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Application of nanotechnology in Indian agriculture: A review

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Abstract
Nanoscience and nanotechnology be a symbol of a new front line for the research community. Nanotechnology is working with lowest particles which raise hopes for not only improving the agriculture productivity but also help monitor the quality of agricultural produce. Nanotechnology application in agriculture is rarely studied in India as well as abroad but now a day many research institutes and agricultural universities have begun research to find solutions to different unidentified field problems. The Jawaharlal Nehru Agricultural University is one of the early birds in such endeavors to begun research in the attracting field of science. The reported reviews of literature across the world suggest potentials of nanotechnology application in Indian agriculture. In this review, application of nanotechnology in Indian agriculture science *viz*. nanofertilizers, nanoherbicides, nanobiotechnology, Nanobiosensor and nanopesticides have been summarized**.**

Keywords: Nanofertilizers, nanoherbicides, nanobiotechnology, biosensor and nanoremediation

Introduction
Nanotechnology applications in agriculture are gradually transforming the theoretical possibility into the practical application. Nanotechnology possesses the potential to augment agricultural productivity through genetic improvement of plants and animals. The potential is increasing with suitable techniques and sensors being indentified for precision agriculture, natural resources management, and efficient delivery system for fertilizers, pesticides, food processing, packaging and other areas. The Department of Science and Technology launched the Nano Science and Technology initiated in 2001 under the leadership of Prof. C.N.R. Rao which has been focusing on research and development in Nanoscience and technology in a comprehensive manner so that India can become a significant player in the area and contribute to the development of new technologies.

Weeds are menace in agriculture. Since 2/3 of Indian agriculture is rainfed farming where usage of herbicide is very limited, weeds have the potential to jeopardize the total harvest in the delicate agroecosystems. 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 nanoherbicides are relevant, keeping in view the need to design and produce a nanoherbicide that is protected under natural environment and acts only when there is a spell of rainfall, which truly mimics the rainfed system. (Yadav and Shrivastava, 2015) [23].

Indian and Global Scenario
The Government of India is currently spending rupees 1000 crores under Nano Mission. During the Eleventh Five year Plan period. The Nano Mission also plan to make special efforts for development and commercialization of nanotechnology, not only through public private partnerships but also by encouraging and enabling the private sector to invest in and leverage this sunrise technology. The investment on agriculture is less than 5% and therefore lots of scope available for agricultural scientists to exploit the fascination technology. Nanotechnology is in its nascent stage and over the next few years, it is expected to grow exponentially. In the Indian scenario, a larger emphasis has been to initiate nanotechnology. In the ancient time, Indian craftsmen used unique smelting techniques to manufacture the Damascus blades which led to nanotisation giving them a unique long-lasting edge.

Wootz also had a high percentage of carbon, which was introduced by incorporating wood and other organic matter during fabrication. India, for ages, was a leading exporter of this steel which was used to make Persian daggers which were quite popular in Europe centuries ago (Indian craftsmen, artisans used nanotech 2000 years ago). Recently under 10th five-year plan (2002-2007), the Indian government has spent Rs. 1000 million for nanotechnology. Currently Department of Biotechnology (DBT), Department of Science and Technology (DST), Council of Scientific and Industrial Research (CSIR), Science and Engineering Research Council (SERC) and Indian Council of Agricultural Research (ICAR) invested huge funds to create and promote nanoscience and nanotechnology in different sections including agriculture.

The global nanotechnology market is expected to touch US$29 billion mark by 2010. The exponential growth of global investment in nanotechnology research closely coincides with the number of patents related to nanoproducts. Recent statistics suggest that 88% of the patents is generated from just seven country including China, Germany, France, South Korea, Switzerland and Japan. India's investment is far from the global club of nanotechnology. In 2008, Both public and private sectors worldwide had invested about US$20 billion. The global nanotechnology market should reach $90.5 billion by 2021 from $39.2 billion in 2016 at a compound annual growth rate (CAGR) of 18.2%, from 2016 to 2021. Furthermore, owing to the application of nanotechnology in various sectors, the demand for the same is poised to observe an escalation at a profitable compound annual growth rate (CAGR) of 13.55% during the forecast period 2020-2025. A key application of nanotechnology is found in electronics and semiconductor products segment, which is estimated to grow at a substantial CAGR of 15.01% through to 2025.

Nanotechnology Application

The emergence of nanotechnology and the development of new nanodevices and nonmaterial open up potential novel application in agriculture. Nanotechnology is defined as "the understanding and control of matter at dimensions of roughly 1-100nm where unique properties make novel application possible". It is highly promising technology that spans many areas of science and technology application. Rapid achievements in Nanoscience and nanotechnologies now-a-days have opened up new horizons for many industrial and consumers sectors as well as agricultural and allied sectors. Nanotechnology is fast emerging as the next generation of development and transformation of agri-food systems. Abdul Kalam (2007) [1] suggested that nanotechnology has potential to bring the next revaluation breakthrough in agricultural based natural resource management nanotechnology gas a wide application in medicine (Zhou *et al*. 2004) [24], environment (Shi *et al.*, 2007) [22] (Table 1). The use of nanotechnology in agriculture and food system is just emerging and expecting to grow alarming. Nanotechnology has the potential to revolutionize the agriculture and food industry with new tools for the molecular treatments of diseases, rapid disease detection, enhancing the ability of plants to absorbs nutrients etc. smart sensors and smart delivery system will help the agriculture industry combat viruses and other crop pathogens. Recently nanostructure catalyst will be available which increase the efficiency of pesticides and herbicides allowing lower doses to be used. Nano-barcode and nano-processing could also help monitor the quality of agriculture produce. If Indian agriculture is to attain its broad national goal of sustainable agriculture growth of over 4%, it is important that the nanotechnology research is extended to the agricultural total production-consumption system that is across the entire agricultural value chain. This would require focusing on technologies that increase agricultural productivities, product quality and resources use efficiencies that reduce on-farm costs, raise the value of production and increase farm income as well as on conserving and enhancing the quality of the natural base. Now a days nanotechnology providing different nano devices and nano materials which having a unique role in agriculture like nano biosensors to detect moisture content and nutrient status in the soil and also applicable for site specific water and nutrient management. Nanofertilizers for efficient nutrient management, nanoherbicides for weed control in crop field, nano-nutrient particles for increasing seed vigor, nano pesticides for efficient pest management, alginate or chitosan nanoparticles can be used as herbicide carrier material especially for herbicides *viz.* paraquat. Hence, nanotechnology have greater role in crop production with environmental safety, ecological sustainability and economic stability.

Table 1: Nanomaterial and their functions

Nano-materials	Functions
Carbon nanotubes	Seed germination
Nano-nutrients	Plant/animal/human nutrition
Nano-pesticides	Plant protection
Nanoscale carrier	Efficient delivery of fertilizer, pesticides herbicides
Nanosensors	To detect nutrients & contamination
Nanochips/ smart machines	For machinery and tracing
Nanocellulose	Light weight material
Identity preseravation & tracking	T promote quality
DNA nanovaccines & gene delivery	For treatment
Nano barcode technology	As ID tags for multiplex analysis
Photocatalysis	TiO_2, ZnO, SnO_2, ZnS etc (oxidizing agent)

Nano-fertilizer

Nanofertilizers are synthesized or modified form of traditional fertilizers, fertilizers bulk materials or extracted from different vegetative or reproductive parts of the plant by different chemical, physical, mechanical or biological methods with the help of nanotechnology used to improve soil fertility, productivity and quality of agricultural produces. Rock phosphate if use as nano form it may increase availability of phosphorus to the plant because direct application of rock phosphate nanoparticles on the crop may prevent fixation in the soil similarly there is no silicic acid, iron and calcium for fixation of the phosphorus hence, it increases phosphorus availability to the crop plants (NAAS, 2013). Attempts are being made to synthesize nanofertilizers in order to regulate the release of nutrients depending on the requirement of crops. A very few nanofertilizers formulations have been synthesized in China, Germany, and USA and are being tested under laboratory conditions. Liu *et al*. (2006) [9] have shown that nanocomposites containing organic polymer intercalated in the layers of Kaolinite clays can be used as a cementing material regulate the release of nutrients from conventional fertilizers (Table 2). These processes increase the nutrient use efficiency, besides preventing environmental hazards. In another study, a patented nanocomposite consist of N.P and K and micronutrients and mannose and amino acids have shown to increase the uptake and utilization of nutrients by grain

crops (Jinghua, 2000) [7]. Subramanian *et al*. (2008) [21] reported that nanofertilizers and nanocomposites can be used to control the release of nutrients from the fertilizer granules so as to improve the NUE while preventing while preventing the nutrient ions from either getting fixed or lost to the environment. Recently, Sharmila Rahale (2011) [20] has monitored the nutrient release pattern of nanofertilizers formulations carrying nitrogen.

Nanofertilizers are capable of releasing nutrients, especially NO^3-N more than 50 days while nutrient release from conventional fertilizer (Urea) ceased to exist beyond 10-12 days (Subramanian and Rahale, 2009) [19]. An enhanced production has been observed by foliar application of nano particles as fertilizer (Raliya, 2012; Tarafdar, 2012) [18]. It has been found that 640 mg ha^{-1} foliar application (40 ppm concentration) of nanophosphorus gives 80 kg ha^{-1} P equivalent yield under arid environment of cluster bean and pearl millet. In order to address a number of issues such as low fertilizer use efficiency, imbalanced fertilization, multi-nutrient deficiencies and decline of organic matter, it is quite pertinent to evolve a nano based fertilizer formulation with multiple function.

Table 2: Application of nanotechnology under soil and water

Application Area	Problem type of Technology	
Soil	1	Nanozeolites for soil conservation and slow release of fertilizers
	2	Nanomegnets for removal of soil contaminants
	3	Nanoparticles for more release of enzymes by activation of plants and microbes
	4	Nanoparticles for enhanced release of polysaccharides by microbes for soil aggregation, moisture retention and carbon build-up
	5	Nanosensors for automation
Plant	1	Nanosensors, polymers, Clays, zeolites for contamination detection
	2	Nanomembranes for purification, salinization, detoxification
	3	Nanomolecules for ROBUS water tank and to prevent leakage
	4	Nanosensors for water flow detection
	5	Nanozeolites for efficient release of water

Nanoherbicides

Weeds are unwanted plants in agriculture production system causing yield loss to the tune of 30-40% depending on the intensity of infestation. A wide range of herbicides is used to manage the weed but found less or ineffective in rainfed agriculture as these chemicals may loose their herbicidal value in the absence of moisture. Encapsulation of herbicides is one of the important strategies to regulate the release of herbicide molecules. Encapsulated nanoherbicides in a MnO_2 core shell shielded with bilayer polymers that open up and excluding the active ingredient on receipt of rainfall (Chinnamuthu, 2010) [6]. Nanotechnology has potential to get rid of weeds by using nanoherbicides in an eco-friendly manner without leaving any toxic residues in soil and environment reported by (Perez-de-Leuque and Rubiales, 2009) [14]. Herbicides available in the market are designated to control or kill the above ground part of the weed plants. None of the herbicides inhibits activity of viable underground ground plant parts like rhizomes or tubers, which act as a source for new weeds in the ensuring season. Developing a target specific herbicide molecule encapsulated with nanoparticles is aimed for specific receptor in the roots of target weeds, which enters into roots system of the weeds and translocated to parts that inhibit glycol sis of food resave in the root system ultimately making the specific weed plant to starve for food and get killed (Yadav and Shrivastava, 2015) [23]. Detoxification of weed residues is necessary as excessive use of herbicides for longer period of times leaves residues in soil and cause damage to succeeding crop reported by Chinnamuthu and Boopathi, (2009) [5]. Controlled release formulations (CRFs) represent an alternative to the conventional systems of herbicide application where the active agent is available for a specific product in duration designed to achieve the intended effect (Sopeña, *et al*. 2009) Intensive use of the herbicides and other classes of chemicals products in agricultural practices has resulted in serious environmental impact, which increased the level of the herbicide residues in natural water, soil, and foodstuffs. Controlled release nano-formulation of herbicides in which the herbicides are incorporated in a nano-sized matrix might be an excellent alternative over the conventional methods of herbicides application that usually employed to control the pathogens, weeds, and several pests, thereby limiting the amount of the active ingredient available for unwanted processes. This review presents a better approach using nanotechnology for controlled release formulation of herbicides in agriculture (Happiness Ugbede Itodo, 2019).

Nanobiotechnology

Nanobiotechnology has the potential to increase the efficiency and quality of agricultural production and food storage to enhance the safety of food supplies for the protection of consumers and producers and to introduce new functionality (value-added products) for food, fibre and agricultural commodities (Subramanian and Tarfdar, 2011) [12]. The development of nanodevices and nano-material could open new applications in plant biotechnology. On the other hand, biotechnology uses the techniques of biology in order to manipulate molecular, genetic and cellular processes to develop products and services and it can be used in diverse fields from medicine to food and agriculture (Prasad *et at*., 2014) [11]. Having said that, the Nanobiotechnology is the integration of nanotechnology, biotechnology and also chemical and physical processing, material science and system engineering with the aim of obtaining new products previously modified at nanoscale that may have improved conditions with respect to the conventional materials (Raj and Ingle, 2012) [15]. Modern technologies such as bio and nanotechnologies can play an important role in increasing the annual reduction and improving the quality of food produced by farmers. Many believe that modern technologies will secure growing world food needs as well as deliver a huge range of environmental, health and economic advantages (Bhagat *et al*., 2015) [3]. Nanobiotechnology will pave ways new researchable areas and applications to study molecules, DNA and cells for food, nutraceutical and pharmaceutical applications which provide higher resolution materials and devices for the separation of enzymes and other biomolecules

that are key catalysts for industrial biotechnology. On the other hand, nanobiotechnology helps to develop novel laboratory on a chip proteomics technology for assessment of metabolic pathways in important biocontrol agents. Biological tests measuring the presence or activity of selected substances become quicker, more sensitive and more flexible when nano particles are put to work as tags or labels. Magnetic nanoparticles bound to suitable antibody are used to label specific molecules structures or microorganism.

For example, gold nano particles tagged with short segments or DNA can be used for detection of genetic sequences in a sample. Nano pore technology for analysis of nucleic acids converts strings of nucleotides directly into electronic signatures. (Table 3)

Table 3: Nanomaterial used now -a -days in Agriculture

SN	Materials	Purpose
1.	Magnetic carbon coated nanoparticles	Controlled release herbicides and smart agrochemical delivery system used in several plants like tomato, sunflower and pea
2.	Polyhydroxybutyrate-co-hydroxyl valerate microphares with atrazine sized 13 mm inorganic Zn-Al layered double hydroxide as release agent	Nano controlled release system of 2-4-dichlorophenophenoxyacetate used as herbicide
3.	Porous hollow silica nanoparticles	Nano controlled release system of water-soluble pesticide
4.	CNT conjugated with INF24 oligonucleotides silver Nanoparticles (AgNPs)	Reduce rust disease and control pathogens
5.	Amphotericin B nanodisks	Treatment of fungal pathogens
6.	Gold nanoparticles (AuNPs)	Delivery of DNA during transformation of plant cells plant growth promoting rhizobacteria

Nanosensors and Nano-biosensors

Nanotechnology has allowed the use of Nanosensors, which are sophisticated instruments that can respond to physical, chemical or biological aspects and transfer that response into a signal that can be used by humans, allowing to detect many factors due to drought, temperature, insect or pathogen pressure, or lack of nutrients (Prasad *et al.* 2014) [11]. The smart sensors in the agriculture sector are considered a powerful tool for track detect and control animal and plant pathogen, mainly because the devices help in the detection of chemical contaminants, virus and bacteria in agricultural systems, nutrient content and plant stress (Mousavi and Rezaei, 2011) [10]. Some specific applications of these sensors in agriculture are the MEMS (Micro Electro Mechanical Systems) that through microelectronic circuits are capable of sensing and monitoring temperature and moisture in soil, to diagnose oil disease (caused by infecting soil microorganisms, such as viruses, bacteria and fungi) via the quantitative measurement of differential oxygen consumption in the respiration of good microbes and bad microbes in the soil. Also, biosensors are developed, using photo system II, known to bind several groups of herbicides and chemicals, among others (Agrawal and Rathore, 2014) [2].

Physical and chemical new properties of nanoscale materials are also exploitable in the development of biosensors. Nanomaterials are used in biosensors with the purpose of improve their sensitivity and efficiency through new signal transduction technologies (Prasad *et al*., 2014) [11]. Nanosensors with immobilized bioreceptor which is selective for target analytic molecules are called Nanobiosensors. In other words, this is a modified version of a biosensor that incorporates a biological derived sensitized element linked to a physical-chemical transducer. This device integrates a biological element with an electronic component to yield a measurable signal and in the other hand; the biological recognition is through the transducer process (Raj *et al.*, 2012) [15]. The conventional nanobiosensors have three principal components. The probe or biologically sensitized elements such as enzymes, antibodies, tissues, microorganisms (pathogens), nucleic acids, among others, which have the function of receive signals from the sample and transmit it to a transducer. The transducer measures physical changes occurring at the biological receptor. After that, the device transforms that energy into measurable electrical emission. The detector, catches the signal from the transducer and then it is passed to a microprocessor where are amplified and analyzed. Finally, the data is transferred to a display and the user can observe the results (Raj *et al*., 2012) [15]. Due to investigations that have been carried out in the last years, Nanobiosensors can be classified into many types such as mechanical, optical, electronic, viral, probes encapsulated by biologically localized embedding (PEBBLE), nano-shell and enzyme-based Nanobiosensors (Table). The use of each type of nanobiosensor depends on the analyte, for example, biosensors are used for the detection of phenols, polyaromatic compounds, halogenated pesticides and volatile organic compounds (VOCs) while electrochemical sensors can be used as chemical gas sensors (Baruah and Dutta, 2009) [4]. Nanobiosensors have been used because of some advantages they have with respect to traditional sensors, such as ultra-sensitivity, what allows the easy detection of virus, small particles and low concentrations of substances that could be potentially harmful; also these devices work at atomic scale with highest efficiency and have increased surface to volume ratio. Nevertheless, it should be mentioned that because of their sensitivity, Nanosensors are error prone and are still under early stage (Raj and lngle 2012) [15] and (Kwak *et al.*, 2017) [8].

Nanopesticides

Every year in India pests and diseases eat away on an average 15- 25% of food produce. Past three financial years (FY14-16) have been a challenging year for crop protection chemicals market in India as well as throughout the world. As per Economic Survey of India, agriculture sector has grown by 4.1% in FY17. The conventional group of insecticides have several major disadvantages like high dosage per unit crop, drift hazards, operational hazards and residues in environment, plants and in marketable produce, they also affect non-target vegetation and non-target organisms. So, they need to be replaced by an alternative pest control strategy that can overcome the above lacunas.

However, the major advantages of use of nano-pesticides over conventional pesticides are:

1. Nanotechnology offers a tool for developing novel formulations of eco-friendly pesticides as majority of nano-pesticide formulations are highly target specific.
2. Generally, targeted delivery and controlled release of nano-pesticides can improve pesticide utilization and

reduce residue and pollution. For example, Nano-microcapsule formulations have slow release and protection performance because they have been prepared using light-sensitive, thermo-sensitive, humidity-sensitive enzyme-sensitive and soil pH-sensitive high polymer materials to deliver pesticides.
3. Nano-pesticide formulations improve adhesion of droplets on plant surface (reduces drift losses) which intern improves the dispersion and bio-activity of active ingredient (A.I.) of pesticide molecules.
4. Therefore, Nano-pesticides will have high efficacy compared to the conventional pesticide formulations (i.e., D-Dust, G-Granule, P-Pellet, EC-Emulsifiable Concentrate, WP-Wettable Powder, WDG-Water Dispersible Granule, etc.) and due to their small size, improvable pesticide droplet ductility, wet ability and target adsorption when sprayed in fields has made these nano-pesticides provide efficient and environmental friendly advantages.
5. Nano-pesticides are extraordinary means for setting up an eco-friendly and sustainable agriculture system because it reduces the overall chemical usage, decreases the toxic residues and enhances the overall crop protection.

Formulations of nano-pesticides: The research in nanotechnology has led to the development of different nano formulation which can be applied in crop protection *viz*., nano-insecticides, nanoherbicides, nano-fungicides and nano-nematicide. Nano-pesticides are formulated according to their intended purpose as formulations improving solubility, slow release of active ingredients, prevent degradation etc. For achieving these purposes, modifications in the chemical nature carrier molecule have been modified and classified as organic polymer-based formulations, lipid-based formulations, nano size metals and metal oxides, clay based nonmaterial etc.

The limitations in the usage of nano-pesticides
1. The risk that nano-particles (nano-pesticides) may pose to human and environment health is not yet fully understood.
2. Nano-pesticides may also create new kinds of contamination of soils and waterways since nano-pesticides are apparently much more persistent and have higher degrees of toxicity when compared to their traditional counterparts.

Therefore, a better understanding of the fate and effect of nanotechnology-based products and its applications in agriculture is required. It is a good thing that all necessary safety precautions are taken before deciding to go ahead and use new technologies on a large scale. In future, nanotechnology served as a prime tool to develop several products in material science, medicine and defense, we begin to scratch the surface in the field of agriculture.

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