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Review Article

Nanotechnology Pros and Cons to Agriculture: A Review

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ABSTRACT

Numerous studies suggest that nanotechnology will have major, long-term effects on agriculture and food production. Nanoparticles have enhanced reactivity due to enhanced solubility, greater proportion of surface atoms relative to the interior of a structure, unique magnetic/optical properties, electronic states, and catalytic reactivity that differ from equivalent bulk materials. The positive morphological effects of nanomaterials include enhanced germination percentage and rate; length of root and shoot, and their ratio; and vegetative biomass of seedlings along with enhancement of physiological parameters like enhanced photosynthetic activity and nitrogen metabolism in many crop plants. Additionally, this technology holds the promise of controlled release of agrochemicals and site targeted delivery of various macromolecules needed for improved plant disease resistance, efficient nutrient utilization and enhanced plant growth.Meanwhile, concerns have been raised about potential adverse effects of nanoparticles on biological systems and the environment such as toxicity generated by free radicals leading to lipid peroxidation and DNA damage. Under this scenario, there is a need to predict the environmental effect of these nanoparticles in the near future.

Keywords

Nanoparticles; Phytotoxcity; Nano-Biofarming; Nano-Biosensors.

Introduction

The 'First Green Revolution' during 1970's targeted to the four basic elements of production system viz. semi-dwarf high yielding varieties of rice and wheat, extensive use of irrigation, fertilizers and agro-chemicals and consequently resulted in terrific increase in the agricultural production. However, the agricultural production is experiencing a plateau nowadays, which has adversely affected the livelihood base of the farming community at large. In fact, the country is in need of a 'Second Green Revolution' (Singh 2012). Nanoscale science and nanotechnologies are envisioned to have the potential to revolutionize agriculture and food systems (Norman and Hongda 2013).

The term "Nanotechnology" was first defined in 1974 by Norio Taniguchi of the Tokyo Science University. Nanotechnology, abbreviated to "Nanotech", is the study of manipulating matter on an atomic and molecular scale. By and large nanotechnology deals with structures in the size range between 1 to 100 nm and involves developing materials or devices within that size (Arivalagan et al. 2011). At the nanoscale the matter presents altered properties which are novel and very different from those observed at macroscopic level. . The change in properties is due to the reduced molecular size and also because of changed interactions between molecules. The properties and possibilities of nanotechnology,which have great interest in agricultural revolution, are high reactivity, enhanced bioavailability and bioactivity, adherence effects and surface effects of nanoparticles (Gutiérrez et al. 2011). Customized manufactured products are made from atoms; their properties depend on how those atoms are arranged. Nanotechnology may be able to create many new materials and devices having vast range of applications, such as medicine (e.g. engineered stem cells, implantable devices, customized antibodies), electronics (e.g. nano-chips, nano-sensors), materials (e.g. green concrete, smart polymers), food production (e.g. nano-modified, nano-additives) and energy creation (e.g., solar cells, light-trapping photo-voltaics) (Lu and Bowles 2013).

Other properties and possibilities of nanotechnology, which have great interest in agricultural revolution, are high reactivity, enhanced bioavailability and bioactivity, adherence effects and surface effects of nanoparticles (Gutiérrez et al. 2011).

The key focus areas for nanotechnology agricultural research are:

- Nanogenetic manipulation of agricultural crops
- Agricultural Diagnostics, Drug Delivery and Nanotechnology
- Controlled release of nano-fertilizers and nano-complexes
- Nano-Biosensors
- Nano pesticides and Nanoherbicides
- Nano-Bio farming

Nanogenetic Manipulation of Agricultural Crops

Nano biotechnology offers a new set of tools to manipulate the genes using nanoparticles, nanofibers and nano capsules. Properly functionalized nanomaterial serve as vehicles and could carry a larger number of genes as well as substances able to trigger gene expression or to control the release of genetic material throughout time in plants (Nair et al. 2010 and Gutiérrez et al. 2011). Proponents say nanotechnology is heading towards taking the genetic engineering of agriculture to the next level down – atomic engineering. Atomic engineering could enable the DNA of seeds to be rearranged in order to obtain different plant properties including colour, growth season and yield (Miller and Kinnear 2007).

Nanofiber arrays with potential applications in drug delivery, crop engineering and environmental monitoring can deliver genetic material to cells quickly and efficiently. Controlled biochemical manipulations in cells have been achieved through the integration of carbon nanofibers which are surface modified with plasmid DNA (Miller and Kinnear, 2007).

Chitosan nanoparticles are quite versatile, as well as their transfection efficiency can be modified, they can be PEGylated in order to control the release of genetic material as time goes by. The application of fluorescent labelled starch-nanoparticles as plant transgenic vehicle was reported in which the nanoparticle biomaterial was designed in such a way that it binds and transports genes across the cell wall of plant cells by inducing instantaneous pore channels in cell wall, cell membrane and nuclear membrane with the help of ultrasound. DNA coated silver nanoparticle (S.N.Ps coated with plasmid) treatments have been demonstrated to penetrate isolated protoplast of petunia and carry plasmatic DNA into nucleus by incubation along with ethylene glycol (Rad et al., 2013).

Nowadays gene gun or particle bombardment is being used for direct delivery of DNA into intact plant cells. Particles used for bombardment are typically made of gold since they readily adsorb DNA and are non-toxic to cells. Experiments showed that the plasmid DNA transferred by gene gun method using gold capped nanoparticles was successfully expressed in intact tobacco and maize tissues. The major advantage is the simultaneous delivery of both DNA and effector molecules to the specific sites that results in site targeted delivery and expression of chemicals and genes respectively (Nair et al. 2010)

The other interesting application of bio-nanosensors is to reduce pollen contamination in wind pollinated crops. Detecting pollen load that will cause contamination is a sure method to ensure genetic purity. Use of bio-nano sensors specific to contaminating pollen can help alert the possible contamination and thus reduces contamination. The same method can also be used to prevent pollen from Genetically Modified Crop from contaminating field crops.

Novel genes are being incorporated into seeds and sold in the market which can be traced with the help of nano barcodes that are encodable, machine - readable, durable and sub-micron sized taggants. Disease spread through seeds and many times stored seeds are killed by pathogens. Nano-coating of seeds using elemental forms of Zn, Mn, Pa, Pt, Au, Ag will not only protect seeds but reduces the requirement of elements to far less quantities than done today. The use of quantum dots (QDs) technique, developed by Su et al. 2004, as a fluorescence marker coupled with immuno-magnetic separation for E coli 0157:H7, proved useful to separate unviable and infected seeds. Seeds can also be imbibed with nano-encapsulations with specific bacterial strain termed as Smart Seed as it will thus reduce seed rate, ensure right field stand and improved crop performance. A Smart Seed can be dispersed over a mountain range for reforestation and programmed to germinate when adequate moisture is available. Nano-membranous coatings on seeds allow sensing the availability of water to seeds to imbibe only when time is right for germination, aerial broadcasting of seeds embedded with magnetic particle, detecting the moisture content during storage to take appropriate measure to reduce the damage and use of bio analytical nano sensors to estimate ageing of seeds are some upcoming thrust areas of research (Chinnamuthu and Boopathi 2009).

Agricultural Diagnostics, Drug Delivery And Nanotechnology

Nanoscale serves as carriers and provide on board chemical detection and decision taking ability for self-regulation. These smart systems deliver precise quantities of drugs or nutrients or other agrochemicals required. These intelligent systems thus monitor and minimize pesticide and antibiotic use (Sharon et al. 2010). Some of the nano particles are used for controlling plant diseases are nano forms of carbon, silver, silica and aluminous-silicates.

Carbon nano-fibers are used to strengthen natural fibers like those from coconuts (*Cocus nucifera*) and sisal (*Agave sisalana*) and also for making nanoparticles that contain pesticides and control their release (Misra et al. 2013).

Nano Silver is known to have strong bactericidal and broad spectrum antimicrobial activities and also reduces various plant diseases caused by spore producing fungal pathogens. The effectiveness of silver NPs is further enhanced by applying them well before the penetration and colonization of fungal spores within the plant tissues. The small size of the active ingredient [diameter of 1–5nm] effectively controls fungal diseases like powdery mildew. The efficacy of Ag NPs in extending the vase life of gerbera flowers was also studied and the results showed inhibited microbial growth and reduced vascular blockage which increased the water uptake and maintained the turgidity of gerbera flowers (Nair et al. 2010). The in vitro and in vivo evaluations of the antifungal action of both silver ions and nanoparticles on *Bipolaris sorokiniana* and *Magnaporthe grisea* showed decreased disease development by phytopathogenic fungi.

Similarly, Zinc oxide nanoparticles inhibited the fungal growth of *Botrytis cinerea* by influencing cellular functions, which caused deformation in mycelia mats. In addition, Zinc oxide NPs inhibited the growth of conidiophores and conidia of *Penicillium expansum*, which finally led to the death of fungal mats as reported by Abd-elsalam (2013).

Silicon (Si) is known to be absorbed into plants to increase disease resistance and stress resistance by promoting the physiological activity and growth of plants. Aqueous silicate solution is reported to exhibit exceptional preventive effects on pathogenic microorganisms causing powdery mildew or downy mildew in plants. Additionally, it promotes the physiological activity and growth of plants and induces diseases and stress resistance in plants. Silver in an ionic state exhibits high antimicrobial activity. However, ionic silver is unstable due to its high reactivity and thus gets easily oxidized or reduced into a metal depending on the surrounding media and it does not continuously exert antimicrobial activity. On the other hand silica itself has no direct effect on pathogenic microorganisms and has no effect on diseases. So a new composition of nano-sized Silica-Silver for control of various plant diseases has been developed (Sharon et al. 2010).

There is an urgent need of ultrasensitive diagnostic tool which can detect the molecular defects, either at genomic or biochemical level, rapidly. Bio-systems are endowed with functional nanometric devices such as enzymes, proteins, and Nucleic acids, which detect vital processes in plants. Disease diagnosis is difficult mainly because of the exceptionally low concentrations of biochemical and also due to the presence of very low amount of detectable virus and many fungal or bacterial infections (Misra et al., 2013).

Controlled Release Of Nano-Fertilizers And Nano-Complexes

Nanotech materials are being developed for slow release and efficient dosages of fertilizers for plant (Singh, 2012). Nano-sizing, in theory, should make fertilizer nutrients more available to nanoscale plant pores and therefore result in efficient nutrient use (Suppan 2013). Nanomaterials used in recommended doses may sometimes fail to exert the desired effects as concentration of these materials much below the minimum effective concentration required of the chemicals, has reached the target site of crops due to obstacles such as leaching of chemicals, degradation by photolysis or microbes and hydrolysis. Hence repetitive application is indispensable to have an effective control consequently, which might cause some unfavourable effects such as soil and water pollution. Nano - encapsulated agrochemicals should be designed in such a way that they possess all indispensable properties such as effective concentration (with high solubility, stability and effectiveness), time controlled release in response to certain stimuli, enhanced targeted activity and less Eco toxicity with harmless and effortless mode of delivery thus avoiding repetitive application(Nair et al. 2010).

Slow-release fertilizers are excellent alternatives to soluble fertilizers as nutrients are released at a slower rate throughout the crop growth; plants are able to take up most of the nutrients without waste by leaching. Slow release of nutrients in the environments could be achieved by using zeolites. Zeolites are a group of naturally occurring minerals having a honeycomb-like layered crystal structure and their network of interconnected tunnels and cages can be laden with nitrogen and potassium along with other slowly dissolving ingredients containing phosphorous, calcium and a complete suite of minor and trace nutrients. Fertilizer particles can be coated with nano membranes that facilitate slow and steady release of nutrients e.g., patented nanocomposite containing N, P, K, micronutrients, mannose and amino acids that enhanced the uptake and utilization of nutrients by grain crops has been reported (Chinnamuthu and Boopathi 2009).

Carbon nanotubes (CNT) are allotropes of carbon with cylindrical shape and can be utilized to use CNT as vehicle to deliver desired molecules either nutrient or biocides into the seeds during germination. Similarly, triazophos can also be effectively protected from hydrolysis in acidic and neutral media by including it in a nano-emulsion (Gutiérrez et al. 2011).

Application of titanium dioxide (TiO_2) on food crops has been reported to promote plant growth, increase the photosynthetic rate, reduce disease severity and enhance yield by 30%. The application of TiO_2 has been found to show excellent efficacy in Oliver cereal like maize by reducing the effect of Curvularia leaf spot and bacterial leaf blight disease incidence and severity. They also reported that application of TiO_2significantly reduced the incidence of rice blast and tomato spray mold with a correspondent 20% increase in grain weight due to the growth promoting effect of TiO_2 nano-particles (Mahmoodzadeh et al. 2000). A combination of titanium dioxide, aluminium and silica was reported to be effective in controlling downy and powdery mildew of grapes by Bowen et al. (1992), possibly through direct action on the hyphae, interference with recognition of plant surface and stimulation of plant physiological defences.

Phytochemicals such as secondary metabolites and essential oils proved to have ecofriendly biological activity but they face problems of stability and cost effectiveness. as observed by Ghormade et al (2011) an essential oil from *Artemisia arborescens*, faced the problem of instability during pesticide activity against Aphis gossipy (citrus fruit pest), adult and young *Bemisiatabaci* and *Lymantriadispar* (cork plant pest). Incorporation of *A. arborescens* essential oil into solid lipid NPs (200–294 nm) reduced the rapid evaporation of essential oil, in comparison to the reference emulsions. Similarly, the essential oil from garlic when loaded on polymer NPs (240 nm) coated with polyethylene glycol (PEG) to evaluate their insecticidal activity against adult *Tribolium castaneum*, showed more than 80% efficacy even after five months, due to the controlled slow release of the active components, in comparison to free garlic essential oil (11%).This indicated the feasibility of PEG coated NPs loaded with garlic essential oil for control of storage pests (Ghormade et al. 2011).

Syngenta (world-leading agro-company), is using nano emulsionsas smart delivery systems, in its growth regulator Primo MAXX®, 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. The ultimate aim is to tailor these products is a controlled release in response to different signals e.g. magnetic fields, heat, ultrasound, moisture, etc.

Nano-Biosensors and Agriculture

Nano sensors with immobilized bio receptor probes that are selective for target analyte molecules are called nano biosensors. Their applications include detection of analytes like urea, glucose, pesticides etc., monitoring of metabolites and detection of various microorganisms/pathogens (Rai et al. 2012). Nanosensors offer the advantage of being are small, portable, sensitive with real-time monitoring, precise, quantitative, reliable, accurate, reproducible and robust and stable which can overcome the deficits of present sensors. Controlled Environmental Agriculture (CEA) can be improved by the use of 'nano-sensors' enhancing the aptitude to determine the time of crop harvest, detect crop health and determine microbial or chemical contamination of the crop. Smart nanosensors have been developed which can be linked to GPS system and has made real-time monitoring of crop husbandary promising by planting autonomous biosensors.

Soil temperature and moisture is of utmost importance in agriculture. Irrigation management systems should get accurate updates about the soil moisture at the root level of plants sensors based on wireless nanotechnology composed of micro machined MEMS (Micro Electro Mechanical Systems) cantilever beams coated with a water sensitive nanopolymer for moisture detection and on chip piezo resistive temperature sensor detects temperature variations. Through microelectronic circuits these sensors are capable of sensing and monitoring temperature and moisture (Sharon et al. 2010).

Nano sensors may be used to diagnose oil disease (caused by infecting soil micro-organisms, such as viruses, bacteria, and fungi) via the quantitative measurement of differential oxygen consumption in the respiration (relative activity) of "good microbes" and "bad microbes" in the soil. The biosensors developed using PSII (photosystem II), known to bind several groups of herbicides, isolated from photosynthetic organisms may have potential to monitor polluting chemicals, leading to the set-up of a low cost, easy-to-use apparatus, able to reveal specific herbicides, and eventually, a wide range of organic compounds pre-sent in industrial and urban effluents, sewage sludge, landfill leak-water, ground water, and irrigation water (Rai et al. 2012).

Nanopesticides and Nanoherbicides

Conventional methods to control the pathogens and pests have affected both the environment and economy of farmers as 90% of the applied pesticides are lost to the air during application and as run-off, affecting both the environment and application costs to the farmer. Additionally, indiscriminate usage of pesticide increases pathogen and pest resistance, reduces soil biodiversity, diminishes nitrogen fixation; contributes to bioaccumulation of pesticides, pollinator decline and destroys habitat for birds (Ghormade et al. 2011).

Pesticides inside nanoparticles are being developed that can be timed-release or have release linked to an environmental trigger (Nair et al. 2010).The benefits of nanoapplication are similar: Less herbicide is required to achieve the weed reduction effects desired. If the active ingredient is combined with a smart delivery system, herbicide will be applied only when necessary according to the conditions present in the field (Gruère et al. 2011a).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 “gut buster” only breaks open to release its contents upon coming in contact with alkaline environments, such as the stomach of certain insects (Joseph and Marrison 2006).

The use of Ag nanoparticles as an alternative to pesticides for the control of sclerotium forming phytopathogenic fungi was investigated. Exposure of fungal hyphae to Ag NPs caused severe damage by the separation of layers of hyphal wall and collapse of hyphae. Detrimental effects of Ag NPs on unidentified fungal species of the genus Raffaelea causing mortality of oak trees was also investigated and studies showed harmful effects of Ag NPs on conidial germination (Nair et al. 2010).

A pesticide like avermectin which blocks neurotransmission in insects by inhibiting chloride channel has a short life as it is inactivated by UV on the fields with half-life of 6 h only. Porous hollow silica NPs with a shell thickness of 15 nm and a pore diameter of 4–5 nm had an encapsulation capacity of 625 g kg^{-1} for avermectin and protected for degradation by UV rays. Slow release of encapsulated avermectin by the NPs carrier was reported for about 30 days (Ghormade et al. 2011).

Adjuvants for herbicide applications are currently available that claim to include nanomaterial. One nano-surfactant based on soybean micelles claims to make glyphosate-resistant crops susceptible to glyphosate when it is applied with the nanotechnology-derived surfactant (Gruère et al. 2011a)

Bacteria, viruses and fungi can function as biological control agents against insect pests. Bacterial and viral formulations are susceptible to desiccation, heat, and UV inactivation and need to be ingested by insect for action. Fungal bio control agents or myco-pesticides are promising as they act by contact and do not need ingestion, can be easily mass produced, and are relatively specific. The use of nano formulations may offer new ways to enhance the stability of these biological agents (Ghormade et al. 2011).

Nano-Bio farming

Nanotechnology can enhance crops yield and nutritional values and can add value to crops or environmental remediation. Particle farming is one such field, which yields nanoparticles for industrial use by growing plants in defined soil. The nanoparticles can be mechanically separated from the plant tissue following harvest (Misra et al. 2013). This process opens up new opportunities in the recycling of wastes and could be useful in areas such as cosmetics, food or medicine.

The most up-to-date research in this field is centered on the production of gold and silver nanoparticles with diverse plants*:* *Medicago sativa, Vignaradiata, Arachishypogaea, Cyamopsis tetragonolobus, Zea mays, Pennisetum glaucum, Sorghum vulgare, Brassica junceaor* extracts from *B. juncea* and *M. sativa*, *Memecylon edule* or *Allium sativum* L. Depending on the nanoparticle’s nature, specie of plant or tissue in which they are stored, metal nanoparticles of diverse shapes and sizes can be obtained. However, all these processes share the advantages of being simple, cost-effective and environmentally friendly (Gutiérrez et al. 2011).

Nanotechnology against Agriculture

With the rapid expansion of nanotechnology, there is concern about the build-up of manufactured nanomaterial and their possible entry into the food chain (Priester et al. 2012). Using nanomaterial is not inherently risky - for instance, traditional foods contain many nanoscale materials (such as proteins found in milk, fat globules found in mayonnaise, carbohydrates, DNA, and so on)—but the use of certain engineered nanoscale materials in agriculture, water, and food may have risks for human use and consumption, for the environment, or for both (Gruère et al. 2011a).Absorption of nanomaterial from soil is a route of exposure for plants (Priester et al. 2013).

Phytotoxicity of nanoparticles

Plants are an essential base component of all ecosystems and play a critical role in the fate and transport of engineered nanoparticles (ENPs) in the environment through plant uptake and bioaccumulation (Xingmao et al. 2010). It is also important to mention that the bioaccumulation, bio-magnification and biotransformation of engineered nanoparticles in food crops are still not well understood. Very few nanoparticles and plant species have been studied with respect to the accumulation and subsequent availability of nanoparticles in food crops.

Most commonly encountered ENPs in the environment fall into one of the five following categories: carbonaceous nanoparticles, metal oxides, quantum dots, zero valent metals and nanopolymers. These ENPs closely interact with their surrounding environment and as a result ENPs will inevitably interact with plants and these interactions such as uptake and accumulation in plant biomass will greatly affect their fate and transport in the environment. ENPs could also adhere to plant roots and exert physical or chemical toxicity on plants.

For interacting with plants ENPs have to penetrate cell walls and plasma membranes of epidermal layers in roots to enter vascular tissues (xylem) in order to be taken up and Trans located through stems to leaves. Cell walls, through which water molecules and other solutes must pass to enter into roots, are a porous network of polysaccharide fiber matrices. ENP aggregates with a size smaller than the largest pore are expected to pass through and reach the plasma membrane and the larger particle aggregates will not enter into plant cells. But the authors also admitted that ENPs may induce the formation of new and large size pores which allow the internalization of large ENPs through cell walls. Once micro- and macromolecules enter plant cell walls, the molecules can be transported through plasmadesmata, the intercellular organelles of 20–50 nm in diameter. Selective and non-selective pathways through plasmadesmata are found to transport regulatory proteins and RNAs in short distances (Xingmao et al., 2010).

In one of the study, that reports phytotoxicity of five types of nanoparticles (multi-walled carbon nanotube, aluminum, alumina, zinc, and zinc oxide) on seed germination and root growth of six higher plant species (radish, rape, rye- grass, lettuce, corn, and cucumber) were investigated. Seed germination was not affected except for the inhibition of nanoscale zinc (nano-Zn) on ryegrass and zinc oxide (nano-ZnO) on corn at 2000 mg/L. Inhibition on root growth varied greatly among nanoparticles and plants. Suspensions of 2000 mg/L nano-Zn or nano-ZnO practically terminated root elongation of the tested plant species. Fifty percent inhibitory concentrations (IC50) of nano-Zn and nano-ZnO were estimated to be near 50 mg/L for radish, and about 20 mg/L for rape and ryegrass. The inhibition occurred during the seed incubation process rather than seed soaking stage. These results are significant in terms of use and disposal of engineered nano-particles (Lin and Xing 2007).

On the contrary, the impacts of nano-cerium oxide were different: even at low levels of exposure to this material, plant growth and the size of soybean pods were reduced. Furthermore, it appeared that the nano-cerium oxide entered the roots and root nodules, the latter of which are important to the nitrogen fixing process that soybean crops perform. With higher amounts of nano-cerium oxide in the soil, soybeans were nearly incapable of fixing nitrogen (Priester et al. 2013). Further, the manufactured nanomaterial may pose potential risk to humans and animals if enter the food chain in an unregulated way.

However it was also observed that a very high concentration of nanosilica–silver produced some chemical injuries on the tested plants (cucumber leaves and pansy flowers). Several plants grown hydroponically are affected by myriad Manufactured –nanomaterials (MNMs), raising concerns regarding the long-term effects of these materials on the food supply (Rico et al. 2011). However, MNMs may not be bioavailable (i.e., accessible to organisms) in soil (Tong Z et al. 2007).

Nanomaterials and Toxicity to Human and Animals

All substances, from arsenic to table salt are toxic to cells, animals or people at some exposure level. Before interpreting toxicological data, it is thus essential to characterize the expected concentrations of engineered nanoparticles that may be present in the air, water and soil. A useful way to approach the problem is to consider how human populations, both in the present and near future, may be exposed to engineered nanoparticles (Colvin 2003).

Toxicological studies of fibrous and tubular nanostructures have shown that at extremely high doses of these materials are associated with fibrotic lung responses and result in inflammation and an increased risk of carcinogenesis. Single-walled carbon nanotubes (SWCNT) have been shown to inhibit the proliferation of kidney cells in cell culture by inducing cell apoptosis and decreasing cellular adhesive ability. In addition, they cause inflammation in the lung upon instillation. Dosing keratinocytes and bronchial epithelial cells in vitro with SWCNT has been shown to result in increases in markers of oxidative stress.

Multiwalled carbon nanotubes (MWCNT) are persistent in the deep lung after inhalation and, once there, are able to induce both inflammatory and fibrotic reactions. Proteomic analysis conducted in human epidermal keratinocytes exposed to MWCNT showed both increased and decreased expression of many proteins relative to controls. These protein alterations suggested dysregulation of intermediate filament expression, cell cycle inhibition, altered vesicular trafficking/exocytosis and membrane scaffold protein down-regulation.

Charge properties and the ability of carbon nanoparticles to affect the integrity of the blood-brain barrier as well as exhibit chemical effects within the brain have also been studied. Reportedly, the neutral nanoparticles and low concentration anionic nanoparticles can serve as carrier molecules providing chemicals direct access to the brain and that cationic nanoparticles have an immediate toxic effect at the blood-brain barrier.

Tests with uncoated, water soluble, colloidal C_{60} fullerenes have shown that redox-active, lipophilic carbon nanoparticles are capable of producing oxidative damage in the brains of aquatic species. The bactericidal potential of C_{60} fullerenes was also observed in these experiments. This property of fullerenes has possible ecological ramifications and is being explored as a potential source of new antimicrobial agents (Oberdorster et al. 2005).

A pioneering study showed that uncoated fullerenes exerted oxidative stress and caused severe lipid peroxidation in fish brain tissue, a possible negative impact of nanomaterial on the health of aquatic organisms (Lin and Xing 2007).

Nanomaterial and Ecotoxicology

The lack of sufficient scientific knowledge about key risk-assessment factors, such as nanoparticle toxicity, bioaccumulation, exposure information, or ingestion risks, causes the most concern. A relatively small share of funding goes to risk research, and that money supports research focused on non-food or agricultural materials, suggesting that this lack of knowledge will persist (Gruère et al., 2011b). The health and environmental risks posed by Nanomaterial cannot be assessed easily as they have diverse properties and behaviour. The kinetic (absorption, distribution, metabolism and excretion) and toxic properties are influenced by the size, shape and charge of these materials and therefore even nanomaterial of the same chemical composition with different sizes or shapes may have vastly different toxicity. Hence, particle size alone is not a good criterion for differentiating between more or less hazardous materials and technologies (Rathore et al. 2012).

Lack of knowledge about the transport and fluxes of these nanoparticles in the natural environment presents a further problem, which is exacerbated by the fact that biological systems did not evolve in the presence of nanoparticles of the types now being manufactured. Industrial products and wastes tend to end up in waterways (like, drainage ditches, rivers, lakes, estuaries and coastal waters) despite safeguards. As the nanotechnology industries start to come on line with larger scale production, it is to be anticipated that nanoscale products and by-products will enter the aquatic environment. This makes it an imperative that we have effective risk assessment procedures in place as soon as possible to deal with potential hazards (Moore, 2006).

Manufacture, use and potential release of NMs have preceded evaluation of risk to ecosystems, including humans. Currently, there are no factual data on concentrations of NMs in the environment, and certainly none on their physicochemical forms or distribution, although models have been use to estimate potential releases and loads. The development of techniques to measure and characterize NMs in atmospheric, aquatic, and terrestrial environments is an important immediate research priority in order to facilitate quantitative ecological risk assessments (Klaine et al. 2008).

Conclusion and Future Perspective

New tools are underway which will be equipped with nanodevices capable of replacing many cellular types of machinery efficiently. Use of nanotechnology could permit rapid advances in agricultural research, such as reproductive science and technology which will produce large amount of seeds and fruits unaffected by season and period, early detection of stresses and alleviating stress effects and disease prevention and treatment in plants. Still, the full potential of nanotechnology in the agricultural and food industry is yet to be realized and is gradually moving from theoretical knowledge towards the application regime. Smart sensors and smart delivery systems will help the agricultural industry combat viruses, spores and other crop pathogens. Nanostructured catalysts will be available which will increase the efficiency of pesticides and herbicides, allowing ‘on demand’ measured doses to be used. In the future, nanoscale devices could be used to make agricultural systems “smart”. Apart from the potential benefits of nanotechnology in agricultural sector it also involves some risks. It cannot be claimed with certainty either those nanotechnologies are fully safe for health or that they are harmful. Risks associated with chronic exposure of farmers to nanomaterial, unknown life cycles, interactions with the biotic or abiotic environment and their possible amplified bioaccumulation effects have not been accounted for and these should be seriously considered before these applications move from laboratories to the field. The common challenges related to commercializing nanotechnology, are: high processing costs, problems in the scalability of R & D for prototype and industrial production and concerns about public perception of environment, health and safety issues. The Governments across the world should form common and strict norms and monitoring, before commercialization and bulk use of these nanomaterials.

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