Octa Journal of Environmental Research

(Oct. Jour. Env. Res.) ISSN: 2321-3655

Journal Homepage: http://www.sciencebeingjournal.com

Scientific Planet

NANOTECHNOLOGY APPLICATIONS IN AGRICULTURE: AN UPDATE

Tejpal Dhewa
Department of Microbiology, Bhaskaracharya College of Applied Sciences,
University of Delhi, Dwarka, New Delhi- 110075, India.
*Corresponding author's Email: tejpal_dhewa07@rediifmail.com
Received: 16th March 2015 **Revised**: 7th April 2015 **Accepted:** 10th April 2015

Abstract: Although the scientific studies on the applications of nanotechnology in the agriculture are less than a decade old yet the prospects of nanotechnology in this field are considerable. The rapid developments in the nanosciences have a great impact on agricultural practices and food manufacturing industries. Nanotechnology has an enormous potential to offer smarter, stronger, cost-effective packaging materials, biosensors for the rapid detection of the food pathogens, toxins and other contaminants or food adulterants. It is also plays an important role in developing new generation of pesticides with the safe carriers, preservation and packaging of food and food additives, strengthening of natural fibre, removal of various contaminants from the soil and water bodies by using functionalized nanoparticles and improving the shelf-life of the vegetables, flowers and fruits. In spite of the above mentioned immense uses, the competency is being exhibited in some of success business models in developing nanotechnology based products. The safety and regulatory concerns of the application of nanotechnology for human beings, environments and ecosystems are required to be debated, particularly in the developing countries. There are few potential points of direct human exposure to nanomaterials along with the agri-food chains (from the worker to the consumers), and the threat of the possibility of the nanoparticles reaching the non-targeted sites which can also pose health and environments problems. Keeping in mind all the above benefits and risks associated with nanotechnology, an effective risk management strategy should be followed in parallel to the technological developments or advancements. Moreover, a stable governance model system should be adopted during the entire process (from production to consumption) of nanomaterials with continuous interactions and involvement of all the stakeholders.
Keywords: Agricultural products, biosensors, nanosensors, nanotechnology, smart dusts, quantum dots.

Postal Address: Department of Microbiology, Bhaskaracharya College of Applied Sciences, (University of Delhi), Sector-2, Phase-1, Dwarka, New Delhi-110075, India.

INTRODUCTION

The term 'Nanotechnology' has been defined as the branch of the science that deals with the understanding and control of matter at the dimensions of about 1-100 nm (Table 1) by the US Environmental Protection Agency. It includes controlling, building and restructuring of the devices and other materials of physical, chemical and biological features at nanoscale level i.e. on the scale of atoms and molecules (a nanometer (nm) is one billionth (10^9) of a meter). The functionality can be added to nanoparticle by interfacing them with biomolecules or structures.

In the twenty first century, nanotechnology has emerged with the great influence on global economy, industries and public lives. If we look at the historical part of agricultural applications of nanotechnology, it came only in recent years but the seeds of research in this field start growing nearly half a century ago (Mukhopadyay, 2014). The uses of nanomaterials specifically for the agricultural purposes are required for improving the fertilization process, increase in yields through nutrient optimization and minimized the requirements of plant protection products (Huang *et. al.,* 2015).

**Table 1: Comparative sizes of organisms and biomolecules at small scale**

Biomolecules and Cells	Size range (in µm)	Size range (in nm)
Atoms (DNA base)	0.0001-0.001	0.1-1
Bio-macromolecules	0.001-0.01	1-10
Acellular Organisms (Viruses)	0.03-0.1	30-300
Prokaryotes (Bacteria)	1-10	100-1000
Eukaryotic Cells: (Plant and Animal Cells)	10-100	10000-100000

Abb.: µm: micrometer, nm: nanometer.

APPLICATIONS OF NANOTECHNOLOGY IN AGRICULTURE

In recent years, some devices and tools developed by nanotechnology such as nanodevices, nanocapsules etc. being used to detect and treat the plant diseases, delivery of active components to the desired target sites, treatment of waste water and also to enhance the absorption of nutrients in plants. The targeted delivery of nanoparticles not only reduces the damage to non- target plant tissues, but also minimizes the amount of harmful chemicals that pollutes the environment. Hence, this technology is not only eco-friendly but also helps in reducing the environmental pollutants. There are some specific nanoproducts that have been developed for using as soil-enhancer products which promote the even distribution of water and storage. Thus, useful in water saving. Besides, some of the important developments in production of nanotechnology products like nanomaterials, nanostructures, nanofibers, nanotubes, etc. with unique physical, mechanical and chemical properties which make them electrochemically active. Such devices play vital role in plants and animal breedings (Prasanna, 2007), genetic engineering and also have been applied in biochemical sensors due to rapid response along with high sensitivity. Nanomaterials can also be used in delivery of nutrients and pesticides in the plants (Srilatha, 2011), analysis of soil samples and waste water treatment (Figure 1). Agricultural wastes have attracted their uses as raw materials for the production of nanomaterials. Several efforts have been taken to obtain the nanocomposites based

on biomaterials. The productions of nanocomposites are more sustainable and have beneficial properties as compared to the conventional materials such as microcomposite and macrocomposite materials.
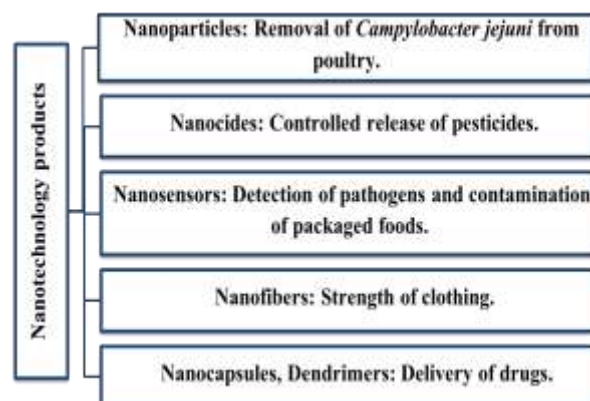
Figure 1: Examples of nanotechnology products with potential area of uses.
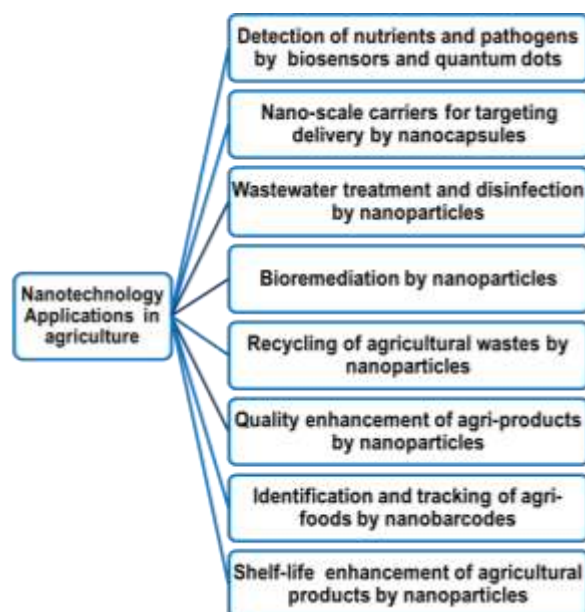
Figure 2: An illustrative presentation of various applications of nanotechnology in agri-food sector.

Nowadays, various applications of the nanotechnology are being explored, tested and applied in agriculture and other fields also (Figure 2).The technical innovations in agriculture are necessary to overcome certain global issues including climate change and limited availability of important nutrients *i.e.* potassium and phosphorus, required for the growth of plants. Nowadays, various applications of the nanotechnology are being explored, tested and

applied in agriculture and other fields also (Figure 2).The technical innovations in agriculture are

The main applications of nanotechnology in agriculture are listed below:

i.   Determination of enzyme-substrate (E-S) interactions (by detection of single molecule).

ii. For more efficient delivery of fertilizers, pesticides, vaccines, growth regulatory hormones and other chemicals using nano-capsules or nanotubes.

iii. In genetic engineering of plants, delivery of desired DNA into the plants using nano-particles.

iv. Delivery of vaccines into plants using nano-capsules.

v.   The use of nanosensors for the detection of the plant pathogens, monitoring the soil conditions and plant growth, etc.

Detection of nutrients and pathogens: For effective protection of agricultural health and environment needs the quick and sensitive devices to detect pollutants and pathogens. To achieve this, accurate sensors are required for *in-situ* detection, as miniaturized portable instruments, remote of *ex-situ* sensors, for the real-time monitoring of large areas in the field. The biosensors have been developed by nanotechnology for the detection of contaminants or pollutants in various kinds of wastes such as water, foods products, etc. with high performance competences. They offer high specificity and sensitivity, rapid response, operator-friendly and small size at a low cost of production. The enzymatic biosensors have also been developed that can used for the specific sensing of many elements. The electronic nose (E-nose) is a biosensor device that consists of gas sensor composed by nanoparticles *i.e.* ZnO nanowires. This is based on the activity of human nose, used for the identification of the odors of various kinds, identification of odorant i.e. the determination of the type of odorant, for estimating its concentration (quantity), and for finding the characteristics (its quality). The detection by this device is based on the operation of human nose. As the a particular gas passes, the resistance of the device changes and generates a changed electrical signal and this signal forms a fingerprint pattern to detect the type, quality and quantity of

that gas (Ditta, 2012). They are also used for the rapid and sensitive detection of various products and organisms. For example, alcohol production during fermentation, growth of variety of microorganisms, bakery products, foul odor produced by bacterial rotting, etc.

Bacteria, beneficial as well as harmful life forms in the nature, are responsible for a variety of diseases. Human beings may acquire certain diseases *i.e.* foodborne illnesses from contaminated water and agricultural products. Therefore, their detection is very important to avoid infections or diagnosis and treatment of the diseases. Bacterial cells can be easily detected by staining method by using different dyes. To stain bacterial cells, the most widely practiced biolabels *i.e.* organic dyes. Such dyes are expensive and their fluorescence disappears with time. Recent advancements in the field of nanotechnology *i.e.* development of luminescent nanocrystals, discovered quantum dots (QDs), which can be used in fluorescent labeling in biological recognition of molecules. As compare to the organic dyes QDs are superior to conventional organic dyes because of their more efficient luminescence, narrow emission spectra and excellent photostability properties.

Nano-scale carriers for targeting delivery: The nanotechnology has developed ways of delivering important compounds to the plants for improving their yields. The nanoscale carriers *i.e.* nanotubes, for this purpose, can be used for delivering pesticides, herbicides, fertilizers, plant growth regulators, other chemicals efficiently to the target site (NAAS, 2013). For this purpose, polymers and dendrimers are used. The agents are attached at the surface of these polymers and dendrimers by ionic and weak bonds. These carriers are able to bind the roots of plants efficiently to the surrounding soil and organic materials. By this way of delivery of these chemicals helps in improving the stability of compounds by reducing the degradation in the environment. Hence, the increased stability of these compounds in the natural environment reduces the amount required to be applied. The reduction in the amount not only reduces the environmental pollution but also the cost of productions. Ultimately, this will also help in the reduction of the wastes produced. The

Oct. Jour. Env. Res. Vol 3(2): 204-211

206

developments and innovations in nanofabrications and characterization of tools have enabled us to understand the interactions (physical, chemical and biological) between plant cells and pathogens. The improved and increased understanding of the mechanisms involved in the interactions and the development of diseases, thus it enabled us to develop better ways of the treatment of such diseases. In addition, the development of the micro-fabricated xylem vessels (nano-sized features) has enabled us to study various types of mechanisms involved between the plant-pathogen interactions which was earlier not possible to study using traditional strategies.

Wastewater treatment and disinfection: An application of photocatalytic decomposition properties of nanoparticle has earned acceptance in cleaning and decontamination of polluted water. The photocatalysis is a process, which involves the use of the nanoparticles (a product of the nanotechnology). The term itself consists of two words 'photo' means 'light' and the 'catalysis' that denote 'reaction catalyzed or due to the catalyst'. In this, nanoparticles are the catalyst. In this process, the reaction of the nanoparticles with the specific chemical compounds occurs in the existence of light. Such process can be used to decompose the toxic chemical compounds including pesticides that are generally not degraded under normal conditions. When a particular compound is bound to the nanoparticles, after the exposure of UV rays, those electrons present in the outermost shell called 'valence electrons' becomes excited and the excitation leads to creation of the electron hole pairs (negative electrons and positive holes). Now, such negative electrons acts as excellent oxidizing agents (i.e. ZnO, ZnS, etc.), and shows very high capacity of degradation and disinfection because of their large surface to volume ratio. The surface atoms are increased as the particle size decreases that cause the tremendous increase in the reactivity of the chemical compounds and other properties that are essential for the activity. The pollution or contamination of natural water bodies is presently a major problem in the growing world. The wastewater has negative influence not only on the environment but also on the health of

animals and human beings. Therefore, the treatment of wastewaters is now very serious issue that required to be solved with an immediate effect using eco-friendly technologies. Although, from past many years, several methods have been applied to treat the polluted water yet, nanotechnology has emerged in this sector with immense potential. For example, the process of photocatalysis can be applied to treat the contaminated water. It has been scientifically proved that by using semiconductor sensitized photosynthetic and photocatalytic processes, the organic compounds, destruction of cancer cells, removal of bacterial cells and viruses can be achieved. Nanotechnology is also useful in cleaning of waste water. During disinfection of water, the nanoparticles, when excited with the light source, negative electrons are released. These electrons can be used for removing the bacterial cells from the contaminated water. In addition, these nanoparticles can also be used as disinfectant in food packaging industries (Soutter, 2014).

Bioremediation: Nanotechnology has played a significant role in microbial remediation. In agricultural system, some chemicals such as pesticides are slow degrading or resistant to degradation in nature hence they remain in the environment for longer time and cause serious problems, by applying nanotechnology, these toxic or harmful compounds can be degraded under certain conditions. If they are not degraded, they may enter the food chain and may cause serious health problems. Recent developments in agricultural nanotechnology have shown a promising step in this direction. For example, nanoparticle-water slurry can be mixed in contaminated soil and in due course of time, these particles will reduce the toxicity of slowly degradable or resistant pesticides.

Recycling of agricultural wastes: In recent years, the continuous deposition of agricultural wastes or byproducts in nature becomes a big challenge to us. Nanotechnology can be applied in reduction of wastes during agricultural manufacturing such as cotton, beverage and rice milling industries. In the cotton industry, when cotton is processed into fabric, some byproduct like cellulose or fibers discarded or used as low value products. By using a technique called

electospinning and recently developed solvents, researchers are producing nanofiber (100 nm diameter). These fibers can be used as a fertilizer or pesticide absorbent. Such high-performance absorbents let targeted application at anticipated time and place. Beverage industries, mainly engaged in ethanol production using maize feedstock continuously. Therefore, the global price of maize has been increased sharply in past few years. Moreover, cellulosic feedstocks are now considered as a viable option for biofuel production. Nanotechnology can be used in enhancing the performance of enzymes involved in conversion of cellulose to ethanol. Recently, scientists developing nano-engineered enzymes which will allow easy and low cost conversion of cellulose from waste plant materials. Rice-milling industries produces rice husk as a byproduct which a potential source of renewable energy. A huge amount of superior quality nanosilica is generated when rice husk is burned into thermal energy or biofuel. This nanosilica can further utilized in making several useful materials like concrete, glass etc. Hence, nanotechnology by producing nanosilica can give an effective and useful solution of rice husk disposal concern.

Quality enhancement of agri-products: The nutritive properties and health related benefits of the agricultural products by applying the nanotechnology have attracted the interest of the consumers and the agri-food industry in this field. From studies, it has been concluded that the Zinc spray of the nanoparticles was found to be essential to increase the vegetarian protein, fat, and fibers in the Indian diets. There are many studies going on for testing the genotoxicity of the nanomaterials and still underway for developing and testing various nanoparticles to protect crops from powdery mildews (Hiregoudar, 2014). From the early years, the gold was also an attractive and useful metal because of its unique and valuable nature. The development of gold nanoparticles has many commercial applications. They are also used for the detection of the biomolecules. The detection is based on the fact that the shape, size, refractive index of the nearby medium and the distance between the gold nanoparticles are the major factors on which the color of these colloids is dependent. Even a

small variation in the above factors may cause the measurable change in the Surface Plasmon Response (SPR) absorption peak. The specific molecules are attached to the gold nanoparticles by their adsorption at the surface of the particle that subsequently changes the RI (refractive index) of the gold nanoparticles. If the bio-molecules to be attached are larger than the gold nanoparticles, only few molecules will be adsorbed at the surface of the nanoparticles and will lead to formation of the lumps and this ultimately changes the color of the gold nanoparticles. The changes in the color of nanoparticles have resulted from the shift in SPR that ultimately cause the reduction in the spacing of particles. A very interesting development in the field of nanotechnology is the 'smart dust'. This technology can be used to monitor different parameters in food or environment such as temperature, humidity etc. (Ditta, 2012).

Identification and tracking of agri-foods: Identification (ID) tags play very important role in our routine life. They have been useful in wholesale trading of food and agricultural products. Because of small size, nanomaterials have been used in different sectors encoding of agricultural products. Nanobarcodes have been used in multiplexed bioassays and usual encoding due to their great potential of development of numerous blends that make them useful for this purpose. For example, UV lamp and optical microscope are used for the identification of micrometer (μm) - sized glass barcodes which are delved by fixing with rare earth comprising a particular type of pattern of various fluorescent materials. Particles that are used in the nanobarcode should have encodeable, readable by the machine, robust enough to be used for longer time and sub-micro nanometer in size. These nanobarcode particles are manufactured by the process which is highly scalable and not fully automated that is called semi-automated. This involves the electroplating of inert metals such as gold, silver, etc., into the prototypes that defines the diameter of the particles. Finally, the resulting stripped nanorods are released from the template. The nanobarcodes have both biological and non-biological applications in the agricultural fields (Ditta, 2012). One of the major biological

applications of the nanobarcode is that they have been used as the ID tags. These tags are used for the multiplexed study of the gene expression and the intracellular histopathology. The advancement and developments in the nanotechnology have led to the improvement in the plant resistance properties against many environmental stresses *i.e.* resistance to drought, salinity, various infections, etc. (Beyrouthya and Azzia, 2014).

The same application that the nanobarcodes can be used as the ID tags has also been applied to the non-biological systems. They have been used for the authentication (or tracking) in the agricultural foods and other products such as husbandry products. Therefore, the nanobarcode technology would enable us for developing the auto- ID technology for tagging the items that was not practical previously to tag these items with the conventional barcodes. Thus, nanobarcode technology is enhancing traceability in food trade and will be promising tools for promoting bio safe global agri-food business.

Shelf-life enhancement of agricultural products: The advancement in nanotechnology can enable us to develop methods for the preservation of not only of the freshness of the agricultural products such as vegetables, fruits, etc. but also their quality and safety. In nano-food system, packaging plays significant role in preventing post production or post-harvest damages, in addition prolonging shelf- life of fresh and stored agricultural produces. It has been expected that more than 45 percent of the food packaging industries across the world will apply nanotechnology concepts to improve the keeping quality of agricultural products by 2016. Till date, more than 300 nanotechnology based packaging materials are being sold worldwide. Currently, nano-films are being produced by adding nano-clays or silver nano-particles into conventional packaging material to improve the tensile properties, stiffness, dimensional stability and thermal resistance. Such processes enable extension of shelf life of products by avoiding microbial contamination or delaying in microbial growth through limiting gaseous exchange along with moisture. Moreover, incorporation of silver nanoparticles in packaging materials will serve as an antimicrobial (inhibitory) agent and protect the agricultural products from spoilage causing microorganisms.

CONSTRAINTS

In spite of several prospective uses of nanotechnology in numerous sectors (i.e. health, medical, agriculture, space research technology etc.), there are certain safety issues concern with the use of this technology on environment are still need to be discussed. Some key limitations and risk associated with agricultural application of nanotechnology are as follows:

i. Exposure of nanomaterials to human beings and accumulation in agri-food chains. The current knowledge on the nanotechnology is still in infancy stage; therefore, it is not possible to predict the impact of the nanoparticles on the human health and environment. It has been concluded from various reports that the nanotechnology may significantly contribute to the alleviating poverty etc. (Mukhopadhyay, 2014).

ii. Interaction of nanoparticles with the non-target sites, which lead to certain environmental and health issues (Claudia *et al.,* 2014).

iii. Higher production costs.

iv. Developments in agricultural sector are greatly limited due to low investment, in research infrastructure and manpower training etc.

v. Public is not aware of many application of nanotechnology and the opinion of public is generally not negative. In addition, the risks of the overlapping patents may also effects on the agri-food areas.

vi. The need of labeling of the products of nanotechnology further prevents the innovative applications of this technology in the agricultural fields. The various products (containing the nanomaterials) of nanotechnology and their commercial use in various fields are still need to be regulated just in order to make or guarantee their safe use in these areas. Hence, the proper knowledge of these materials and their possible interactions in human body is always needed to be examined prior to commercial application.

FUTURE PROSPECTS

Nanotechnology applications have the huge potential to change agricultural production by allowing better scientific management and conservation efforts to plant production. Scientists in nanotechnology can do countless contributions for the betterment of society by applying this technology in agriculture and food production systems. Nanotechnology provides a much better effective way of environment detection, sensing and bioremediation. It can enhance agricultural productivity by using:

i. Nanoporous zeolotes for controlled release and efficient amount of water, fertilizer etc.
ii. Nanocapsules for delivering of herbicide, vector and managing of pests.
iii. Nanosensors for detecting aquatic toxins and pests.
iv. Nanoscale biopolymers, (proteins and carbohydrates) based nanoparticles with few properties such as low impact on human health and the environment may be used in disinfection and recycling of heavy metals.
v. Nanostructured metals can be explored in decomposition of harmful organics at room temperature.
vi. Smart particles can be useful in effective environmental monitoring and purification processes.
vii. Nanoparticles as a novel photocatalyst.

Thus, nanotechnology will transform agricultural practices including advanced pest management in future. Over the next 20 years, green revolution would be hastened by means of nanosciences. Nanomaterials would be beneficial in the development and formulation of next generation pesticides, insecticides and insect repellents. Thus, nanotechnology is considered as one of the best possible solution of the problems present in food and agriculture sector.

CONCLUSION

Nanotechnology offers a plethora of user-friendly option in the agricultural world. Some of them are stronger and cost effective packaging materials, preservation and packaging of food additives, enhancement of shelf-life of fruit and vegetables. It also aids in strengthening of natural fibers, removal of contaminants from soil and water bodies. Moreover, Nanotechnology offers biosensors for detecting food pathogens, toxins, contaminants, adulterants, etc. Recently, nanofertiliozers have also come in play which has pesticides with safe carriers. Despite of these potential applications, before the introduction in the various fields, the new applications must be examined and regulated carefully. There are several issues on the safety to the human beings, environment, and ecosystem that are still need to be addressed. The exposure of human beings to the nanomaterials along with the agri-food chain may cause adverse impacts on health and environment due to attack of nanoparticles on the non-target sites. Thus, effective and practical risk management strategies should be practiced during the technological developments. The success of the nanotechnology is most probably depends on many factors such as the market demand, risk assessments and supervisions, profit margin, environmental benefits in the background of many other technologies that are competing with this technology. However, the future of nanotechnology is still uncertain due to some negative reactions of the scientific community towards applying of nanotechnology in food and agriculture sectors.

REFERENCES

Beyrouthya Marc El and Azzia Desiree El (2014). Nanotechnologies: Novel Solutions for Sustainable Agriculture. *Adv. Crop Sci Tech* 2:e118. Doi: 10.4172/2329-8863.1000e118.

Ditta Allah (2012). How helpful is nanotechnology in agriculture? *Adv. Nat. Sci.: Nanosci. Nanotechnol.* Available online at Doi:10.1088/2043-6262/3/3/033002.

Hiregoudar Sharanagouda (2014). Application of Nanotechnology in Enhancing Quality of Agricultural Produce. Available online at http://www.isssonline.in/isss-2014/agri.html.

Huang Shiwen, Wang Ling, Liu Lianmeng, Hou Yuxuan and Li Lu (2015).

Nanotechnology in agriculture, livestock, and aquaculture in China. A review. *Sustain. Dev.* 35:369– 400; DOI 10.1007/s13593-014-0274-x.

Mukhopadhyay Siddhartha S. (2014). Nanotechnology in agriculture prospects and constraints. *Nanotechnol: Sci. Appl.* (7):63-71. Available online at http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4130717/

NAAS (2013). Nanotechnology in Agriculture: Scope and Current Relevance. Policy Paper No. 63, *Nat. Acad. Agri. Sci.,* New Delhi, 20 p. Available online: http://naasindia.org/Policy%20Papers/Policy%2063.pdf.

Claudia Parisi, Mauro Vigani and Emilio Rodriguez-Cerezo (2014). *In:* Proceedings of Workshop on "Nanotechnology for the agricultural sector: from research to the field". Available online at https://ec.europa.eu/jrc.

Prasanna B.M. (2007). Nanotechnology in Agriculture. Available online at http://www.iasri.res.in/design/ebook/EBADAT/6-Other%20Useful%20 Techniques/10-nanotech_in_Agriculture__BM_Prasanna__1.2.2007.pdf.

Soutter Will (2014). Nanotechnology in Agriculture. Available online at. http://www.azonano.com/article.aspx?ArticleID=3141.

Srilatha B (2011). Nanotechnology in Agriculture. *J. Nanomedic. Nanotechnol.* 2:123. doi:10.4172/2157-7439.1000123.