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Review

Nanotechnology in sustainable agriculture: Present concerns and future aspects

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Nanotechnology is a promising field of interdisciplinary research. It opens up a wide array of opportunities in various fields like medicine, pharmaceuticals, electronics and agriculture. The potential uses and benefits of nanotechnology are enormous. The current global population is nearly 7 */billion with 50% living in Asia. A large proportion of those living in developing countries face daily food shortages as a result of environmental impacts or political instability, while in the developed world there is surplus of food. For developing countries, the drive is to develop drought and pest resistant crops, which also maximize yield. The potential of nanotechnology to revolutionise the health care, textile, materials, information and communication technology, and energy sectors has been well publicized. The application of nanotechnology to agriculture and food industries is also getting attention nowadays. Investments in agriculture and food nanotechnologies carry increasing weight because their potential benefits range from improved food quality and safety to reduced agricultural inputs and improved processing and nutrition. While most investment is made primarily in developed countries, research advancements provide glimpses of potential applications in agricultural, food, and water safety that could have significant impacts on rural populations in developing countries. This review is concentrated on modern strategies used for the management of water, pesticides, limitations in the use of chemical pesticides and potential of nano-materials in sustainable agriculture management as modern approaches of nanotechnology.

Key words: Agriculture, nanotechnology, nanofertilizer, nanoencapsulation, nanoherbicides.

INTRODUCTION

Nanotechnology is a novel scientific approach that involves the use of materials and equipment capable of manipulating physical as well as chemical properties of a substance at molecular levels. On the other hand, biotechnology involves using the knowledge and techniques of biology to manipulate molecular, genetic and cellular processes to develop products and services and is used in diverse fields from medicine to agriculture (Fakruddin et al., 2012). Agriculture is the backbone of developing countries, with more than 60% of the population depending on it for their livelihood (Brock et al., 2011).

Nanotechnology has the potential to revolutionize the agricultural and food industry with novel tools for the molecular management of diseases, rapid disease

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Abbreviations: CEA, Controlled Environment Agriculture; **GPS,** global positioning system; **IPM,** Integrated Pest Management; **CHIP,** Chicken and Hen Infection Program; **PDA,** potato dextrose agar; **PHSNs,** porous hollow silica nanoparticles; **DDT,** dichorodiphenyltrichloroethane.

detection, enhancing the ability of plants to absorb nutrients, among others. On the other hand, nanobio-technology can improve our understanding of the biology of various crops and thus can potentially enhance yields or nutritional values, as well as developing improved systems for monitoring environmental conditions and enhancing the ability of plants to absorb nutrients or pesticides (Tarafdar et al., 2013).

Agricultural and food systems security, disease management delivery systems, new techniques for molecular and cellular biology, new materials for pathogen detection and protection of the environment are examples of the important links of nanotechnology to the science and engineering of agriculture and food systems (Welch and Graham, 1999; Suman et al., 2010). There are new challenges in this sector including a growing demand for healthy, food safety, an increasing risk of disease and threats to agricultural production from changing weather patterns (Biswal et al., 2012).

Nanobiotechnology operates at the same level with virus or disease infecting particle, and thus holds the potential for primordial detection and eradication. It also holds out the possibility that smart sensors and delivery systems will help the agricultural industry combat viruses and other crop pathogens. Long before the symptoms develop, the integrated sensing, monitoring and con-trolling system could detect the presence of disease and notify the farmer and activate bioactive systems such as drugs, pesticides, nutrients, probiotics, nutraceuticals and implantable cell bioreactors. In the near future, nano-structured catalysts will be available which will increase the efficiency of pesticides and herbicides, allowing lower doses to be used. Nanotechnology will also protect the environment indirectly through the use of alternative (renewable) energy supplies, and filters or catalysts to reduce pollution and clean-up existing pollutants in soil and water. In the agricultural sector, nanotech research and development is likely to aid and frame the next level of expansion of genetically modified crops, animal pro-duction inputs, chemical pesticides and precision farming techniques (Prasad et al., 2012a).

Changes in agricultural technology have been a major factor shaping modern agriculture. Among the latest line of technological innovations, nanotechnology occupies a prominent position in transforming agriculture and food production. The development of nano-devices and nano-materials could open up novel applications in plant biotechnology and agriculture. Currently, the main thrust of research in nanotechnology focuses on applications in the field of electronics, energy, medicine and life sciences (Scrinis and Lyons, 2007), as agriculture is not consi-dered as potent industry. While nano-chemical pesticides are already in use, other applications are still in their early stages, and it may take many years before they are commercialized or reach the common man. These applications are largely intended to address some of the limitations and challenges facing large scale, chemical and capital intensive farming systems. This includes the fine tuning and more precise microma-nagement of soils; the more efficient and targeted use of inputs, new toxin formulations for pest control, new crop and animal traits, and the diversification and differentiation of farming practices and products within the context of large scale and highly uniform systems of production. Nano-technology will leave no field untouched by its ground breaking scientific innovations. The agri-cultural industry is no exception. So far, the use of nanotechnology in agriculture has been mostly theo-retical, but it has begun and will continue to have a significant impact in the main areas of food industry, development of new functional materials, product development and design of methods and instrumentation for food safety and bio-security. The effects on society as a whole will be dramatic (Prasad et al., 2012a). This review is focused on modern strategies used for the management of water, pesticides, sensors, fertilizers, limitations in the use of chemical pesticides and potential of nanomaterials in sustainable agriculture management as modern approaches of nanotechnology.

OVERVIEW OF NANOTECHNOLOGY APPLICATIONS IN AGRICULTURE

Nanotechnology and agricultural production developments

In the near future, nanostructured catalysts will be available which will increase the efficiency of pesticides and herbicides, allowing lower doses to be used. An agricultural system widely used in the USA, Europe and Japan, which efficiently utilises modern technology for crop management is called Controlled Environment Agriculture (CEA). CEA is an advanced and intensive form of hydroponically based agriculture. Plants are grown within a controlled environment so that agricultural practices can be optimized. The computerized system monitors and regulates localised environments such as fields of crops and irrigated water. CEA technology provides an excellent platform for the introduction of nanotechnology to agriculture. Nanotechnological devices for CEA that provide “scouting” capabilities could tremendously improve the grower’s ability to determine the best time to harvest the crop, the vitality of crop, and food security issues, such as microbial or chemical contamination.

Nanosensors for monitoring soil conditions and plant growth hormone

Nanotechnology delivery systems for nutrients and plant hormones

The proficient use of agricultural natural assets like water, nutrients and chemicals during farming as nanosensors is user friendly. It makes use of nanomaterials and global positioning systems with satellite imaging of fields and might make farmers to detect crop pests or facts of stress such as drought. Nanosensors disseminated in the field are able to sense the existence of plant viruses and the level of soil nutrients (Ingale and Chaudhari, 2013). They also minimize fertilizer consumption and environmental pollution. Nano-encapsulated slow- release fertilizers have been widely used (DeRosa et al., 2010). To check the quality of agricultural manufacture, nanobarcodes and nanoprocessing could be used. Li et al. (2005) used the idea of grocery barcodes for economical, proficient, rapid effortless decoding and recognition of diseases. They created nanobarcodes that may tag perhaps multiple pathogens in a farm, which may simply be detected using any fluorescent based tools. Nanotechnocrates are capable of studying plant's regulation of hormones such as auxin, which is accountable for root growth and seedling organization. Nanosensors that react with auxin have been developed. This is a step forward in auxin research, as it helps scientists to know how plant roots acclimatize to their environment, particularly to marginal soils (McLamore et al., 2010).

Nanobiosensors

Sensors are sophisticated instruments which respond to physico-chemical and biological aspects and transfer that response into a signal or output that can be used by humans (NNCO, 2009). They allow the detection of contaminants such as microbes, pests, nutrient content and plant stress due to drought, temperature, insect or pathogen pressure, or lack of nutrients. Nanosensors have the potential to allow farmers to utilize inputs more efficiently by indicating the nutrient or water status of crop plants over fine spatial and temporal scales. This makes the farmers to apply nutrients, water, or crop protection (insecticide, fungicide or herbicide) only where necessary. One of the major roles of nanotechnology enabled devices is to increase the use of autonomous sensors linked to a global positioning system (GPS) system for real time monitoring. These nanosensors could be distributed throughout the field where they can monitor soil conditions and crop growth. Nanoparticles or nanosurfaces can be engineered to trigger an electrical or chemical signal in the presence of a contaminant such as bacterium. Ultimately, precision farming, with the help of smart sensors leads to enhanced productivity in agriculture by providing accurate information, thus helping farmers to make better decisions.

Nanotechnology in irrigation water filtration

The emerging technologies that will benefit farmers all over world, especially in developing countries include several nanomaterials which are considered economically effective in purification of irrigation water. Nano-enabled water treatment techniques based on membranes filters derived from carbon nanotubes, nanoporous ceramics, and magnetic nanoparticles inspite using chemicals and UV light are common in traditional water treatment (Hillie and Hlophe, 2007). Filters made from carbon nanotube could be employed in removing contaminants and toxicants from potable water. Carbon nanotube fused mesh that can remove water-borne pathogens, heavy metals like lead, uranium and arsenic has been suggested by researchers. Employing nanoceram filter with positive charge can trap bacteria and viruses with negative charge. This sophisticated filtering machine removes microbial endotoxins, genetic materials, pathogenic viruses, and micro-sized particles (Argonide, 2005).

Magnetic nanoparticles for filtration

At very low magnetic field gradients, the use of magnetic nanoparticles and magnetic separations is now possible. Nanocrystals, such as monodisperse magnetite (Fe_3O_4) have a strong and irreversible interaction with arsenic while retaining their magnetic properties (Yavuz et al., 2006).

A simple handheld magnet can be used to remove nanocrystals and arsenic from water. Such a treatment could be used for irrigation water filtration process.

Detoxification or remediation of harmful pollutants

Using synthetic clay nanomineral does not require expensive laboratory equipment for arsenic removal. The water to be filtered is percolated through a column of hydrotalcite (synthetic clay mineral). Gilman (2006) suggests that this technology can be coupled with leaching through porous pots or filter candles, the technology available in many developing countries to filter organisms from drinking water. Zinc oxide nanoparticles can be used to remove arsenic using a point-of-source purification device. Nanoscale zero-valent iron is the most widely used the set of nanomaterials that could be deployed to remediate pollutants in soil or groundwater. Other nanomaterials that could be used in remediation include nanoscale zeolites, metal oxides, carbon nanotubes and fibers, enzymes, various noble metals (mainly as bimetallic nanoparticles) and titanium dioxide.

Nanoparticle filters can be used to remove organic particles and pesticides (for example, dichorodiphenyl-trichloroethane (DDT), endosulfan, malathion and chlorpyrifos) from water. A variety of nanoparticle filters have been used in remediation of waste sites in developed countries (Karn et al., 2009).

Nanocapsules for efficient delivery of pesticides, fertilizers and other agrochemicals

Nanoencapsulation is a process through which chemicals like insecticides are slowly but efficiently released to a particular host plant for insect pest control. Nanoencapsulation with nanoparticles in the form of pesticides allows for proper absorption of the chemicals into the plants (Scrinis and Lyons, 2007). This process can also deliver DNA and other desired chemicals into plant tissues for protection of host plants against insect pests (Torney, 2009). Release mechanisms of nanoencapsulation include diffusion, dissolution, biodegradation and osmotic pressure with specific pH (Ding and Shah, 2009; Vidhyalakshmi et al., 2009). Nanoencapsulation is currently the most promising technology for protection of host plants against insect pests. Now, most leading chemical companies focus on formulation of nanoscale pesticides for delivery into the target host tissue through nanoencapsulation.

Fertilizer plays a pivotal role in agriculture production (35 to 40%). To enhance nutrient use efficiency and overcome the chronic problem of eutrophication, nanofertilizer 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 (Liu et al., 2006a). Nanofertilizers could be used to reduce nitrogen loss due to leaching, emissions, and long-term incorporation by soil microorganisms. They could allow selective release linked to time or environmental condition. Slow controlled release fertilizers may also improve soil by decreasing toxic effects associated with fertilizer over- application (Suman et al., 2010).

Technologies such as encapsulation and controlled release methods have revolutionised the use of pesticides and herbicides. Pesticides inside nanoparticles are being developed that can be timely released or have release linked to an environmental trigger. Combined with a smart delivery system, herbicide could be applied only when necessary, resulting in greater production of crops and less injury to agricultural workers. Many companies make formulations which contain nanoparticles within the size ranges of 100-250 nm; they are able to dissolve in water more effectively than existing ones (thus increasing their activity). Other companies employ suspensions of nanoscale particles (nanoemulsions) which can be either water or oil-based and contain uniform suspensions of pesticidal or herbicidal nanoparticles in the range of 200-400 nm. These can be easily incorporated in various media such as gels, creams, liquids among others, and have multiple applications for preventative measures, treatment or preservation of harvested products.

Syngenta, world’s largest agrochemical corporation, is using nanoemulsions in its pesticide products. One of its successful growth regulating products is the Primo MAXX® plant growth regulator, which if applied prior to the onset of stress such as heat, drought, disease or traffic can strengthen the physical structure of turf grass and allow it to withstand ongoing stresses throughout the growing season. Another encapsulated product from Syngenta delivers a broad control spectrum on primary and secondary insect pests of cotton, rice, peanuts and soybeans. Marketed under the name Karate® ZEON this is a quick release microencapsulated product containing the active compound lambda-cyhalothrin (a synthetic insecticide based on the structure of natural pyrethrins) which breaks open on contact with leaves. In contrast, the encapsulated product “gutbuster” only breaks open to release its contents when it comes into contact with alkaline environments, such as the stomach of certain insects.

Nano based smart drug-delivery systems

Smart delivery systems can detect and treat an animal infection or nutrient deficiency and provide timed-release drugs or micronutrients. The use of pesticides increased in the second half of the 20th century with DDT becoming one of the most effective and widespread throughout the world. However, many of these pesticides, including DDT were later found to be highly toxic and persistent, affecting human and animal health and as a result whole ecosystems. As a consequence, they were banned. To maintain crop yields, Integrated Pest Management (IPM) systems, which mix traditional methods of crop rotation with biological pest control methods, are becoming popular and implemented in many countries, such as Tunisia and India.

In the future, nanoscale devices with novel properties could be used to make agricultural systems smart. For example, devices could be used to identify plant health issues before these become visible to the farmer. Such devices may be capable of responding to different situations by taking appropriate remedial action. If not, they will alert the farmer to the problem. In this way, smart devices will act as both a preventive and an early warning system. Such devices could be used to deliver chemicals in a controlled and targeted manner in the same way as nanomedicine has implications for drug delivery in humans.

Zeolites for water retention

These are naturally occurring crystalline aluminum silicates. Zeolite assists water infiltration and retention in the soil due to its very porous properties and the capillary suction it exerts. Acting as a natural wetting agent, it is an excellent amendment for non wetting sands and assists water distribution through soils.

This can improve significantly the water retention of sandy soils and increase porosity in clay soils. Improving water-retention capacity of soils could result in increased crop production in areas prone to drought. With subsequent applications, zeolite will further improve soil's ability to retain nutrients and produce improved yields.

Nanocoatings and nanofeed additives

Self-sanitizing photocatalyst coating used in poultry houses with nano-titanium dioxide (TiO_2) could be used to oxidize and destroy bacteria in the presence of light and humidity. Poultry feed having nanoparticles that binds pathogenic bacteria could help in decreasing food-borne pathogens. The unique photocatalytic properties of the nano TiO_2 are activated when the coating is exposed to natural or UV light. In the presence of light and humidity, TiO_2 oxidizes and destroys bacteria. Once coated, the surface remains self-sanitizing as long as there is enough light to activate the photocatalytic effect. The coating is approved by the Canadian Food Inspection Agency. In Denmark, the Chicken and Hen Infection Program (CHIP) involves self-cleaning and disinfection nanocoatings (Clemants, 2009). The nanoscale smooth surface makes more effective disinfection and cleaning. Ultimately, Danish researchers are also working on coatings incorporating nanosilver which does not need UV light for activation. The ions from nanosilver avert the progress of biofilms (Clemants, 2009). Surface-modified hydrophobic as well as lipophilic nanosilica can be significantly used as new drugs for healing nuclear polyhedrosis virus (BmNPV), a major problem in silkworm industry. *Bombyx mori* (Silk worm) has clearly shown that nanoparticles could stimulate more fibroin protein production which can assist in the future in producing carbon nano tube (Bhattacharyya et al., 2008; Bhattacharyya, 2009). Modified nanoclays (montmorillonite nanocomposite) can ameliorate the harmful effects of aflatoxin on poultry (Shi et al., 2006). Research on nanoparticles and insect control should be geared toward introduction of faster and eco-friendly pesticides in the future (Bhattacharyya et al., 2010).

Nanoherbicides

The easiest way to eliminate weeds is to destroy their seed banks in the soil and prevent them from germinating when weather and soil conditions become favourable for their growth. Being very small, nanoherbicides will be able to blend with the soil, eradicate weeds in an eco-friendly way without leaving any toxic residues, and prevent the growth of weed species that have become resistant to conventional herbicides. Weeds survive and spread through underground structures such as tubers and deep roots. Ploughing infected fields while removing weeds by hand can make these unwanted plants spread to uninfected areas. Whether the nano application is due to a nanosized active ingredient or the creation of a nanosized formulation through the use of an adjuvant, the use of nano application is same. If the active ingredient is combined with a smart delivery system, herbicide will be applied only when necessary according to the conditions of the agriculture field. Lower agricultural yields are obtained in soils contaminated with weeds and weed seeds. Improvements in the efficacy of herbicides through the use of nanotechnology could result in more crop production without causing any harmful effects to agricultural workers who are supposed to physically remove weeds if no application of herbicides is practised.

Nanotechnology in organic farming

Organic farming has been a long-desired goal to increase productivity (that is, crop yields) with low input (that is, fertilizers, pesticides, herbicides among others) through monitoring environmental variables and applying targeted action. Organic farming makes use of computers, GPS systems, and remote sensing devices to measure highly localized environmental conditions, thus determining whether crops are growing at maximum efficiency or precisely identifying the nature and location of problems. By using centralised data to determine soil conditions and plant development, seeding, fertilizer, chemical and water use can be fine-tuned to lower production costs and potentially increase production all benefiting the farmer. Precision farming can also help to reduce agricultural waste and thus keep environmental pollution to a minimum.

Nanoparticles and plant disease control

Some of the nano particles that have entered into the arena of controlling plant diseases are nanoforms of carbon, silver, silica and alumino-silicates. At such a situation, nanotechnology has astonished scientific community because at nano-level, material shows different properties. The use of nano size silver particles as antimicrobial agents has become more common as technology advances, making their production more economical. Since silver displays different modes of inhibitory action to microorganisms (Young, 2009), it may be used for controlling various plant pathogens in a relatively safer way compared to commercially used fungicides. Silver is known to affect many biochemical processes in the microorganisms including the changes in routine functions and plasma membrane (Pal et al., 2007). The silver nanoparticles also prevent the expression of ATP production associated proteins (Yamanka et al., 2005). In a nutshell, the precise mechanism of bio molecules inhibition is yet to be understood.

Thus, use of nanoparticles has been considered an alternate and effective approach which is eco-friendly and cost effective for the control of pathogenic microbes (Kumar and Yadav, 2009; Prasad et al., 2011; Swamy and Prasad, 2012; Prasad and Swamy, 2013). These nanoparticles have a great potential in the management of plant diseases compared to synthetic fungicides (Park et al., 2006). Zinc oxide (ZnO) and magnesium oxide (MgO) nanoparticles are effective antibacterial and anti-odour agents (Shah and Towkeer, 2010). The increased ease in dispensability, optical transparency and smoothness make ZnO and MgO nanostructures an attractive antibacterial ingredient in many products. Both have also been proposed as an anti-microbial preservative for wood or food products (Aruoja et al., 2009; Huang et al., 2005; Sharma et al., 2009). Properly functionalized nanocapsules 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 et al., 2008).

Nanosilver is the most studied and utilized nano particle for bio-system. It has long been known to have strong inhibitory and bactericidal effects as well as a broad spectrum of antimicrobial activities (Swamy and Prasad, 2012; Prasad et al., 2012b; Prasad and Swamy, 2013). Silver nanoparticles, which have high surface area and high fraction of surface atoms, have high antimicrobial effect compared to the bulk (Suman et al., 2010). Fungicidal properties of nano-size silver colloidal solution are used as an agent for antifungal treatment of various plant pathogens; the most significant inhibition of plant pathogenic fungi was observed on potato dextrose agar (PDA) and 100 ppm of AgNPs (Kim et al., 2012).

Nanoparticles as pesticides

Nanoparticles are also effective against insects and pests. Nanoparticles can be used in the preparation of new formulations like pesticides, insecticides and insect repellants (Barik et al., 2008; Gajbhiye et al., 2009). Torney (2009) reviewed that nanotechnology has promising applications in nanoparticle gene mediated DNA transfer. It can be used to deliver DNA and other desired chemicals into plant tissues for protection of host plants against insect pests. Porous hollow silica nanoparticles (PHSNs) loaded with validamycin (pesticide) can be used as efficient delivery system of water-soluble pesticide for its controlled release. Such controlled release behaviour of PHSNs makes it a promising carrier in agriculture, especially for pesticide controlled delivery whose immediate as well as prolonged release is needed for plants (Liu et al., 2006b). According to Wang et al. (2007), oil in water (nano-emulsions) was useful for the formulations of pesticides 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 et al., 2006b). Nanosilica, a silica product, can be effectively used as a nanopesticide.

Barik et al. (2008) reviewed 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, the nanosili caparticles when applied on plant surface, cause death by physical means of insects by being absorbed into the cuticular lipids. Modified surface charged hydrophobic nano-silica (~3-5 nm) could be successfully implemented to manage a variety of ectoparasites of animals and agricultural insect pests (Ulriches et al., 2005). The insecticidal activity of polyethylene glycol-coated nanoparticles loaded with garlic essential oil against adult *Tribolium castaneum* insect was found in stored products.

It has been observed that the control efficacy against adult *T. castaneum* was about 80%; presumably due to the slow and persistent release of the active components from the nanoparticles (Yang et al., 2009). The applications of diverse kind of nanoparticles viz. silver nanoparticles, aluminium oxide, zinc oxide and titanium dioxide in the management of rice weevil and grasserie disease in silk worm (*B. mori*) are caused by *Sitophilus oryzae* and baculovirus BmNPV (*B. mori* nuclear polyhedrosis virus, respectively (Goswami et al., 2010). Teodoro et al. (2010) studied the insecticidal activity of nanostructured alumina against two insect pests viz. *S. oryzae* L. and *Rhyzopertha dominica* (F.), which are major insect pests in stored food supplies throughout the world. Significant mortality was observed after 3 days of continuous exposure to nanostructured alumina-treated wheat. Therefore, compared to commercially available insecti-cides, inorganic nanostructured alumina may provide a cheap and reliable alternative for control of insect pests, and such studies may expand the frontiers for nanoparticle-based technologies in pest management.

POTENTIAL BENEFITS OF NANOTECHNOLOGY APPLICATIONS

Currently the research and development pipeline has the potential to make agriculture more efficient, increase yields and product quality, and thereby increasing nutriational benefits. Developed countries are using or testing nanosensors and nanoagricultural chemicals, nanoparticles for soil cleaning and nanopore filters, nanoceramic devices, and nanoparticles. An increasing number of applications are expected for food and agriculture uses, including nanosensors, potentially capable of detecting chemical contaminants, viruses, and bacteria; nano-delivery systems, which could precisely deliver drugs or micronutrients at the right time and to the right part of the body; as well as nanocoatings and films, nanoparticles, and quantum dots (Bouwmeester et al., 2009).

There are several reports on the great potential of agricultural and food nanotechnology in developing countries. Promising nanotechnology applications address low use efficiency of agricultural production inputs and stress of drought and high soil temperature. Nanoscale agrichemical formulations can increase efficiency use and decrease environmental losses. Nanoporous materials capable of storing water and slowly releasing it during times of water scarcity could also increase yields and save water.

Researchers have shown that applying nanotechnology to reduce the effects of aflatoxin (a fungal toxin) increases the weight of food animals. The potential for nanotechnology in agriculture continues to grow (Shi et al., 2006).

Barik et al. (2008) opined that more ambitious uses of nanoparticles are bio-remediation of contaminated environments, biocides and antifungals on textiles. Photocatalysis in agriculture is another direction in which nanomaterials can play an important role. Different nanostructures of titanium dioxide (TiO_2) and zinc oxide (ZnO) have been widely studied as photocatalysts (Ullah and Datta, 2008). Chemicals presented in pesticides are transformed in relatively harmless molecules such as CO_2, N_2 and H_2O.

Under progress is also the removal of pesticides and herbicides on plants and the soil through photocatalysis. Carbamate pesticides used in a variety of field crops are completely mineralized in the presence of ZnO and TiO_2, dichloropyrifos being an example of an often used pesticide.

Apart from nanoparticles, there are reports on the use of nanotubes and nanostructures thin films for degrading pesticides.

Nanotechnology for crop biotechnology

Nanocapsules can facilitate successful incursion of herbicides through cuticles and tissues, allowing slow and regular discharge of the active substances. This can act as 'magic bullets', containing herbicides, chemicals origins which target exacting plant parts to liberate their substance (Pérez-de-Luque and Rubiales 2009). Torney et al. (2007) exploited a 3 nm mesoporous silica nanoparticle in delivering DNA and chemicals into isolated plant cells. Mesoporous silica nanoparticles are chemically coated and 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. This technique firstly has been applied to establish DNA fruitfully to tobacco and corn plants.

Nanotechology and societal stigma

The effects of exposure to engineered nanoparticles may be different from the effects caused by naturally occurring nanoparticles. Engineered nanoparticles may be better to evade the body's defences because of their size or protective coatings. Moreover, the health and environmental risks raised due to the exposure to engineered nanoparticles need further study.

Up-coming nanotechnologies in the agricultural field seem quite interesting and promising. However, the probable risks in using nanoparticles in agriculture are no diverse than those in any other business. Through the rapid distribution of nanoparticles to food products, whether it is in the food itself or part of the packaging, nanoparticles will virtually come in direct or indirect contact with everyone. The probability could be that "the merger of nanotech and biotech may cast unknown consequences on soil, health, biodiversity and the environment. Since there is no standardization for the use and testing of nanotechnology, products incorporating the nanomaterials are being produced without check. The ability for these materials to infiltrate the human body is well known, but there is really no information on the effects that they may have. While there is no evidence of harm to people or the environment at this stage, nanotechnology is a new and evolving area of study that could cause a great deal of harm due to its still ambiguous chemical properties. With the current application and advancements soon to come, nanotechnology will have a great impact on the direction that agriculture 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. In the field of agriculture, there are still many possibilities to explore and a great deal of potential with up-coming products and techniques. Therefore, extensive studies are required to understand the mechanism for nanoparticles materials toxicity and their impacts on natural environment.

CONCLUSIONS AND FUTURE PERSPECTIVES

Nanotechnology applications have the potential to change agricultural production by allowing better management and conservation of inputs to plant production. Researchers in nanotechnology can do a lot to benefit society through applications in agriculture and food systems (Sugunan and Dutta, 2004). Introduction of any new technology always has an ethical responsibility associated with it to be apprehensive to the unforeseen risks that may come along with the tremendous positive potential. Public awareness about the advantages and challenges of nanotechnology will lead to better acceptance of this emerging technology. Rapid testing technologies and biosensors related to the control of pests and cross contamination of agriculture and food products will lead to applications of nanotechnology in the near future.

Nanotechnology application in agriculture and food systems is still at the nascent stage and a lot more applications can be expected in the years to come. Nanoparticles present an extremely gorgeous platform for a diverse range of biological applications. As it provides the single step process for biosynthesis of nanoparticles, it attracts more researchers to go for future developments in the area of electrochemical sensor, biosensors, medicine, healthcare and agriculture. New research also aims to make plants use water, pesticides and fertilizers more efficiently, to reduce pollution and to make agriculture more environmental friendly (Suman et al., 2010).

As in the case of every nonconventional technology, for example, genetic engineering, some fear that nanotechnology can give people too much control. Agriculture technology should take advantage of the powerful tools of nanotechnology for the benefit of mankind. Nanotechnology can endeavour to provide and fundamentally streamline the technologies currently used in environmental detection, sensing and remediation. The potential uses and benefits of nanotechnology are enormous. These include agricultural productivity enhancement involving nanoporous zeolites for slow release and efficient dosage of water and fertilizer, nanocapsules for herbicide delivery and vector and pest management and nanosensors for pest detection (Scrinis and Lyons 2007; Scott 2007).

Some nanotechnology applications are near commercialization: nanosensors and nanoscale coatings to replace thicker, more wasteful polymer coatings that prevent corrosion, nanosensors for detection of aquatic toxins, nanoscale biopolymers for improved decontamination and recycling of heavy metals, nanostructured metals that break down hazardous organics at room temperature, smart particles for environmental monitoring and purification, nanoparticles as a novel photocatalyst for environmental catalysis, among others. Thus nanotechnology will revolutionize agriculture including pest management in the near future. Over the next two decades, the green revolution would be accelerated by means of nanotechnology. Nanoparticles help to produce new pesticides, insecticides and insect repellents (Owolade et al., 2008).

Nanotechnology has great potential in agriculture as it can enhance the quality of life through its applications in fields like sustainable and quality agriculture and the improved and rich food for community. All over the world, this technology has become the future of any country. One has to be very cautious with any novel technology to be introduced about its probable unforeseen and unexpected jeopardy that could land through its optimistic possibilities. Though, it is also significant for the future of a state to create skilled prospect manpower for this novel technology. Therefore, it becomes vital to inform the common man about its benefits at the first step, which will incredibly augment in the awareness and innovation of novel applications in all spheres. The outlook of nanoscience in agriculture is vague owing to a lot of grounds, for example, the unconstructive response from people towards genetically modified (GM) crops, need of a lot of required cleverness in government agricultural research and technology units for nano type of explorations and poorly-equipped new instruments and new-fangled technologies. There is a terrible call to slash down the jagged outline existing among the society, common man and budding scientific notions and if we achieve something in overcoming this line, then an unexpected bright and beneficial future will be at the door step of society.

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