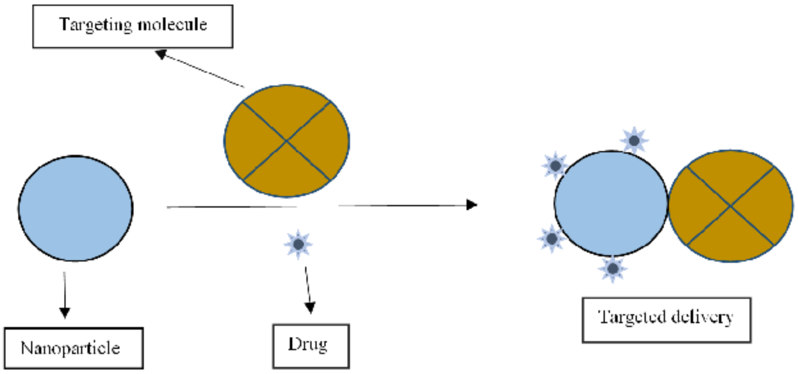

Fig. 3. Targeted delivery of nano-fertilizer.

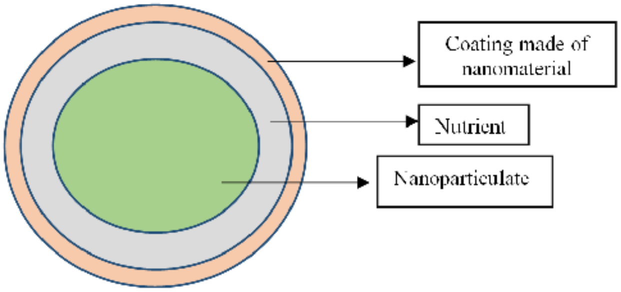

Fig. 4. Fertilizer coated with nanoparticles for slow delivery of nutrient.

1. Nanoherbicides

Herbicides enclosed in polymeric core shell nanoparticles are nanoherbicides, which are alternate types of herbicides developed in conjunction with nanomaterials (Kumar *et al.* 2015). Encapsulated target specific herbicides in nanoparticles are employed to eliminate specific weeds by acting on specific root receptors (Jamplek and Kralova, 2015). The invention of a nanoparticle-encapsulated target-specific herbicide chemical is focused at a particular binder of target weed roots, that penetrates the root system and is translocated to the portions that hinder glycolysis of the roots. As a result, the weed plant will get hungry and die (Chinnamuthu *and* Kokiladevi, 2007). Also by creating tubes that generate breaches in the seed coat, enabling water and chemicals to enter, carbon nanotubules break the dormancy of weed seeds, speeds up germination, and cuts germination time in half (Mariya *et al.*, 2009).

Detoxification of herbicide residues*:* Atrazine accepted worldwide for the control of weeds characterized as pre and post-emergence broad leaved and grassy in nature, having long half-life (125 days) and higher mobility in some soils. Under regulated conditions, the use of silver modified with magnetite nanoparticles stabilised with Carboxy Methyl Cellulose (CMC) nanomaterial resulted in an 88 percent breakdown in residues of atrazine (Susha *et al.*, 2009).

$$\text{Atrazine} + \text{Fe based nanocomposites} \longrightarrow \text{Hydrolyzed Atrazine} + CO_2 + NH_3$$

2. Nanotechnology and Abiotic Stresses

Various nanoparticles used, have been proven beneficial on the growth and yield of crop by altering the physiological systems during drought of the crop. It has been found, for example, that foliar sprays of NPs of iron and oil per centage of safflower species can mitigate, negative effects in drought stress on parameters of yield thus yield can be enhanced (Davar *et al.*, 2014). During drought conditions, the addition of NPs of titanium dioxide at the rate of 0.02 percent increased the plant height, ear number, biomass, ear weight, seed number, 1000-seed weight, harvest index and ultimate yield (starch and gluten content) (Jaberzadeh *et al.*, 2013). Therefore these investigations revealed that the formulations enabling selected nanoparticles can favourably interact with probiotics of the plants that promotes drought tolerance and robust plant tissues (Jacobson *et al.*, 2018) (Table 4).

Table 4: Beneficial impacts in abiotic stresses by nanopaticles.

Sr. No.	Type of the stress	Crop	Type of the Nanoparticle	References
1.	Waterlogging	(*Glycine max* L.)	Ag Nanoparticles	Mustafa *et al.* (2015)
2.	High Temperature	*Sorghum bicolor* (L.) Moench	NPs of selenium	Djanaguiraman *et al.* (2018)
3.	Drought	*Carthamus tinctorious* L.	Iron nanoparticle	Davar *et al.* (2014)
4.	High Temperature	*Moringa oleifera*	NPs of siliver	Iqbal *et al.* (2017)
5.	Drought	*Sesasum indicum* L.	Oxide of iron	Mostafa *et al.* (2016)
6.	Chilling	*Triticum aestivum* L	Nanoparticles of Biogenic silver	Bhati-Kushwaha *et al.* (2013)
7.	Waterlogging	(*Glycine max* L.)	Al_2O_3 NP	Mustafa *et al.* (2015)
8.	Drought	*Zea mays* L. and *Triticum aestivum* L.	Analcite Nanoparticles	Nataliya *et al.* (2014)
9.	Salinity	*Trigonella foenum-graecum*	Nano particles of silver	Hojjat and Kamyab (2017)
10.	High CO_2	*Oryza sativa* L.	$nTiO_2$	Du *et al.* (2017)
11.	Heavy metals	*Triticum aestivum* L.	Oxide of zinc	Hussain *et al.* (2018)
12.	UV-B	*Triticum aestivum* L	Nano Ag	Kumar and Swati (2016)
13.	Salinity	*Vicia faba* L.	$nTiO_2$	Mojtaba and Lam-Son (2018)

3. Nanotechnology in Diagnosis and Management of Plant Diseases

The most challenging aspects of plant disease management is detecting the disease at the proper stage. Because a huge percentage of plant illnesses are only discovered at later stages, controlling them becomes a difficult effort. Recent research has found that nanoparticles can have antibacterial characteristics, which can be generated by either oxidative stress or bacterial cell wall physical breakdown caused by reactive oxygen species (ROS) generation (Gurunathan *et al.*, 2012). There are numerous instances in the literature that support the findings, such as zinc nanoparticles showing the highest inhibitory value against P. aeruginosa (Jayaseelan *et al.*, 2012).

Higher anti-microbial activity was found against *S. aureus*, *E. coli*, *P. aureginosa* with the aid of nanoparticles (Guzman *et al.*, 2009).

Another nanomaterial, nanoparticles of copper oxide (CuO NPs), has been found to have antibacterial action against *Pseudomonas aeruginosa*, *S. aureus*, *E. coli*, and *Bacillus subtilis* (Azam *et al.*, 2012). Disease of *Helianthus annuus* like charcoal rot or damping off were suppressed by micronutrients like Zn (zinc) or Mn (manganese) particles (Abd El-Hai *et al.*, 2010). Against microorganisms, a mixture of PVP and Ag nanoparticles had effective antifungal properties (Bryaskova *et al.*, 2011). Plant patho-fungi *Rhizoctonia solani*, *B. cinerea*, *Macrophomina phaseolina*, *Curvularia lunata*, *Sclerotinia sclerotiorum*, *Alternaria alternate* were also studied with silver nanoparticles. All pathogens studied had stronger inhibitory action when NPs were present in lower concentrations (Krishnaraj *et al.*, 2012). *A. flavus* growth can be stopped by the Zn NPs (25 mg mL^{-1}) (Jayaseelan *et al.*, 2012). Various scientists have also used nanoparticle mRNA for disease control (Table 5).

Table 5: Nanoparticles for plant disease control.

Sr. No.	Nano-particle type	mRNA	Plant disease managed	References
1.	*Oryza sativa*	Osa-pre-miR528	Rice black streaked swarf virus and Rice stripe virus.	Sun *et al.* (2016)
2.	Artificial miRNA in transgenic Arabidopsis	amiR-Hc-Pro159 and amiR-P69159	(1) Turnip mosaic Virus (2) Turnip yellow mosaic virus	Niu *et al.* (2006)
3	*Nicotiana tabacum*	amiR-159a	Cassava brown streak virus	Wagaba *et al.* (2016)
4.	*Arabidopsis thaliana*	Pre-miR-159a	Water melon silver mottle virus	Kung *et al.* (2012)
5.	AmiRNA against Hc-Pro *Arabidopsis thaliana*	miRNA171a miRNA167b and miRNA159a,	(1) TGBp1/p25 of Potato virus X (PVX) (2) Potato virus Y (PVY)	Duan *et al.* (2008)
6.	*Arabidopsis thaliana*	amiR159-P69	Turnip mosaic virus	Lin *et al.* (2009)
7.	*Triticum aestivum*	Pre-miR395	Wheat streak mosaic virus	Fahim *et al.* (2012)
8.	*Nicotiana tabacum*	Pre-miR-159a	Tomato spotted wilt virus	Mitter *et al.* (2016)
9.	*Solanum lycopersicum*	amiR-2a/b	Viral infection	Zhang *et al.* (2011)
10.	*Hordeum vulgare*	huv-pre-miR171	Wheat dwarf virus	Kis *et al.* (2016)
11.	*.Arabidopsis thaliana*	amiR-159a	Cucumber mosaic virus	Duan *et al.* (2008)
12.	*Nicotiana tabacum*	amiR-Hc-Pro167b, amiR-Hc-Pro159a, amiR-Hc-Pro171a	Potato virus X and potato virus Y	Ai *et al.* (2011)
13.	*Vitis vinifera*	amiRCP-2	Grapevine fan leaf virus	Jelly *et al.* (2012)
14.	*Solanum lycopersicum*	amiR-AV1-3	Tomato leaf curl virus	Van *et al.* (2013)
15.	AmiRNA based on Arabidopsis	pre miRNA159a	Cucumber mosaic Virus	Ai *et al.* (2011)

4. Nanopesticides

Nanoparticles can be effectively used in insect pest control and prevention of host infections (Khota *et al.*, 2012). A new nano-encapsulated pesticide formulation with better permeability solubility, stability and specificity is developed (Bhattacharyya *et al.*, 2010). Organic polymers mineral nanoparticles or surfactants of nanometer size are employed in the nano-pesticidal development (Alfadul *et al*., 2017). Insect-specific nanopesticides are going to be included in the new generation of pesticides while causing no harm to other critical soil insects (Kah *et al.*, 2013). Non-toxic and promising pesticide delivery technologies are being developed in order to increase crop output per unit of time while limiting negative consequences on ecosystem (Grillo *et al.*, 2016). Rao and Paria. (2013) found phytopathogens of *Venturia inaequalis*, *Fusarium solani were controlled by* Sulfur nanoparticles (SNPs) that were regarded as green nanopesticide. Rouhani *et al.* (2012) found *A. nerii.* was controlled by Ag nanoparticles' as these particles were found to have insecticidal properties. Using a solvo thermal technique, nanoparticles of Ag-Zn or Ag were developed and several doses of insecticidal solutions were tested on *A. nerii.*

5. Nanomaterials and Genetic Transformation

NPs-mediated transmittance has become extremely important in plant nanobiotechnology. Nanoparticles can be used to facilitate genetic change in tissue cultures of plants. Nanoparticles are utilised in the isolation of protoplasm, for example, in reducing the impact of enzymes of the cell. Endocytosis is employed for the DNA delivery into the tobacco protoplast using mesoporous silica nanoparticles. Biolistic cannon is also employed to deliver drugs, nanoparticles that are gold-coated and DNA to leaves and calluses (Torney *et al.*, 2007). In contrast to typical gold particles used with a gene gun, nanoparticles with gold coatings, transported DNA into *Nicotiana tabacum*, *Oryza sativa* and *Leucaena leucocephal* (Kumar *et al.*, 2010). Plasmid DNA that was Green-fluorescent protein (GFP)-encoded was efficiently transported into cells of turf-grass using poly (amidoamine) dendrimer nanoparticles (Pasupathy *et al.*, 2008). The DNA transfection effectiveness was improved by adjusting the medium pH and dendrimer molar concentration. Nanoparticles of calcium phosphate were used to transmit the 1301 vector of pcambia into *Brassica juncea* in order to maintain the GUS quality (Naqvi *et al.*, 2012). Silver nanoparticles that were expanded on culture media were successful in activating callus morphology and anatomy by altering the protein composition and DNA sequence in *Solanum nigrum*. However, in order to improve somaclonal variants, it is necessary to examine the vast range of nanoparticle uses.

6. Iron Nanoparticles for soil cleaning

Several ways of using nanotechnology, particularly nanoparticles, used for cleaning the soil that are contaminated with heavy metals are being developed. Nanoclean-up procedure that involves introduction of iron nanoparticle within a contaminated area is developed. Nanoparticles flow along ground water and disinfect along the way, saving money over digging up the soil to decontaminate it. Activity of this nanoscale iron inside the soil is for 6-8 weeks, before dissolving in ground water or blending in with naturally occurring iron.

7. Wastewater treatment methods with nano-based materials

Nanomaterials have the capacity to improve the effectiveness in wastewater treatment (Khan *et al.*, 2021) (Table 6). Nanomaterials, such as nanoparticles, nanomembranes and nanotubes are recognized and eliminated in variety of biological and chemical substances, including organic materials, bacteria, viruses, algae, antibiotics and micronutrients (Khan *et al.*, 2018). These materials offer exceptional properties that can be utilised to make photocatalytic reactive materials, change membranes, and make perfect adsorbents (Castaneda and Lau, 2017). Silver oxides, titanium dioxides, aluminium oxide, and zinc oxides are nanoparticle catalysts for removing microbiological and hazardous materials pollutants from water with great efficiency and are reusable (Chang *et al*., 2017).

Table 6: Nanomaterials for waste water treatment (Mansoori *et al.*, 2008).

Sr. No.	Nanoparticle type	Target to be removed	Mechanism of Treatment
1.	Nanoparticle based TiO_2	Organic pollutants	Photocatalysis
2.	Nanoparticle based Fe	Heavy metals, anions, organic pollutants	Reduction, absorption.
3.	Nanoparticle based bimetallic	Dicholrination	Reduction, absorption.
4.	Nanofiltration and nanomembranes	Organic and inorganic substances	Nanofiltration
5.	Magnetite nanoparticles	organic compounds, Heavy metals,	Adsorption
6.	Metal-sorbing vesicles	Heavy metals	Adsorption
7.	Nanoclay	Heavy metals, organic pollutants, anions	Adsorption
8.	Micelles	Organic pollutants	Adsorption
9.	Nanotube	Anions, heavy metals, organic pollutants	Adsorption
10.	Dendrimers	Pollutants, Heavy metals	Encapsulation

CONSTRAINTS

Nanotechnology is a fast expanding subject of science that has applications in practically every field. Despite its potential, it has had unforeseen negative consequences on humans and the environment during the manufacturing and processing of nanoparticles (Bouwmeester *et al.,* 2009).

- Bandyopadhyay *et al.* (2013) found that nanoparticles when invaded within the food web and water sources, have an influence on humans. According to many reports, nanotechnology can aid in the alleviation of poverty and other challenges (Mukhopadhyay, 2014).
- The particles' size poses a difficulty when breathed because they penetrate the lungs (Jinquan *et al.,* 2004). Buzea *et al.* (2007) demonstrated that asbestos nanoparticles and carbon nanotubes have a considerable impact on lung diseases.
- Bonne *et al.* (2000) found that because of environmental and residual concerns, the durability and disintegration of nanoparticles that are inorganic is a point of discussion. Nanoparticles interact with non-target areas, causing health and environmental problems (Claudia *et al.,* 2012).
- Various commissions and unions have been founded in various countries to assess the risks of nanotechnological breakthroughs, such as the European Union and the Royal Commission on Environmental Pollution (COT, 2005).
- Nanoparticle-related dangers are difficult to spot (Dhawan *et al.,* 2009).
- It's difficult to quantify nanotechnological danger and its impact on the environment and people (Nel *et al.*, 2006).
- To apply nanoparticles in a certain way and at a specific concentration, a thorough understanding in the mechanisms of phytotoxicity of nanopaticles is essential. Table 7 lists some of the phytotoxic consequences of nanoparticles.

Table 7: Phytotoxicity symptoms of nanoparticles.

Sr. No.	Type of Nanoparticle	Plant	Size (nm) of the particle	Phytotoxicity symptoms	References
1.	Ferric oxide	*Oryza sativa*	7–13	Root phytohormone Inhibition	Gui *et al.* (2015)
2.	Zinc oxide	*Brassica pekinensis Glycine max, Oryza sativa, Zea mays, ,Pisum sativum*	<50	loss of root cell viability, decrease in root growth	Hossain *et al.* (2016)
3.	Silver	*Oryza sativa*	50	Breakage in vacuole and cell wall	Mazumdar and Khairou (2011)
4.	Copper oxide	*Oryza sativa, Zea mays*	40–80	Inhibited shoot length, reduced root elongation	Yang *et al.* (2015)

FUTURE SCOPE

Nanotechnology has the power to reshape agricultural output by enabling for further scientific crop development, planning and conservation measures. By using nanotechnology to agriculture and food production systems, nanotechnology experts can assist society's development in a multitude of ways. Bioremediation, environmental surveillance etc can all be greatly simplified owing to nanotechnology. In future, we can increase agricultural output by implementing the following strategies:

- Herbicide delivery, pest vectoring and management by nanocapsules.
- Detection of aquatic toxins using nanosensors.
- Biopolymers that are within nano-range with low environmental and economic impact, could also be used in heavy metal detoxification and reprocessing.
- Smart particles could be useful for monitoring and purifying the environment.
- At normal temperature, nanostructured metals can be used to degrade hazardous organic wastes.

Farming practices, particularly pest management, could change the dynamics of nanotechnology in the future. Over the next 20 years, nanosciences will accelerate the sustainable agriculture. Nanostructures could be valuable in the development of next-generation herbicides, pesticides, and insect repellents. As a result, nanotechnology is thought to be one of the most promising solutions to issues in the agricultural and food industries.

CONCLUSION

There are a variety of user-friendly nanotechnology applications in the agricultural environment ranging from nanoherbicides, nanofertilizers, manufacturing of biosensors, plant disease diagnosis and its management etc. Regardless of these potential uses, new applications must be properly examined and regulated before being introduced into various businesses. A lot of challenges relating to human safety, the environment, and the ecosystem have yet to be resolved. Human exposure to nanomaterials, as well as the agri-food chain, may have detrimental repercussions for human health and the environment since nanoparticles attack non-target areas. As a result, effective and realistic risk management methods should be utilised during technology advancements. However, owing to certain negative responses from the scientific community to its application in the food and agriculture industries, the future of nanotechnology remains questionable.

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