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Nanotechnology in Agriculture

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Abstract: ***The application of nanotechnology to agriculture and food industries is carrying increased weight because of the good benefits ranging from improved food quality, processing and nutrition and safety to reduced agricultural inputs. Nano-materials in agriculture reduce the amount of spread chemicals, minimize nutrient losses in fertilization and increased yield through water and nutrient management. The significant interest of using nanotechnology in agriculture includes specific applications like nano-fertilizers and nano-pesticides to track products and nutrients levels to increase the productivity without decontamination of soils and waters and protection against pest and diseases. The nano-particles like Ag, ZnO and CuO are relevant in the growth of agriculture by bioactivity and bio-modification. The delivered nanotechnology devices are also being explored in the field of plant breeding and genetic transformation. For the crop production and plant protection the nano-capsules nano-particles and nano-emulsion act as a smart delivery system of active ingredients for disease and pest control. Also these particles are used in fertilizers for the enhancement of nutrients adsorption by plants and delivery of nutrients. The nano-particles carrying DNA or RNA can be delivered to plant cells for genetic transformation hence plant breeding. From many different technological innovations including hybrid varieties, synthetic chemicals and biotechnology nanotechnology seeks a new source of agricultural improvements benefitting from food processing, distribution, packaging and functional food. The increased use of pesticides and herbicides in the agricultural system effectively utilizes modern technology for crop management called Controlled Environment Agriculture (CEA). For insect pest control a slow but efficient chemical like insecticide is released through a process called Nano-encapulation. To enhance nutrient use efficiency and overcome the chronic problem of eutrophication, nano-fertilizer might be a best alternative. Nanofertilizers are synthesized in order to regulate the release of nutrients depending on the requirements of the crops. Nanofertilizers could be used to reduce nitrogen loss due to leaching, emissions, and long-term incorporation by soil micro-organisms. This study provides a review of the current challenges of sustainability, food security and climate change that are exploring by the researchers in the field of nanotechnology in the improvement of agriculture.***

Keywords: Bio nanotechnology, Nano-encapsulation , Nano-fertilizers, Eutrophication, nano-fabrication, nano-particles.

1. Introduction

Proper nutrition and clean environment promote human health. Nanotechnology is used to a limited extent at the moment for achieving these aims although it has the potential to revolutionize agriculture by its ground breaking scientific innovations and applications. So far, the use of nanotechnology in agriculture has been mainly theoretical but to some extant a little bit practical. Undoubtedly, some agri-scientists Joseph, T. and M. Morrison, 2006 have introduced this concept in their working areas and will continue to have significant effect in the main areas of the agriculture industry: development of new functional materials; product development; design of methods and instrumentation for food safety including bio-security. It is described by the Environmental Protection Agency (EPA 2007) as a technology of understanding and control of matter at dimensions of roughly 1-100 nm, where unique physical properties make novel applications possible. This definition is slightly rigid on the size dimensions, rather than inherent properties of nano-material. The dimensions of nano particles are in the close vicinity of colloidal particulate i.e. in the range of 10- 1000 nm. Conceptually, nanotechnology could be illustrated as the science that deals in designing and building machines in which every atom and chemical bond is specified precisely.

A UN Survey (M.C. Roco, et.al. 2005) on potential applications of nanotechnology in Asian and African countries identified agricultural productivity enhancement as the second most critical area of application for new millennia achievement while energy conversion and storage was ranked first and water treatment as the third areas of focus. Nanotechnology provides novel materials which offer the unique and important solutions to the limitations of other conventional materials and have numerous potential. Nano-materials and nano-structures exhibit novel and significantly changed physical, chemical, optical, structural and biological characteristics as a result of their smaller size, larger specific surface area, and quantum confinement. It may bestow expected result by increasing productivity of crops and meet challenges of food security of the country in the coming years. Hence, Government of India had been looking towards nanotechnology as a means of boosting agricultural productivity (**Madhuri Sharon1, 2010).** Planning commission of India recommended nanotechnology research and development as one of six areas of critical investment. Agricultural and food security systems, disease-treatment, delivery methods, sensors for pathogen detection, ecological protection, education of the public and future workforce are the areas where nanotechnology could have major impact on the science and engineering of agriculture (Muhammad Azam Ali., et. al., 2014).

Some of the benefits of nanotechnology will be passed on to the food sector through agriculture and agricultural research like the development of new tools in molecular and cellular biology which will enhance reproductive science and technology; conversion of agricultural and food wastes into energy and useful by-products through enzymatic nano bio-processing, and disease prevention and treatment of plants and animals.(http://www.avensonline.org/blog/application-of-nanotechnology-in-agriculture.)

Nanotechnologies in future agriculture
Presently, the agricultural sector is facing various global challenges: climate change, urbanization, sustainable use of resources, and environmental issues such as run-off an accumulation of pesticides and fertilizers. These situations

are further exacerbated by the growing food demand that will be needed to sustain nest mated population growth from the current level of about 6 billion to 9 billion by 2050. In addition, considering the world's diminishing petroleum sources, agricultural products and materials will soon be viewed again as the foundation of commerce and manufacturing, hence additional demands on agricultural production (Avensblog, 2016). Reduce the amount of spread chemicals, minimize nutrient losses in fertilization and increased yield through water and nutrient management is the main aim of nonmaterials in agriculture. Nanotechnology has the potential to develop the agricultural and food industry with novel tools for the molecular management of rapid disease detection, increasing the ability of absorption of nutrients by plants among others. The significant interest of using nanotechnology in agriculture includes specific applications like nanofertilizers and nanopesticides to track products and nutrients levels to increase the productivity without decontamination of soils and waters and protection against pest and diseases (Anupam M., et. al., 2015). Advances in science and technology could offer potential solutions for developing countries to innovate and add value to their current commodities production systems. Many technologies being developed have the potential not only to increase farm productivity but also to reduce the environmental and resource costs often associated with agricultural production (Muhammad Azam Ali., *et. al*., 2014).

Nanofabricated Gel-Free Systems and High Throughput DNA Sequencing

As a central process DNA sequencing needs to be improved in terms of its throughput and accuracy. Nano-fabrication technology will be critical towards this goal both in terms of improving the existing methods as well as delivering novel approaches for sequence detection. The scaling down in size of the current sequencing technology allows the process to be more parallel and multiplex. (Suman P. R., et al., 2010) Chemically coated Mesoporous silica nanoparticles act as containers for the genes delivered into the plants; they trigger the plant to take the particles through the cell walls, where the genes are put in and activated in a clear-cut and controlled way, without any toxic side effects. Firstly this technique was applied to establish DNA fruitfully to tobacco and corn plants. (N. Gupta, et al., 2013) reported that plant breeding and genetic modification by Nanoparticles carrying DNA or RNA delivered to plant cells for their genetic transformation or to trigger defense responses, activated by pathogens. **(Amit kumar, 2014)**, Research in nano-biotechnology is advancing towards the ability to sequence DNA in nano-fabricated gel-free systems, which would allow for significantly more rapid DNA sequencing. Coupled with powerful approaches such as association genetic analysis, DNA sequencing data of the crop germ plasm, including the cultivated crop gene pool and the wild relatives can potentially provide highly useful information about molecular markers associated with agronomical and economically important traits.

Nanotechnology in crop improvement

Microarrays are being used to (i) detect mutations in disease related genes; (ii) monitor gene activity; (iii) identify genes important to crop productivity; and (iv) improve screening for microbes used in bioremediation **(Amit kumar, 2014)**. An agricultural system widely used in the USA, Europe and Japan, they utilizes modern technology efficiently for crop management called Controlled Environment Agriculture (CEA). CEA is an advanced and intensive form of hydroponically based agriculture. Controlled-environment agriculture (CEA) is any agricultural technology that enables the farmers to control a crop's environment to the desired conditions. CEA technologies include greenhouse, aquaculture, hydroponics, and aquaponics. Temperature, humidity, pH, and nutrient analysis are the controlled variables. Plants are grown within a controlled environment so that agricultural practices can be optimized (Electro spinning Nano-fibres 2003).

Nanotechnology in pest control

Characteristics of a successful modern crop protection chemical are: to remain active in the spray environment (sun, heat, rain), penetrate the organism (fungus, insect), transport to the target, resist defense of the pest/pathogen, remain benign to plants and mammals, be cost effective to formulate and manufacture, preferably possess a new mode of action, and provide economic returns and social benefits. These requirements prompted the development of the concept of 'Pesticide Delivery System' PDS makes the active ingredients available to a specified target at concentrations and durations designed to accomplish the intended effect by maintenance of the fullest biological efficacy and reduction of various harmful effects. PDSs face the main difficulty of application to an open environmental system. Initially, the controlled release formulations with microcapsules (N10 μm) encapsulating pesticides were developed for delivery developed a new nano precipitation method that involved formation of spontaneous nano emulsions with poly condensation at oil–water interface, to prepare NPs (200–300 nm) in an easy and reproducible way. (Wang L, et al., 2007), for the formulations of pesticides oil in water (nano-emulsion) was useful and these could be effective against the various insect pests in agriculture. Similarly, essential oil-loaded solid lipid nanoparticles were also useful for the formulations of nano-pesticides (Liu F., 2006). Nano-silica, a silica product, can be effectively used as a nano-pesticide. (Barik, T. K., 2008) the use of nano-silica as nano-insecticide. The mechanism of control of insect pest using nano-silica is based on the fact that insect pests used a variety of cuticular lipids for protecting their water barrier and thereby prevent death from desiccation. But here, when on plant surface nano-silica particles are applied they cause death by physical means of insects by being absorbed into the cuticular lipids.

Delivery of pesticides/bio-pesticides: Nanotechnology has potential for efficient delivery of chemical and biological pesticides using nano sized preparations or nano material based agrochemical formulations. The benefits of nano material based formulations are the improvement of efficacy due to higher surface area, higher solubility, induction of systemic activity due to smaller particle size and higher mobility and lower toxicity due to elimination of organic solvents in comparison to conventionally used pesticides and their formulations (DeRosa, M.C., et. al, 2010). Nano-encapsulation is a process through which chemicals like insecticides are slowly but efficiently released to a particular host plant for insect pest control. Nano-encapsulation with nano-particles in the form of pesticides allows for proper absorption of the chemicals into the plants (Scrinis G. and Lyons, K., 2007). This process can also deliver DNA and other desired chemicals into plant tissues for protection of host plants against insect pests (Suman, P. R., 2010). Release mechanisms of nano-encapsulation include diffusion, dissolution, bio-degradation and osmotic pressure with specific pH (Park, H. J., 2006). The most promising technology for protection of host plants against insect pests is nano-encapsulation.

Nanotechnology in plant nutrition:

To overcome the chronic problems, enhancing nutrient use efficiency and of eutrophication, nano-fertilizer might be a best alternative. Nanofertilizers are synthesized in order to regulate the release of nutrients depending on the requirements of the crops, and it is also reported that nanofertilizers are more efficient than ordinary fertilizer. Leaching losses of nitrogen could be reduced by using Nanofertilizers. It also reduces emissions and long-term incorporation by soil micro-organisms. Organic farming has been a long-desired goal to increase productivity of crop yields with low input i.e. fertilizers, pesticides, herbicides among others through monitoring environmental variables (Anupam M., et. al., 2015). Delivery systems in agriculture are important for application of pesticides and fertilizers as well as during genetic material mediated plant improvement. Application systems for pesticides need to focus on efficacy enhancement and spray drift management while fertilizers face problems of bioavailability due to soil chelation, over-application and run-offs (S. B. Manjunatha, D. P. Biradar and Y. R.Aladakatti, 2016). (Vidhyalakshmi, R., 2009), Application of nano-technology in the agri-food sector is still a relatively new concept; the main reasons for its late incorporation are mainly due to issues relating to product labelling, potential consumer health risks, and a lack of unifying regulations and guidelines on nanotechnology governance (Coles, D., & Frewer, L. J., 2013). The nanoparticles like Ag, ZnO and CuO are relevant in the growth of agriculture by bioactivity and bio-modification (Christian, O., 2009).

Nanotechnology understanding of plant disease mechanisms:

The advancement in nanofabrication and characterization tools have enabled studies of physical, chemical and biological interactions between plant cell organelles and various disease causing pathogens, i.e., plant pathology (Yao, K.S., S.J. Li, K.C. Tzeng, T.C. Cheng and C.Y. Chang *et al*., 2009). The use of nano-particles has been considered an alternate and effective approach which is eco-friendly and cost effective for the control of pathogenic microbes (Prasad, K. S., et al., 2011) and (Swamy, V. S., and Prasad, R., 2012). The management of plant diseases compared to synthetic fungicides, nano-particals have good potential (Park, H. J., 2006). Zinc oxide (ZnO) and magnesium oxide (MgO) nanoparticles are effective antibacterial and anti-odour agents(Shah, M. A., 2010). The increased ease in dispensability, optical transparency and smoothness make ZnO and MgO nano-structures an attractive antibacterial ingredient in many products. For wood or food products both have proposed anti-microbial preservative (Aruoja, V., 2009). Properly functionalized nano-capsules provide better penetration through cuticle and allow slow and controlled release of active ingredients on reaching the target weed. The use of such nano-biopesticide is more acceptable since they are safe for plants and cause less environmental pollution in comparison to conventional chemical pesticides Barik, T. K., 2008). A better understanding of plant pathogenic mechanisms such as flagella motility and biofilm formation will lead to improved treatment strategies to control the diseases and protect production. For example, spatial and temporal studies of plant pathogenic xylem inhabiting bacteria have traditionally been conducted by monitoring changes in bacterial populations through destructive sampling techniques of tissues at various distances from inoculation sites. This approach seriously limits the information that can be obtained regarding colonization, biofilm development, and subsequent movement and re-colonization at new areas, primarily because the same region or sample site cannot be followed temporally. Micro-fabricated xylem vessels with nano-size features have been shown very useful in gaining an appreciation of the mechanisms and kinetics of bacterial colonization in xylem vessels such that novel disease control strategies may be developed (Sharon, M., A.K. Choudhary and R. Kumar, 2010).

Nano-materials and nano-particle preparation

Nano materials of inorganic and organic origin are used for NP synthesis by a variety of physical and chemical methods. Synthesis of NPs involves size reduction by top-down methods such as milling, high pressure homogenization and sanitation while bottom up processes involve reactive precipitation and solvent displacement.

Polymeric NPs made from natural and synthetic polymers by wet synthetic routes are widely used due to their stability and ease of surface modification. NPs prepared from biopolymers or natural sources possess advantages, such as availability from replenishable agricultural (cellulose, starch, pectin) or marine (chitin and chitosan) resources, biocompatibility, biodegradability and ecological safety. Biodegradable polymers are studied mainly for fabrication of delivery systems for controlled release of active ingredients, stabilization of labile molecules (e.g., proteins, peptides, or genetic material). Depending on the method of preparation nano spheres (round NPs), nano fibres (~100 nm long fibers) or nano capsules (hollow NPs) can be constructed to possess different properties and release characteristics for the best delivery or encapsulation of the active ingredient.

2. Conclusion

With the current application and advancements soon to come, nanotechnology will have a great impact on the direction that agriculture and food sector will take. Scientists are blazing a trail for a new technology and looking at every possible avenue to improve upon current methods in every possible field. Nanotechnology is emerging as the technological platform for the next wave of development and transformation of agri-food systems. It is rapidly moving from the laboratory to the farm, supermarket shelves and the kitchen table, for example, a new range of 'smart' agricultural inputs and products are being developed, such as nano-seed varieties with in-built pesticides that will be released under certain environmental conditions. Promising results and applications are already being developed in the areas of delivery of pesticides, bio-pesticides, fertilizers and genetic material for plant transformation. The use of nano materials for delivery of pesticides and fertilizers is expected to reduce the dosage and ensure controlled slow delivery. A main contribution anticipated, is the application of nano particles to stabilize bio-control preparations that will go a long way in reducing the environmental hazard. A major hurdle in the removal of harmful contaminants from soil was its detection in the field, which was costly with conventional methods. Nanotechnologies, by exploiting the unique properties of nano materials, this industrial and scientific collaboration strategically place the corporate sector to shape the research trajectory and commercial applications of nanotechnology, and the future of agri-food systems.

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