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Review Article

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Application of Nanotechnology in Agriculture

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ABSTRACT

Nanotechnology opens a large scope of novel application in the fields of biotechnology and agricultural industries, because nanoparticles (NPs) have unique physicochemical properties, i.e., high surface area, high reactivity, tunable pore size, and particle morphology. Nanoparticles can serve as "magic bullets", containing herbicides, nano-pesticide fertilizers, or genes, which target specific cellular organelles in plant to release their content. Despite the plenty of information available on the toxicity of nanoparticles to plant system, few studies have been conducted on mechanisms, by which nanoparticles exert their effect on plant growth and development. Therefore, the present review highlights the key role of nanoparticles in plants. Moreover, nanoscience contributes new ideas leading us to understand the suitable mode of action of nanoparticles in plants. The appropriate elucidation of physiological, biochemical and molecular mechanism of nanoparticles in plant leads to better plant growth and development.

Key words: *Nanotechnology, Agriculture, Benefits, Crop improvement, Nanoparticles, Nano Pesticide, Nanofertilizer, Bio-scale carrier, Bio sensors.*

INTRODUCTION

Agriculture is the backbone of most developing countries, with more than 60% of the population reliant on it for their livelihood. Agricultural scientists are facing a wide spectrum of challenges such as stagnation in crop yields, low nutrient use efficiency, declining soil organic matter, multi-nutrient deficiencies, climate change, shrinking arable land and water availability and shortage of labour besides exodus of people from farming. In spite of immense constraints faced, we need to attain a sustainable growth in agriculture at the rate of 4% to meet the food security challenges. To address these problems, there is a need to explore one of the frontier technologies such as 'Nanotechnology' to precisely detect and deliver the correct quantity of nutrients and pesticides that promote productivity while ensuring environmental safety and higher use efficiency.

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The nanotechnology can be exploited in the value chain of entire agriculture production system[18]. Nanotechnology is emerging as the sixth revolutionary technology in the current era after the Industrial Revolution of Mid1700s, Nuclear Energy Revolution of the 1940s, The Green Revolution of 1960s, Information Technology Revolution of 1980s and Biotechnology Revolution of the1990s. It is now emerging and fast growing field of science which is being exploited over a wide range of disciplines such as physics, chemistry, biology, material science, electronics, medicine, energy, environment and health sectors.

Nontechnology deals with the matter at nano scale (1-100 nm) dimensions. These materials when reduced to the nano scale show some properties which are different from what they exhibit on a macro scale, enabling unique applications. Nano science has brought revolution in different fields by helping develop processes and products that are hardly possible to evolve through conventional methods. The nanotechnology aided applications have the potential to change agricultural production by allowing better management and conservation of inputs of plant and animal production. A survey by Salamanca–Buentella *et al.*[16] predicted several nanotechnology applications for agricultural production for developing countries within next 10 years. These included - (1) Nano forms zeolites for slow release and efficient dosage of water and fertilizers for plants; drugs for livestock; nano capsules and herbicide delivery. (2) Nano sensors for soil quality and for plant health monitoring; nano sensors for pest detection.
(3) Nano magnets for removal of soil contaminants and (4) Nanoparticles for new pesticides, insecticides, and insect repellents.

The recent statistics suggest that about 90% of the nano-based patents and products have come from just seven countries, namely, China, Germany, France, Japan, Switzerland, South Korea and USA while India's investments and progress is far from satisfactory. However, to take advantage of the fascinating field of nano-science, the Government of India has invested Rs. 1000 crore through the Nano Mission Project during 11th Five Year Plan and the investment is likely to be several folds higher during the 12th Five Year Plan period.

The Indian Council of Agricultural Research (ICAR) has opened up an exclusive platform to target Nanotechnology Applications in Agriculture. The ICAR – Nanotechnology Platform encompasses major themes such as synthesis of nano-particles for agricultural use, quick diagnostic kits for early detection of pests and diseases, nano-pheromones for effective pest control, nano agri-inputs for enhanced use efficiencies, precision water management, stabilization of organic matter in soil, nano food systems and bio safety besides establishing the policy frame work. Green-synthesis and microbial synthesis of nano materials for their agricultural use may be very important as they are naturally encapsulated with mother protein, therefore, more stable and safer to biological system. At present in India research is mainly concentrated on nano particle synthesis, smart release of nutrients from nano-fertilizers, nano-induced polysaccharide powder for moisture retention/soil aggregation and C build up, regulated release of active ingredients from nano-encapsulated herbicides, nano-seed invigoration, and slow and steady release of pesticides, nano-film for extended shelf-life of perishables and nano-remediation of soil and aquatic pollutants. These are cutting-edge researchable areas which are expected to expand in the years to come. However, if the nano products and the processes for creating them are not managed judiciously, there could be serious health and environmental risks.

2. Why should agriculture scientist think of nanotechnology?

(1) Crop yield stagnation, (2) Declining organic matter, (3) Multi nutrient deficiencies, (4) Climate change, (5) Shrinking arable land

and water availability, (6) Resistance to GMOs crops and (7) Shortage of labor.

3. Application of nanotechnology in agriculture and allied science:

Agriculture is the backbone of most developing countries, with more than 60% of the population reliant on it for their livelihood[4]. As well as developing improved systems for monitoring environmental conditions and delivering nutrients or pesticides as appropriate, nanotechnology can improve our understanding of the biology of different crops and thus potentially enhance yields or nutritional values. In addition, it can offer routes to added value crops or environmental remediation. Nanotechnology, as a new enabling technology, has the potential to revolutionize agriculture and food systems. Agricultural and food systems security, disease treatment delivery systems, new tools for molecular and cellular biology, new materials for pathogen detection and protection of the environment are examples of the important links of nanotechnology to the science and engineering of agriculture and food systems[24]. Nanotechnology operates at the same scale as a virus or disease infecting particle, and thus holds the potential for very early detection and eradication. Nanotechnology holds out the possibility that "Smart" treatment delivery systems could be activated long before macro symptoms appear. For example, a smart treatment delivery system could be a miniature device implanted in an animal that samples saliva on a regular basis. Long before a fever develops, the integrated sensing, monitoring and controlling system could detect the presence of disease and notify the farmer and activate bioactive systems such as drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactors.

3.1. Nano fertilizer:

Fertilizer play pivotal role in the agriculture production upto 35 to 40% of the productivity. To enhance nutrient use efficiency and overcome the chronic problem of eutrophication, Nano fertilizer might be a best alternative. Attempts have been made to synthesize nano fertilizer in order to regulate the release of nutrients depending on the requirements of the crops, and it is also reported that nano fertilizer are more efficient than ordinary fertilizer.

3.2. Nano food:

The definition of nano food is that nanotechnology techniques or tools are used during cultivation, production, processing or packaging of the food. It doesn't mean atomically modified food or food produced by nano machines. Although there are ambitious thoughts of creating molecular food using nano machines, this is unrealistic in the foreseeable future. Instead

Nanotechnologists are more optimistic about the potential to change the existing system of food processing and to ensure the safety of food products, creating a healthy food culture. They are also hopeful of enhancing the nutritional quality of food through selected additives and improvements to the way the body digests and absorbs food.

3.3. Food science and technology:

Nano technology for enhancing food security in India[17]. Hybrid polymer: Smart packaging with Nano silicon embedded durethan polymer to enhance the shelf life of the food materials Bayer polymers.

3.4. Crop improvement:

Gene therapy for plants: use of 3-nm mesoporous silica nanoparticle (MSN) for smuggling foreign DNA into cells. Shown the feasibility of **DNA sequencing** using a fluidic nano channel functionalized with a graphene nanoribbon.

3.5. Seed technology:

Seed is most important input determining productivity of any crop. Conventionally, seeds are tested for germination and distributed to farmers for sowing. In spite of the fact that seed testing is done in well equipped laboratories, it is hardly reproduced in the field due to the inadequate moisture under rainfed conditions. In India, more than 60% of the net area sown is rainfed; hence, it is quite appropriate to develop technologies for rainfed agriculture. A group of research workers is currently working on metal oxide nano-particles and carbon nanotube to improve the germination of rainfed crops. Khodakovskaya *et al.*[9] have reported the use of carbon nanotube for improving the germination of tomato seeds through better permeation of moisture. Their data show that carbon nanotubes (CNTs) serve as new pores for water permeation by penetration of seed coat and act as a passage to channelise the water from the substrate into the seeds. These processes facilitate germination which can be exploited in rainfed agricultural system.Use of carbon Nanotubes increases the germination through better penetration of the moisture[9].

3.6. Precision farming:

3.6.1. Smart Field System:

Bio-Nanotechnology has designed sensors which give increased sensitivity and earlier response to environmental changes and linked into GPS. These monitor **soil conditions** and **crop growth** over vast areas. Such sensors have already been employed in US and Australia UASD Plant pathology. 100% growth inhibition was seen in the *Pythium ultimum*, *Magnaporthe grisea*, *Colletotrichum gloeosporioides*, *and Botrytis cinere* and, *Rhizoctonia solani*, showed at 10 ppm of the nano sized silica-silver[13]. QDs have emerged as pivotal tool for detection of a particular biological marker with extreme accuracy.

3.6.2. Soil remediation:

Nanotech-based soil binder called Soil Set employed to avoid soil erosion Sequoia Pacific Research of Utah (USA)

3.6.3. Removal of heavy metals:

Ligand based nano coating can be utilized for effective removal of heavy metals as these have high absorption tendency

3.7. Water management:

Nanotechnology, offers the potential of novel nonmaterial's for the treatment of surface water, groundwater and wastewater contaminated by toxic metal ions, organic and inorganic solutes and microorganisms. Due to their unique activity towards recalcitrant contaminants many non materials are under research and development for use for water purification. To maintain public health, pathogens in water need to be identified rapidly and reliably. Unfortunately, traditional laboratory tests are time consuming. Faster methods involving enzymes, immunological or genetic tests are under development. Water filtration may be improved with the use of nano fiber membranes and the use of nano biocides, which appear promisingly effective. Biofilms contaminating portable water are mats of bacteria wrapped in natural polymers which are difficult to treat with antimicrobials or other chemicals. They can be cleaned up only mechanically, which cost substantial down-time and labour. Work is in progress to develop enzyme treatments that may be able to break down such biofilms. Magnetite (iron oxide) nano crystals to capture and remove arsenic from contaminated water.

3.7.1. Nano-fertilizer technology:

In India, fertilizers, along with quality seed and irrigation, are mainly responsible for enhanced food grain production (55 mt) in 1960s to (254 mt) in 2011 coinciding with the spectacular increase in fertilizer consumptions from 0.5 mt to 23 mt, respectively. It has been conclusively demonstrated that fertilizer contributes to the tune of35-40% of the productivity of any crop. Considering its importance, the Government of India is heavily subsidizing the cost of fertilizers particularly urea. This has resulted in imbalanced fertilization and occurrence in some areas, nitrate pollution of groundwater due to excessive nitrogen application. In the past few decades, use efficiencies of N, P and K fertilizers have remained constant as 30-35%, 18-20% and 35-40%, respectively, leaving a major portion of added fertilizers to accumulate in the soil or enter into aquatic system causing eutrophication. In order to address issues of low fertilizer use efficiency, imbalanced fertilization, multi-nutrient deficiencies and decline of soil organic matter, it is important to evolve a nano-based fertilizer formulation with multiple functions.

Nano-fertilizer technology is very innovative but scantily reported in the literature. However, some of the reports and patents strongly suggest that there is a vast scope for the formulation of nano-fertilizers. Significant increase in yields has been observed due to foliar application of nano particles as fertilizer[21,22,20]. It was shown that 640 mg ha-1 foliar application (40 ppm concentration) of nano phosphorus gave 80 kg ha-1 P equivalent yield of cluster bean and pearl millet under arid environment. Currently, research is underway to develop nano-composites to supply all the required essential nutrients in suitable proportion through smart delivery system. Preliminary results suggest that balanced fertilization may be achieved through nanotechnology[19]. Indeed the metabolic assimilation within the plant biomass of the metals, e.g., micronutrients, applied as Nano-formulations through soil-borne and foliar application or otherwise needs to be ascertained. Further, the Nano-composites being contemplated to supply all the nutrients in right proportions through the "Smart" delivery systems also needs to be examined closely. Currently, the nitrogen use efficiency is low due to the loss of 50-70% of the nitrogen supplied in conventional fertilizers. New nutrient delivery systems that exploit the porous nano scale parts of plants could reduce nitrogen loss by increasing plant uptake. Fertilizers encapsulated in nano particles will increase the uptake of nutrients. In the next generation of nano fertilizer, the release of the nutrients can be triggered by an environmental condition or simply released at desired specific time.Foliar application of nano Phosphorous as fertilizer (640 mg ha^{-1}) and soil application of phosphorous fertilizer (80 kg ha^{-1}) yielded equally in cluster bean and pearl millet under arid environment[21,22].

3.8. Weed management:

Weeds are menace in agriculture. Since two-third of Indian agriculture is rainfed farming where usage of herbicide is very limited. Herbicides available in the market are designed to control or kill the above ground part of the weed plants. None of the herbicides inhibits activity of viable belowground plant parts like rhizomes or tubers, which act as a source for new weeds in the ensuing season. Soils infested with weeds and weed seeds are likely to produce lower yields than soils where weeds are controlled. Improvements in the efficacy of herbicides through the use of nanotechnology could result in greater production of crops. The encapsulated nano-herbicides are relevant, keeping in view the need to design and produce nano-herbicide that is protected under natural environment and acts only when there is a spell of rainfall, which truly mimics the rainfed system.

Developing a target specific herbicide molecule encapsulated with nanoparticles is aimed for specific receptor in the roots of target weeds, which enter into roots system and translocated to parts that inhibit glycolysis of food reserve in the root system. This will make the specific weed plant to starve for food and gets killed[5]. Adjuvant for herbicide application are currently available that claim to include nonmaterial. One nano surfactant based on soybean micelles has been reported to make glyphosate-resistant crops susceptible to glyphosate when it is applied with the 'nanotechnology-derived surfactant'.Soybean based nano surfactant reported to make glyphosate resistant crops susceptible to glyphosate[5].

3.8.1. Nano-pesticide:

Persistence of pesticides in the initial stage of crop growth helps in bringing down the pest population below the economic threshold level and to have an effective control for a longer period. Hence, the use of active ingredients in the applied surface remains one of the most cost-effective and versatile means of controlling insect pests. In order to protect the active ingredient from the adverse environmental conditions and to promote persistence, a nanotechnology approach, namely "nano-encapsulation" can be used to improve the insecticidal value. Nano encapsulation comprises nano-sized particles of the active ingredients being sealed by a thin-walled sac or shell (protective coating). Recently, several research papers have been published on the encapsulation of insecticides. Nano-encapsulation of insecticides, fungicides or nematicides will help in producing a formulation which offers effective control of pests while preventing accumulation of residues in soil. In order to protect the active ingredient from degradation and to increase persistence, a nanotechnology approach of "controlled release of the active ingredient" may be used to improve effectiveness of the formulation that may greatly decrease amount of pesticide input and associated environmental hazards. Nano-pesticides will reduce the rate of application because the quantity of product actually being effective is at least 10-15 times smaller than that applied with classical formulations, hence a much smaller than the normal amount could be required to have much better and prolonged management.

Several pesticide manufacturers are developing pesticides encapsulated in nanoparticles[12]. These pesticides may be time released or released upon the occurrence of an environmental trigger (for example, temperature, humidity, light). It is unclear whether these pesticide products will be commercially available in the short-term. Plant diseases are major factors limiting crop yields. The problem with the disease management lies with the detection of the exact stage of prevention. Most of the time appropriate plant protection chemicals are applied to the crop as a precautionary measure leading to avoidable environmental hazards, or else applications are made after the appearance of the disease symptoms, thereby causing some amount of crop losses. Among the different diseases, the viral diseases are the most difficult to control, as one has to stop the spread of the disease by the vectors. But once it starts showing its symptoms, pesticide application would not be of much use. Therefore, detection of the exact stage such as stage of viral DNA replication or the production of initial viral protein is the key to the success of control of viral diseases. Nano-based viral diagnostics, including multiplexed diagnostics kits development, have taken momentum in order to detect the exact strain of virus and the stage of application of some therapeutic to stop the disease. Detection and utilization of biomarkers, that accurately indicate disease stages, is also an emerging area of research in bio-Nanotechnology. Measuring differential protein production in both healthy and diseased states leads to the identification of the development of several proteins during the infection cycle. Clay nanotubes (halloysite) have been developed as carriers of pesticides at low cost, for extended release and better contact with plants, and they will reduce the amount of pesticides by 70-80%, thereby reducing the cost of pesticide with minimum impact on water streams.

3.10. Nano-scale carriers

Nano scale carriers can be utilized for the efficient delivery of fertilizers, pesticides, herbicides, plant growth regulators, etc. The mechanisms involved in the efficient delivery, better storage and controlled release include: encapsulation and entrapment, polymers and dendrimers, surface ionic and weak bond attachments among others.

These help to improve stability against degradation in the environment and ultimately reduce the amount to be applied, which reduces chemical runoff and alleviates environmental problems. These carriers can be designed in such a way that they can anchor plant roots to the surrounding soil constituents and organic matter. This can only be possible if we un revel the molecular and conformational mechanisms between the nano scale delivery and targeted structures, and soil fractions. Such advances as and when they happen will help in slowing the uptake of active ingredients, thereby reducing the amount of inputs to be used and also the waste produced.

3.11. Biosensors to detect nutrients and contaminants

Protection of the soil health and the environment requires the rapid, sensitive detection of pollutants and pathogens with molecular precision. Soil fertility evaluation is being carried out for the past sixty years with the same set of protocols which may be obsolete for the current production systems and in the context of precision farming approaches. Accurate sensors are needed for *in situ* detection, as miniaturized portable devices, and as remote sensors, for the real-time monitoring of large areas in the field.

These instruments are able to reduce the time required for lengthy microbial testing and immunoassays. Application of these instruments includes detection of contaminants in different bodies such as water supplies, raw food materials and food products. Enzymes can act as a sensing element as these are very specific in attachment to certain biomolecules. Electronic nose (E-nose) is used to identify different types of odors; it uses a pattern of response across an array of gas sensors. It can identify the odorant, estimate the concentration of the odorant and find characteristic properties of the odor in the same way as might be perceived by the human nose. It mainly consists of gas sensors which are composed of nanoparticles e.g. ZnO nanowires. Their resistance changes with the passage of a certain gas and generates a change in electrical signal that forms the fingerprint pattern for gas detection. Biosensors provide high performance capabilities for use in detecting contaminants in food or environmental media. They offer high specificity and sensitivity, rapid response, user-friendly operation, and compact size at a low cost[2]. While the direct enzyme inhibition sensors currently lack the analytical ability to discriminate between multiple toxic substances in a sample (such as simultaneous presence of heavy metal and pesticide), they may prove useful as a screening tool to determine when a sample contains one or more contaminants. These methods are amenable to deployment in single-use test strips (making them useful to those in the field).According to[8], detection of multiple residues of organo phosphorus pesticides has been accomplished using a nonmagnetic particle in an enzyme linked immune sorbent assay (ELISA) test. The authors suggest that ELISA is more cost-effective than analytical tests requiring expensive laboratory equipment with high levels of skill.

4. Agricultural Engineering Issues

Nanotechnology has many applications in the field of agricultural machinery. These cover: application in machine structure and agricultural tools to increase their resistance against wear and corrosion and ultraviolet rays; producing strong mechanical components with use of Nano-coating and use of bio-sensors in smart machines for mechanical-chemical weed control; production of Nano-cover for bearings to reduce friction. The use of Nanotechnology in production of alternative fuels and reduction of environmental pollution are also worth mentioning. Nano coating of agricultural tools to increase their resistance against wear and corrosion.

5. Health & Environmental Concerns

Researchers noted that rats breathing in Nano particles generally have those particles settle in the brain and lungs, which led to significant increases in biomarkers for inflammation and stress response and that Nano-particles include induce skin aging through oxidative stress in hairless mice. Extremely small fibers, so called Nano fibers, can be as harmful for the lung as asbestos is The Royal Society report identified a risk of Nanoparticles or Nano-tubes being released during disposal, destruction and recycling, and recommended that "manufacturers of products that fall under extended producer's responsibility regimes such as end-of-life regulations to publish procedures outlining how these materials will be manage to minimize possible human and environmental exposure". Reflecting the challenges for ensuring responsible life cycle regulation, the Institute for Food and Agricultural Standards has proposed that standards for Nanotechnology research and development be integrated across consumer, worker and environmental standards. They also propose that the NGOs and other citizen groups play a meaningful role in the development of these standards. The ultra-small sizes that make the nanoparticles of immense usefulness, unfortunately the same characteristic also causes several adverse effects and may represent significant hazards to environment, animals, human beings and plants when used non-judiciously. The possible hazards are mentioned hereunder:

- Nanoparticles as pesticides, fertilizers or in other formulations, when air-borne, may deposit on above ground parts of plants.

They may plug stomata and create a fine physical and toxic barrier layer on stigma preventing pollen tube penetration. They may also enter the vascular tissue and impair translocation of water, minerals and photo synthate.
- Animals may inhale nanoparticles resulting into various ill effects and disorders. The particles may enter the bloodstream.
- Nano-pesticides may reduce environmental contamination through the reduction in pesticide application rates, but they may also create new kinds of contamination of soils and waterways due to enhanced transport, longer persistence and higher toxicity.
- Air-borne nanoparticles present some specific hazards for human health; they may enter the body through the respiratory system.
- Due to the entry of nanoparticles into lungs and blood stream, there is possibility of inflammation, protein fibrillation and induction of genotoxicity.

Because of these risks, the use of nanotechnology in fertilizer and pesticide formulations has to be addressed very cautiously, and this warrants mandatory need to critically analyze and examine the risks involved with the nano-formulations.

CONCLUSION

Nanotechnology is capable of being used in agricultural products that protect plants and monitor plant growth and detect diseases**.** Scientists are still seeking new applications of nanotechnology in agriculture and the food industry. The agricultural sector and the food industry will indeed see tremendous changes for the better in the coming years.

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