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Wonder of Nanotechnology – A Review

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ABSTRACT

Nanotechnology is the creation and utilization of materials, devices, system through the control of the properties and structure of the matter at the nanometric scale. Nanotechnology is an emerging technology that has the potential for use in a broad array of foods, medical products and cosmetics. These nanomaterials can have different chemical, physical as well as biological properties. This review is focused on applications of nanotechnology in agriculture as well as in medicines. Nanotechnology can be used for combating the plant diseases either by controlled delivery of functional molecules or as diagnostic aids for disease detection. The potential contribution of nanotechnology in the medical sector is extremely broad and includes new diagnostic tools, imaging agents and methods, drug delivery systems and pharmaceuticals, therapies, implants and tissue engineering.

KEYWORDS : nanotechnology, nanotubes, liposomes, dendrimers

Introduction

Nanotechnology is the latest scientific trend that utilizes the materials and system by controlling the properties and structure of matter at the nanometric level and because of its high surface area to volume size ratio, they exhibit significantly novel and improved properties, functions and phenomenon which are applied in various fields such as optical devices, catalytic, bactericidal, electronic sensor technology, biological labelling, cosmetics, clothing and numerous consumer products, and treatment of few types of cancer. Thus it has attracted various researchers and scientists from various fields of physics, chemistry, biology and engineering across the globe to this terrific new science.

Norio Taniguchi used the term "nano-technology" to describe the process of creating semiconductors with nanometer precision while the term "nanotechnology" (abbreviated to "nanotech") was coined by Eric Dexler. By and large, nanotech deals with structures ranging from 1 to 100 nm and involves development of devices and materials within that size (Arivalagan *et al*, 2011). At the nanoscale, the matter exhibits altered properties than those observed at the microscopic level due to reduced molecular size and changed interaction between molecules. The Green revolution started in 1970s targeting four basic production system- semi-dwarf high yielding varieties of rice and wheat, extensive use of irrigation, fertilizers and agro-chemicals. In fact, India is now in need of a 'second green revolution'! Nanoscale science and nanotechnologies are envisioned to have the potential to revolutionize agriculture and food system (Norman and Honda, 2003). Nanobiotechnology holds the key to increase the agricultural potential to harvest feedstocks for industrial processes. Agro nano connects the dots in the industrial food chain and goes back one step further down by providing atomically-modified plants using the new nano-scale techniques of mixing and harnessing genes. With the help of agro-nano, pesticides can be more accurately produced to selectively knock-out pests, plants can be engineered to include the artificial flavors and natural nutrients that can please the palate and an automated, centrally-controlled industrial agriculture can now be implemented using molecular sensors and molecular delivery. The use of nanotechnology in agriculture will have a significant effect in the main areas of the food industry development and instrumentation for food safety and bio-security. Nanotechnology holds the key to transform and modernize the entire food industry sector i.e. changing the way the food is produced, processed, packaged, transported and consumed. They will also help in rapid detection and treatment of plant diseases enhancing the ability of plants to perform their activities. Smart drug delivery systems will help to plants to combat viruses and other crop pathogens. They may also help in creating non-polluting pesticides and herbicides with better efficacy. Filters and catalysts developed from nanoparticles can be used to reduce pollution and clean-up existing pollutants. Thus, nanotechnology will not only affect the agricultural and environmental sector but also the society on the whole for a better and healthier tomorrow.

Nano-nutrient

Fertilizers play a pivotal role in increasing the agricultural production upto 35%-40%. Nanofertilizers may be the best alternative attempt to increase the fertilizer's efficacy and to overcome the problem of eutrophication. Attempts are being made to synthesize nanofertilizers particularly for zinc in order to regulate the release of nutrients depending on the requirement of the crop. They have observed that foliar application of nanoparticles as fertilizer gives a better production. It is also reported that the nanonutrients are much more efficient than the ordinary nutrients, though there is scanty literature available on this. However, some of the reports and planted products strongly suggest that there is vast scope for nanofertilizer formulation.

Precision farming

Nanotechnology uses Information technology to manage commercial agriculture. Precision farming employs the use of technologies satellite-positioning system, geographic information systems and remote sensing devices. By connecting the global positioning systems with satellite imaging of fields, farm managers remotely detect crop pests or evidences of drought which triggers an automatic adjustment of pesticide application or irrigation levels. Dispersed throughout the field are network of sensors with really detailed data about the crops and the soil. These sensors would need to have nanoscale sensitivity to monitor the level of soil nutrients or the presence of plant viruses. Nanoparticles or nanocapsules could provide an efficient distribution of pesticides and fertilizers, thus reducing the quantities of these chemicals introduced into the environment. Livestock can be easily tracked using implanted nanochips. Nanoparticles may be used to deliver growth hormone or vaccines to livestock or genetically engineer plants.

Food processing

Nanosensors may be used in agriculture and food production monitoring crop growth and pest control by early detection and animal and plant diseases. They can also help to enhance the production and improve food safety and function as external monitoring devices which do not end up in food itself. The effectiveness of pesticides may be improved by enclosing them in a hollow capsule with a diameter in nanometer range. Nanopesticide residues on food, animal feed and veterinary medicines may end up inside the stomach but what happens next is not clear.

Detection of Plant diseases.

A need for detection of the plant diseases at an early stage and in less time has tempted the nanotechnologists to look for a solution that is simple, portable, accurate and without any complications that even a farmer can use it. They are trying come up with nanosensors linked into a GPS for a real-time monitoring of soil condition and crop. The union of Biotechnology and Nanotechnology in sensors are trying to create an equipment of increased sensitivity to respond to minute environmental changes and diseases.

Nano genetic manipulation of crops

Nanotechnology offers a new set of tools like nanoparticles, nanofibres and nanocapsules to manipulate the genes. Properly functionalized nanometrical devices serve as a vehicle that can carry large number of genes as well as a substance that can trigger gene expression or control of release of genetic material throughout time in plants. Nanotechnology is heading towards replacing genetic engineering with atomic engineering that can allow the DNA of seeds to be re-arranged in order to obtain different plant properties including colour, growth season and yield. Nanofiber arrays can efficiently deliver genetic material to the cells by genetic manipulation and crop engineering along with environmental monitoring. Controlled biochemical manipulation has been achieved in cells using carbon nanofibres which are surface modified with plasmid DNA.

Agricultural diagnostics and Drug delivery system

Nanoscale capsules serves as carriers and provides on board chemical detection and decision making by recognizing self and non-self. These smart systems deliver precise amount of drugs, nutrients and agrochemical and monitor the antibiotic use. Some of the nanoparticles are used for controlling plant diseases are themselves nano forms of carbon, silver, silica and aluminous silicates.

Nanopesticides and Nanoherbicides

The conventional methods to control the pathogens has proven to be harmful to both the environment as well as the farmers as 90% of the applied pesticides are lost to air or washed away as run-off. Additionally, it also affects the soil biodiversity, diminishes nitrogen fixation, contributes to bio-accumulation, pollinator decline and destroys the habitat for birds. Pesticides inside nanoparticles can be timed-release linked to an environmental trigger. The benefits of nano application are that less herbicide is required for weed reduction. The active ingredients are combined with a smart delivery system i.e. herbicide will be applied only when necessary according to the field. Marketed under the name KARATE ZEON®, this is a quick release microencapsulated product containing an active compound called lambda-cyhalothrin (a synthetic insecticide based on the structure of natural pyrethrins) which breaks open on coming in contact with the leaves. In contrast, the "gut buster" (i.e. the encapsulated product) breaks open only when it comes in contact with the alkaline environment like the gut of the insects. Thus, it targets the pests specifically and in turn, prevents pollution.

The use of agricultural nanoparticles for control of Sclerotium forming pathogenic fungi was investigated. Exposure of these fungal hyphae to Ag NPs caused severe damage to the hyphae walls and lead to the collapse of hyphae. Detrimental effects were also observed on the other unidentified fungal species of family Raffaelea which causes the mortality of oak trees.

A pesticide like Avermectin blocks the neurotransmission in insects and can be inactivated by UV on fields with half-life of 6 hours only. A porous hollow silica NP with the shell thickness of 15nm and pore diameter of 4-5 nm has an encapsulation capacity of 625g per kg for avermectin using super critical fluid loading method and is protected from degradation by UV rays. Slow release of encapsulated Avermectin by the NPs was reported for about 30 days.

Adjuvants for herbicide application are available that claim to include nanomaterial. A surfactant based on soybean micelles claim to make glyphosate resistant crops susceptible to glyphosate when applied with nanotechnology derived surfactant.

Biological agents can also be used to control pests. Bacterial and viral formulations are susceptible to heat, dessication and UV-inactivation and hence need to be ingested by the insects for action while fungal bio-control agents or micro-pesticides can act without being ingested and are therefore preferred as they can also be easily mass produced and are relatively specific. Nanoformulations may also offer new ways to stabilize these biological agents.

Nanotechnology has revolutionized the field of medicine where the treatment is now possible at the molecular level. Due to greater cell specificity, the adverse effects of drugs have been minimized. Nanotech is being used to develop better systems for drug delivery for breast cancer, diabetes, gene therapy and viral diseases. It has already found its use in diagnostic medicine by acting as contrast agents, fluorescent dyes and also as magnetic nanoparticles. They have also made their place in the field of molecular biology to provide targeted drug therapy, tissue regeneration, biosensors, cell culture, etc.

Gold nanoparticles

Gold nano-particles are well suited for biomedical applications, including synthesis, stability and the ability to selectively incorporate the recognition molecules such as peptide or protein. They are targeted to remove the Alzheimer's amyloid deposit by using local heat dissipated by irradiation of the particles with the weak microwaves. It is a type of molecular surgery or thermal scalpel that has the potential to halt or slow the progression of the diseases. However, for the gold nanoparticles to be applicable in the drug delivery and therapy, it is necessary to know their bioaccumulation and the local and systemic toxicity. In the case of the use in the Central Nervous System (CNS), it is important to assess whether GNPs can cross the Blood Brain Barrier (BBB) to reach the neural tissue in the meaningful quantities.

In vivo studies have been done to check the particle size dependent organ distribution by Hillier and Albertch by orally administering the GNPs in mice. The results show that the amount of absorption and distribution is inversely co-related with the size of the particles. In most studies, systematically administered NPs were mostly taken up by liver and spleen and the lungs, kidney, heart and brain absorbed a small amount after single administration of GNPs.

Liposomes

Discovered in 1960s, these were the original models of nanoscaled drug delivery devices. These spherical particles are made up of lipid bilayer membranes with an aqueous interior which can be unilamellar (with a single lamella of membrane) or multilamellar i.e. with multiple membranes. The liposomes can be loaded with water soluble drugs in the aqueous compartment and with the lipid soluble drugs in the lipid membrane. Antibody Directed Enzyme Prodrug Therapy (ADEPT) consists of-

a. An enzyme conjugated liposome to activate a Prodrug

b. An antibody directed to a tumour's antigen (i.e. enzyme linked immunoliposome) which are administered prior to administration of a prodrug.

This antibody directs the enzyme to the target tissue which in turn selectively activates the prodrug by converting it to its active form. In this way, action of the drug on other normal tissues is avoided, thus minimizing its toxicity. Studies have been tried on drugs like epirubicin and doxorubicin. In ovarian cancer, folate receptors are over-expressed by the tumor tissues. The liposomal drug conjugated with folate is directed to the tumors. The same method is being tried in the treatment of Leishmaniasis where liposomal hamycin is conjugated with mannosyl human serum albumin are targeted toward the human macrophages and Asialofetuin conjugation is being tried to target liver cells for gene therapy. The targeted liposomal preparations has been found to have better efficacy then non-targeted liposomes.

Nanospores

Desai and Ferrari designed the nanopores in 1997 consisting of wafers with high density of pores (i.e.20nm in diameter) which allows the entry of oxygen, glucose, and other products like insulin. However, immunoglobin is not allowed to pass through thus, they can be used to protect the transplanted tissue from the host immune system. This could be used for the treatment of insulin dependent diabetes mellitus by enclosing the β-cells of pancreas within the nanopores device and implanting in the recipient's body. This tissue sample receives nutrients from the surrounding tissue and remains undetected by the host immune system and hence is not rejected. Nanopores are also being developed to differentiate the purines and pyrimidines.

Nanotubes

There was a breakthrough in the field of nanotechnology in 1991 due to the discovery of carbon nanotubes. They can either be Single walled carbon nanotube (SWCNT) or Multi walled carbon nanotube (MWCNT). SWCNT has an internal diameter of 1-2 mm and the MWCNT has 2-25 nm with 0.36 nm between its layers. They are characterized by greater strength and stability and are therefore used as stable drug carriers. Incorporation of carboxylic and ammonium groups to the structure of carbon nanotubes makes them more soluble and help in the transport of peptides, nucleic acids (i.e. DNA and RNA) and other drug molecules. Indium-11 radionuclide labelled carbon nanotubes are being investigated for selectively killing cancer cells. The ability of nanotubes to transport DNA across cell membrane by attaching the DNA to the tips of the nanotubes or by incorporating it within the tubes is being studied for gene therapy. Functionalized SWCNT can be used with small interfering RNA (siRNA) to silence targeted gene's expression as a mode of cancer therapy where tumour cells can be selectively modulated.

Quantum dots

They are nano-crystals measuring around 2-10 nm which are made to fluoresce when stimulated by light. Their structure consists of an inorganic core, whose size determines the colour emitted; an inorganic shell and an aqueous organic coating to which the biomolecules are conjugated to target the various biomarkers. Quantum dots can be used for biomedical purposes as a diagnostic as well as therapeutic tool. They are used as highly sensitive probes by tagging with biomolecule therapy planning. They can also be used for tumour staging by using it for imaging of sentinel node in cancer patients suffering from various malignancies like melanoma, breast, lung and gastrointestinal tumours. Functionalization of the quantum dots protects the toxic core, leads to increase in size of the nanoparticle greater than the pore size of the endothelium and renal capillaries, thus resulting in toxicity. In vivo studies also lack the metabolism and excretion of quantum dots.

Nanoshells

This technology is being considered for cancer therapy. Drugs can be embedded in the hydrogen polymer of the nanoshell after which they are directing to the tumour tissue by immunological methods. With an infrared laser, these can be heated up, thus melting the polymer and releasing the drug at the tumour tissue. These nanoshells are currently being investigated for micro metastasis of tumour and treatment of diabetes mellitus.

Nanoshells are also an important diagnostic tool in whole blood immunoassays. Gold nanoshells are coupled with antibodies and its size is modulate to respond to NIR wavelength which can penetrate whole blood specimens and can make detection of immunoglobulins at a concentration of nanograms per milliliter possible in whole blood and plasma.

Nanobubbles

These nanoscaled bubble like structures are incorporated with cancer therapeutic drugs. They remain stable at room temperature and when heated to physiological temperature within the body, coalesce to form microbubbles. They target the tumour tissue and selectively deliver the drug under the influence of ultrasound exposure resulting in increased intracellular uptake of the drug by the tumour cells. The nanobubble loaded with doxorubicin reaches the tumour tissue through leaky vasculature and gets accumulated at the site of tumour followed by formation of microbubbles by coalescing which can be visualized by ultrasound technique. When the site is targeted by High Intensity Focused Ultrasound (HIFU), it results in release of the drugs. This results in attainment of higher levels of drugs to target cells and in turn reduced toxicity and therefore increased efficacy. Thus it has a greater advantage as it is non-invasive in nature and causes lesser damage to endothelium.

Dendrimers

These are nanomolecules with regular branching structure. The size of the dendrimer is determined by the number of branching which can be controlled. These branches arise as spherical structures from the core by means of polymerization. The dendrimer molecule's end can be attached to other molecules for transport thus providing dendrimers with various potential applications in cancer chemotherapy as a mode of targeted drug therapy. Dendrimers can be used as a substitute for viral vectors in gene therapy. The advantage of using a dendrimer based therapy is absence of stimulation of immune reaction. Several tests have already been performed in mammalian cell types and in animal models. Dendrimers are also used as contrast agents for imaging. The 1,4-diaminobutane (DAB) core dendrimer and the Poly amidoamine (PAMAM) dendrimer are well studied and commercially available dendrimers for imaging studies.

CONCLUSION

Although the expectations from nanotechnology in medicine are high and the potential benefits are endless, the safety of the nano-medicines have not been fully studied and defined. They need adequate evaluation of safety and risk factors. However, nanotechnology holds a great potential for treatment of diseases and also enhancement of normal human physiology. In agricultural industry, nanotechnology can be precisely used to control and improve the production by reducing the disease incidence and enhancing the availability of nutrients. With the current applications of nanotechnology, its utility is likely to extend further into diagnostics and molecular research techniques and tools.

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