Smart agriculture: Role of nanotechnology in agriculture

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Abstract

Nanotechnology has gained much attention in recent years, as it can enhance the quality of life through its applications in various fields like agriculture, medicine industry, defence and security, bio-engineering, optical engineering, nanofabrics and nanoelectronics. Nanoscience and technology has immense potential in providing state-of-the-art solutions to the limitations posed by conventional technologies in agriculture in particular and society as a whole. Nanotechnology provides new agrochemical agents and new delivery mechanisms to improve crop productivity, and it promises to reduce pesticide use. Nanotechnology also promises to accelerate the development of biomass-to-fuel production technologies.

The potential applications of nanotechnology in the field of agriculture particularly in crop production, as delivery systems for disease & pest control, crop protection, staining of bacteria, food packaging, hydroponics and animal reproduction has been extensively studied and a review of the recent advances in this sector are presented in this paper. Also, concerns about the safety of usage of these nano materials in agriculture are discussed. Researchers and companies will need to take these issues in to consideration and prove that these nanotechnologies do not have a negative impact on the environment.

***Keywords**: Hydroponics, Nanosize, Quantum Dots, Nanofabrics.*

1. Introduction

Nanotechnology applications are currently being researched, tested and always applied across the entire spectrum of food technology in agriculture fields. Specially in agriculture, technical innovation is important with regard to addressing the global challenges such as population growth, climate change and the limited availability of important plant nutrients such as phosphorous and potassium. Nanotechnology is considered as one of the possible solution to problems in food and agriculture. Just like biotechnology, issues related to safety of health, biodiversity and environment along with appropriate regulation are inflated on nanotechnology.

Nanotechnology is defined as developing and exciting technology at the scale of one-billionth of a meter sweeping away the barriers between the physics, chemistry and biology. Nanotechnology is the pattern, picture, production and application of structures, devices and systems by controlling shape and size at nanometer scale [1]. Nanotechnology in biomedical research has emerged as an interdisciplinary science that has rapidly found its own clinical methodologies including imaging, diagnostic, and therapeutics, drug delivery and tissue engineering [2]. Nano medicine can design, build, control and optimize biological components at the nanoscale level. This includes the applications of nanomaterials and the fabrication of nanodevices which is to be used for nano diagnostic, nanodrug delivery and drug discovery [3].

2. Overview of nanotechnology research activities in the agricultural Fields

Application of Nanotechnology in agriculture, medicine, industry, defence and security, bio-engineering, optical engineering, nanofabrics and nanoelectronics. In the future, demand for food will increase enormously while natural resources such as land, water and soil fertility are limited. The cost of production inputs like chemical fertilizers and pesticides is expected to increase at an alarming rate due to limited reserves of fuel such as natural gas and petroleum. In order to overcome these constraints, precision farming is a better option to reduce production costs and to maximize output, i.e. agricultural production[4].

New devices and tools, like nanocapsules, nanoparticles and even viral capsids, are examples of uses for the detection and treatment of diseases, the enhancement of nutrients absorption by plants, the delivery of active ingredients to specific sites and water treatment processes. The use of target-specific nanoparticles can reduce the damage to non-target plant tissues and the amount of chemicals released into the environment. Nanotechnology derived devices are also explored in the field of plant breeding and genetic transformation. The potential of nanotechnology in agriculture is large, but a few issues are still to be addressed, such as increasing the scale of production processes and lowering costs, as well as risk assessment issues. In this respect, particularly attractive are nanoparticles derived from biopolymers such as proteins and carbohydrates with low impact on human health and the environment. For instance, the potential of starch-based nanoparticles as nontoxic and sustainable delivery systems for agrochemicals and biostimulants is being extensively investigated[5].

Nanomaterials and nanostructures with unique chemical, physical, and mechanical properties have been recently developed and applied for highly sensitive bio-chemical sensors. These nanosensors have also relevant implications for application in agriculture, in particular for soil analysis, control, water management and delivery, pesticide and alimentary delivery[5].

3. Application of Nanotechnology in agriculture

3.1 Nanomaterials as smart delivery systems for disease and pest control in plants

The most relevant nanodevices for plant protection are nanocapsules and nanoparticles, both at a scale ranging from 0.1 to 1,000 nm[5]. Today, application of agricultural fertilizers, pesticides, antibiotics, and nutrients is typically by spray or drench application to soil or plants, or through feed or injection systems to animals. Delivery of pesticides or medicines is either provided as “preventative” treatment, or is provided once the disease causing organism has multiplied and symptoms are evident in the plant[6].

In this context, nanotechnologies offer a great opportunity to yield new products against pests[7]. Nanotechnology improves their performance and acceptability by increasing effectiveness, safety, patient adherence, as well as ultimately reducing health care costs[8]. Nanoparticles have a solid core or a matrix that can be composed by different materials and surrounded by linkers and biomolecules. Due to the small size, the ratio between surface area and volume is increased in the nanomaterials, improving the biochemical reactivity and conferring unusual and valuable physical properties.

An important aspect concerning about plant protection products involves the way in which they are absorbed by the plant and their translocation within the plant tissues and organs. Absorption through the roots could be easier due to their biological role for nutrient assimilation, but the advantage of getting absorption through leaf tissues is that they are more easily available for field treatments. However, the knowledge about how these mechanisms work with nanomaterials is still to be improved. Magnetic carbon-coated nanoparticles can be tracked and used to analyse nanomaterials behaviour moving all along the plant structure[9]. They are easily detectable and their magnetic properties allow their accumulation in tissues by way of using magnetic fields[4].

3.2 Nanotechnology in animal production/reproduction and animal nanofeed applications

Nanotechnology has been increased, especially that focused on drug for human health and there in order to improve animal production process.Improving the feeding efficiency and nutrition of agricultural animals, minimizing losses from animal diseases, and turning animal by-products and waste and environmental concerns into value-added products are among applications of nanotechnology in animal husbandry[10].

Surface-functionalized nanomaterials and nanosized additives can bind and remove toxins or pathogens. Nanofeed (a food supplement for animals) encourages the activation of the animals own self-healing forces, equal to improved resistance against diseases. Nanofeed also acts as an antioxidant to maintain healthy cell activity and overall animal health. Benefits can be seen in the reduction of antibiotics needed, improved bone growth, improved phosphate utilization, and reduction in mortality rates[11]. Zinc oxide in piglet feed prevents diarrhea in young piglets to ensure minimum weight loss and generally better performance. However, the high dosage of zinc oxide needed for sufficient effects results in a high level of excretion in the environment. The nanoproduct Fra ZN C4

(Framelco, Raamsdonksveer, the Netherlands) Dry, a nanocoated zinc oxide, ensures minimum weight loss at lower dosage with less environmental excretion[12].

The results of a study of the effect of silver nanoparticles used as an additive in diets for weanling pigs on the digestive microbiota and gut morphology, and in productive performances and silver retention in tissues, suggested that silver effect may be mediated through its antimicrobial properties, either by acting against certain bacterial groups or just reducing the microbial load of the small intestine[13]. Silver nanoparticles could be applied to animal feeding[14] and are also a potent antimicrobial agent for use in broiler chickens[15]. Magnetic nanoparticles were found successful for the recovery of aflatoxin B1 and zearalenone from feed utilizing monoclonal antibodies against aflatoxin B1 and zearalenone[16].

3.3 Nanosensor/ Nanobiosensor in Agri-Food production

Although biosensors have been around, since glucose monitors were commercialized in the 1970s, the transition of laboratory research and innumerable research papers on biosensors into the world of commerce has lagged[17]. Nanobiosensors can be effectively used for sensing a wide variety of fertilizers, herbicide, pesticide, insecticide, pathogens, moisture, soil pH, and their controlled use can support sustainable agriculture for enhancing crop productivity[18]. The developed biosensor system is an ideal tool for online monitoring of organophosphate pesticides and nerve agents. Bioanalytical Nanosensors are utilized to detect and quantify minute amounts of contaminants like viruses bacteria, toxins bio-hazardous substances etc. in agriculture and food systems. Most analysis of these toxins is still conducted using conventional methods; however, biosensor methods are currently being developed as screening tools for use in field analysis[19].

Nanosensors are expected to impact agricultural, food, and environmental sectors. The Nanotechnology Signature Initiative "Nanotechnology for Sensors and Sensors for Nanotechnology: Improving and Protecting Health, Safety, and the Environment" is the fifth to be launched by agencies of the National Nanotechnology Initiative. Portable nanodevices can rapidly detect insects, diseases, pathogens, chemicals, and contaminants and can result in faster treatments[20]. Nanosensors based on using electrochemically functionalized SWCNTs with either metal nanoparticles or metal oxide nanoparticles, and metal oxide nanowires and nanotubes for gases such as ammonia, nitrogen oxides, hydrogen sulfide, sulfur dioxide, and volatile organics have potential application in monitoring agricultural pollutants for the assessment of impacts of these pollutants on biological and ecological health and in increase of crop productivity and reducing land burden. Researchers addressed the fabrication, functionalization, assembly/alignment, and sensing applications of field-effect transistors based on carbon nanotubes, silicon nanowires, and conducting polymer nanowires. Further, they evaluated how such sensors have been used for detection of various biological molecules and how such devices have enabled the achievement of high sensitivity and selectivity with low detection limits[21].

3.4 Nanocomposites/ Nanobiocomposites

Composites made from particles of nanosize ceramics or metals smaller than 100 nm can suddenly become much stronger than predicted by existing materials-science models. For example, metals with a so-called grain size of around 10 nm are as much as seven times harder and tougher than their ordinary counterparts with grain sizes in the hundreds of nanometers. A nanocomposite is a multiphase solid material where one of the phases has one, two, or three dimensions of less than 100 nm, or structures having nanoscale repeat distances between the different phases that make up the material[22-24].

Nanocomposites are polymers reinforced with small quantities (up to 5% by weight) of nanosized particles, which have high aspect ratios and are able to improve the properties and performance of the polymer. Polymer composites with nanoclay restrict the permeation of gases. Examples of polymer nanocomposites incorporating metal or metal oxide nanoparticles utilized mainly for their antimicrobial action include nanozinc oxide and nanomagnesiumoxide[25]. Cellulose nanocrystals are an attractive material to incorporate into composites because they provide highly versatile chemical functionality[26].

In food packaging, nanocomposites focus on the development of high barrier properties against the diffusion of oxygen, carbon dioxide, flavor compounds, and water vapor. Nanoclay (montmorillonite, a hydrated alumina–silicate-layered clay consisting of an edge-shared octahedral sheet of aluminum hydroxide between two silica tetrahedral layers) minerals are found abundantly in nature and might be incorporated into the packaging films. Bionanocomposites suitable for packaging applications include starch and cellulose derivatives, poly(lactic) acid, polycaprolactone, poly(butylenes succinate), and polyhydroxybutyrate[27].

3.5 Nanotechnology and the crop protection industry

Private companies are investigating whether intentionally manufactured nano-size active ingredients can give increased efficacy or greater penetration of useful components in plants. Indeed, decreasing the particle size and consequently increasing the surface area can be beneficial for parameters like the rate of solubility, the coverage of a leave surface etc. In particular, the use of nano materials as carriers and delivery systems for active ingredients is being researched (in particular solid-liquid formulations). However, the nano-size so far did not demonstrate to hold important product changes of agrochemical interest[5].

A variety of nanomaterials, mostly metal-based nanomaterials and carbon-based nanomaterials, have been exploited for their absorption, translocation, accumulation and particularly effects on growth and development in an array of crop plants[28-29]. In specific cases, the effects obtainable at macro scale (>1µm) can even be more advantageous than at smaller size, since smaller sizes can result in poorer efficacy due to rapid sunlight degradation because of larger surface area. Indeed, larger size can increase the longevity of a fungicide or improve larvacidal activity of an insecticide. Size matters when, for instance, spraying droplets on crops. By reducing the size of the droplets, the leaf surface coverage improves drastically. However, smaller droplets do also evaporate before. Therefore, there is no trace of nanotechnology there after the treatment[5].

Magnetic nanoparticles coated with tetramethylammonium hydroxide led to an increase in chlorophyll-a level in maize[30]. Use of iron oxide in pumpkin was also observed to increase root elongation that was attributed to the iron dissolution[31].

3.6 Quantum dots (QDs) for staining bacteria

Bacteria, the most primitive life forms present almost everywhere, are useful as well as harmful for life. There are numerous bacteria which are responsible for many diseases in humans like tetanus, typhoid fever, diphtheria, syphilis, cholera, food-borne illness, leprosy and tuberculosis caused by different species. As a remedial process, we need to detect bacteria and for this, dye staining method is used. To stain bacteria, the most commonly used biolabels are organic dyes, but these are expensive and their fluorescence degrades with time. So the need of the hour is to find durable and economical alternatives.

Fluorescent labeling by quantum dots (QDs) with bio-recognition molecules has been discovered through the recent developments in the field of luminescent nanocrystals. QDs are better than conventional organic fluorophores (dyes) due to their more efficient luminescence compared to the organic dyes, narrow emission spectra, excellent photostability, symmetry and tunability according to the particle sizes and material composition. By a single excitation light source, they can be excited to all colors of the QDs due to their broad absorption spectra[32]. Bio-labeled bacillus bacteria with nanoparticle consisting of ZnS and Mn^{2+}capped with bio compatible 'chitosan' gave an orange glow when viewed under a fluorescence microscope.

3.7 Green nanotechnology in agriculture

Green nanotechnology has been developed for a flexible and efficient source of energy in the form of solar cells which have long been an ambition for tropical countries. However, the use of glass photovoltaic panels is delicate and too expensive. A high priority of research in most industrialized countries has been given to the development of photovoltaic panels, energy storage and other nanotechnology-enhanced solar-thermal energy conversion systems. Economic feasibility is the critical factor for developing these photo catalysts and energy materials and if we address this factor properly, we will be able to develop more and more 'out-of-box' ideas. A substantial technical breakthrough has been made by Jennings and Cliffel at Vanderbilt University who have explored the use of photosynthesis protein units derived from leafy vegetables and plants for direct conversion of solar energy to electricity[33], and has remained functional for about one year. A glass microscope slide that serves as the cell base is the most expensive component of this system.

Nanotechnology is also helpful for the conversion of biomass into fuels, chemical intermediates, special chemicals and products including catalysts in order to reduce production cost while being economically feasible. These nanostructured catalysts have large surface area per unit volume and are capable of having precisely controlled composition, structure functionalization and other important properties of catalysts[34].

3.8 Nanotechnology in hydroponics (a branch of agriculture)

Hydroponics (a branch of agriculture) is the technology of growing plants without soil and is widely used around the globe for growing food crops[35]. Hydroponics technology in food production is less well known despite the fact that many fruits and vegetables on display in supermarkets are grown hydroponically. The most popular crops grown hydroponically are tomatoes, cucumbers and sweet peppers, melons, lettuce, strawberries, herbs, eggplant, and chillies. Other applications include the production of fodder and biofuel crops. Scientists have exploited hydroponics in nanotechnology by “growing” metal nanoparticles in livingplants[36-38].

Nutrient management in agricultural production is increasingly important and is more effective in hydroponic than in soil-based production[39]. A nanophosphor-based electroluminescence lighting device has the potential to reduce energy costs significantly[40]. Such nanotechnology-based light could reduce energy costs and encourage photosynthesis in indoor, hydroponic agriculture[41].

4. Conclusion:

Around the world it has become the future of any nation. Many diverse opportunities for nanotechnology exist to play an important role in agriculture, medicine industry and nanoelectronics as well as in livestock production. Even so, less effort is going into applications of nanotechnology in agri-food sectors. Experts envision numerous nanoparticulate agroformulations with higher bioavailability and efficacy and better selectivity in the near future. This research is aimed to put forward a number of tools for the detection of plant diseases and analysis of nanoparticles introduced into plants and to assess the use of such nanoparticles in selected plant tissues. A study in which the benefits of public prefers for certain products can help manufacturers come up with new products and can help researchers to understand more about the public perception of nanotechnology. Nanotechnology has great potential as it can enhance the quality of life through its applications in various fields like agriculture and the food system.

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Reference

[1] Vijaya Shanti B, Mrudula T, Naga Deepth CH, SreeVenkateshwarluY,“Novel Applications of Nanotechnology in Life Sciences”. J BioanalBiomed(2011)S11.

[2] Suh KS, Tanaka T, “ Nanomedicine in Cancer”. Translational Medic(2011) 1:103e.

[3] Yun Y, ConfortiL, Muganda P, SankarJ,“Nanomedicine-basedSynthetic Biology”. JNanomedicBiotherapeuDiscover(2011)1:102e.

[4] Allah Ditta, “How helpful is nanotechnology in agriculture?”, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad 38040, Pakistan,(2012).

[5] Claudia Parisi, Mauro Vigani and Emilio Rodríguez-Cerezo Proceedings of a workshop on “Nanotechnology for the agricultural sector: from research to the field”(2014).

[6] Begum N, Sharma B, Pandey RS, “Evaluation of Insecticidal Efficacy of CalotropisProcera and Annona Squamosa Ethanol Extracts Against Musca Domestica”, J BiofertilBiopestici(2010) 1:101.

[7] Caraglia M, Rosa GD, Abbruzzese A, Leonetti C,"Nanotechnologies: New Opportunities for Old Drugs. The Case of Aminobisphosphonates”. J NanomedicBiotherapeu Discover (2011)1:103e.

[8] Anwunobi AP, Emeje MO, “Recent Application of Natural Polymers in NanodrugDelievery”. J NanomedicNanotechnol(2011)S4:00.

[9] Cifuentes et al., “ Absorption and translocation to the aerial part of magnetic carbon-coated nanoparticles through the root of different crop plants”. J Nanobiotechnol(2010)8:26.

[10] Chen H, Yada R, “Nanotechnoogies in agriculture: new tools for sustainable development. Trends Food” Sci Technol. (2011);22(11):585–594.

[11] Vitaflora ,“Benefits with our products”,Vitaflora; (2012), UlicaBraćeRadić 32 33514, Čačinci Croatia.

[12] AllAboutFeed.net [webpage on the Internet]. “Nano technology in animal feed.Doetinchem” The Netherlands: Reed Business; (2013).

[13] Fondevila M, Herrer R, Casallas MC, Abecia L, Ducha JJ., “Silver nanoparticles as a potential antimicrobial additive for weaned pigs”. Animal Feed Science and Technology.(2009);150(3–4):259–269.

[14] Fondevila M. “Potential use of silver nanoparticles as an additive in animal feeding”. In: Peres DP, editor. Silver Nanoparticles. Rijeka, Croatia: InTech; (2010):325–334.

[15] Pineda L, Sawosz E, Lauridsen C, et al., “Influence of in ovo injection and subsequent provision of silver nanoparticles on growth performance, microbial profile, and immune status of broiler chickens”. Open Access Anim Physiol. (2012):2012(4):1–8.

[16] Kim HJ, Kim SH, Lee JK, et al., “ A novel mycotoxin purification system using magnetic nanoparticles for the recovery of aflatoxin B1 and zearalenone from feed”. J Vet Sci.(2012);13(4):363–369.

[17] AchyuthanK ,“Whither Commercial Nanobiosensors”. J BiosensBioelectron(2011) 2:102e.

[18] Rai V, Acharya S, Dey N. “Implications of nanobiosensorsin agriculture”. J BiomaterNanobiotchnol.(2012);3:315–324.

[19] Tothill EI “Biosensors and Nanomaterials and their application for Mycotoxin determination”, World Mycotoxin Journal 4:(2011),351-374.

[20] Farrell D, Hoover M, Chen H, Friedersdorf L, “Overview of Resources And Support for Nanotechnology for Sensors and Sensors for Nanotechnology: Improving and Protecting Health, Safety, and the Environment”, Arlington VA: US National Nanotechnology Initiative; (2013).

[21] Wanekaya AK, Chen W, Myung NV, Mulchandani A, “Nanowire-based electrochemical biosensors”. Electroanalysis.(2006);18(6):533–550.

[22] Ajayan PM, Schadler LS, Braun PV, editors, “Nanocomposite Science and Technology”,Weinheim, Germany: Wiley-VCH Verlag GmbH and Co, KGaA; (2003).

[23] Kumar SK, Krishnamoorti R, “ Nanocomposites: structure, phase behavior, and properties”, Annu Rev ChemBiomol Eng. (2010);1:37–58.

[24] Ke YC, Stroeve P, “ Polymer-Layered Silicate and Silica Nanocomposites”, 1st ed. Amsterdam, The Netherlands: Elsevier BV; (2005).

[25] Chaudhry Q, Castle L, Watkins R, editors, “ Nanotechnologies in Food”, Cambridge, UK: Royal Society of Chemistry, (2010).

[26] Cao X, Habibi Y, Magalhães WLE, Rojas OJ, Lucia LA, “Cellulose nanocrystals-based nanocomposites: fruits of a novel biomass research and teaching platform”. Curr Sci. (2011);100(8):1172–1176.

[27] Tiwari A, editor,“Recent Developments in Bio-Nanocomposites for Biomedical Applications”, 1st ed. Hauppauge, NY: Nova Science Publishers, Inc.; (2010).

[28] Nair R, Varghese SH, Nair BG, MaekawaT, Yoshida Y, Kumar DS,“Nanoparticulate material delivery to plants”, Plant Science. (2010);179(3): 154–163.

[29] Rico CM, Majumdar S, Duarte-Gardea M, Peralta-Videa JR, GardeaTorresdeyJL,“Interaction of nanoparticles with edible plants and their possible implications in the food chain”. J Agric Food Chem. (2011);59(8):3485–3498.

[30] Răcuciu M, CreangăDE,“TMA-OH coated magnetic nanoparticles internalized in vegetal tissue”. Romanian Journal of Physics.(2006);52(3–4):395–402.

[31] Wang H, Kou X, Pei Z, Xiao JQ, Shan X, Xing B,“Physiological effects of magnetite (Fe3O4) nanoparticles on perennial ryegrass (Loliumperenne L.) and pumpkin (Cucurbita mixta) plants”, Nanotoxicology. (2011);5(1):30–42.

[32] Warad H C, Ghosh S C, Thanachayanont C, Dutta J and Hilborn J G “Highly luminescent manganese doped ZnS quantum dots for biological labeling” Proc. Int. Conf. on Smart Materials/Intelligent Materials (2004)(SmartMat ’04) (1–3 December 2004, Chiang Mai, Thailand) pp 203–6

[33] Ciesielski P N et al , (2010)BioresourceTechnol 101 304

[34] Davis R, Guliants V V, Huber G, Lobo R F, Miller J T, Neurock M, Sharma R and Thompson L, “ An International Assessment of Research in Catalysis by Nanostructured Materials”, (Baltimore, MD: WTEC) (2009)

[35] Seaman C, BricklebankN,“Soil-free farming”, Chemistry and Industry Magazine. (2011):19 –21.

[36] Giordani T, Fabrizi A, Guidi L, et al. “Response of tomato plants exposed to treatment with nanoparticles”, Environmental Quality,(2012);8(2012):27–38.

[37] Schwabe F, Schulin R, Limbach LK, Stark W, Bürge D, Nowack B, “Influence of two types of organic matter on interaction of CeO2 nanoparticles with plants in hydroponic culture”, Chemosphere. (2013);91(4):512–520.

[38] Dimkpa CO, McLean JE, Martineau N, Britt DW, Haverkamp R, Anderson AJ,"Silver nanoparticles disrupt wheat (Triticumaestivum L.) growth in a sand matrix", Environ Sci Technol. (2013);47(2): 1082–1090.

[39] Seaman C, BricklebankN,"Soil-free Farming", Chemistry and Engineering Magazine.(2011);6.

[40] Wipro Insights [webpage on the Internet], " Green nanotechnology: Making way for a sustainable future", Bangalore, India: Wipro Limited; (2012).

[41] Witanachchi S, Merlak M, Mahawela P, "Nanotechnology solutions to greenhouse and urban agriculture". TechnolInnov,(2012);14(2): 209–217.