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Nesreen Ahmed Sabry Helal [1]

NANOTECHNOLOGY IN AGRICULTURE: A REVIEW

SUMMARY

Developments during the past decade in biochemistry, physical chemistry, microscopy and engineering have resulted in a tremendous upsurge of interest in the properties of very small particles and their possible application for a wide range of industrial and consumer sectors. The potential of nanotechnology to revolutionize the health care, textile, materials, information and communication technology and energy sectors has been well publicized. In fact several products enabled by nanotechnology are already in the market. As in other sectors, the advent of nanotechnology promises to revolutionize the development of products and applications in agriculture. Researchers in universities are now investigating possible application for using nanotechnology in agriculture, this aspect is still in infancy and requires attention of the scientific fraternity for its widespread use to harness its potential benefits. In the present paper a review in the application of nanotechnology in agriculture is presented.

Keywords: Nanotechnology, Agriculture, Application.

Abbreviations:

NM, nanometers; **UV**, ultraviolet; **DNA**, deoxyribo nucleic acid; **RFID**, radio frequency identification; **PF**, precision farming; **RS**, remote sensing; **GIS**, geographical information system; **GPS**, global position system; VRT, variable rate technology; **VRA**, variable rate application; **GIT**, gastrointestinal tract; **VACNFs**,, vertically aligned carbon; **PV**, solar photovoltaic; **CCS**, carbon capture and storage; **CNTs**, carbon nanotubes; **SWCNTs**, single wall carbon nanotubes; **MWCNTs**, mutli wall carbon nanotubes.

Nanotechnology and opportunities for Agriculture

The world population is projected to reach 7.6 billion in 2020. The growing population is, in addition, facing environmental threats including climate change that would affect food productivity. In this context, it is imperative to ensure intensification of agriculture, coupled with efficient food handling, processing and distribution. In addition to biotechnology solutions, nanotechnology is expected to play an important role in this sector (The Energy and resources institute, 2009).

[1] Nesreen Ahmed Sabry Helal (corresponding author: nesreen_mostafa@agr.asu.edu.eg), Horticulture Department, Faculty of Agriculture, Ain Shams University, Hadayek Shobra, 11241 Cairo, Egypt.

The advent of nanotechnology has unleashed enormous prospects for the development of new products and applications for a wide range of industrial and consumer sectors. The new technological developments have already opened up a multibillion dollar industry in recent years, the global market impact of which is expected to reach US$1 trillion by 2015, with around 2 million workers (Roco and Bainbridge, 2001). Nanotechnology applications in food and agriculture sector encompass development of new functional materials and products as well as methods and instrumentation to ensure food safety and bio-security (Sozer and Kokini, 2009).

Nanotechnology promises to revolutionize the whole food chain – from production to processing, storage, and development of innovative materials, products and applications. Although the potential applications of nanotechnology are wide ranging, the current applications in the food and agricultural sectors are relatively few, because the science is still newly emergent. An overview of more than 800 nanotechnology-based consumer products that are currently available worldwide (Woodrow Wilson International Centre for Scholars, 2009). Only around 10 percent of these are foods, beverages and food packaging products. However, nanotechnology-derived products and applications in these sectors have been steadily increasing in recent years, and are predicted to grow rapidly in the future. Nanotechnology has provided new solutions to problems in plants and food science and offers new approaches to the rational selection of raw materials, or the processing of such materials to enhance the quality of plant products (Sharon and Ajoy 2010). Nanoscale science, engineering, and technology have demonstrated their relevance and great potential to enable revolutionary improvements in agriculture and food systems, including "plant production & products; animal health, food safety & quality, nutrition, health, renewable bioenergy & biobased products, natural resources & the environment, agriculture systems & technology, and agricultural economics & rural communities" (NSTC, 2011). Despite their promise, agricultural and food nanotechnologies, especially those that could reduce poverty or increase food and nutrition security, will likely face many challenges in each step of development from investment in research and development to use by the rural poor area. All these challenges (and more) must be overcome to transform a concept into a tangible product (*International Food Policy Research Institute, 2011).*

What is nanoscience and nanotechnology?

Nanoscience is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale (The Royal Society and the Royal Academy of Engineering, 2004). Nanoscience is an emerging science which comprises the world of atoms, molecules, macromolecules, quantum dots, and macromolecular assemblies. It is a growing field of research in chemistry, biology and physics but cannot really be classified as one or the other as many scientific disciplines are studying very small things in order to better understand the world. (Anane-Fenin, 2008).

Nanotechnology is not a separate techno-scientific field, but rather a new platform for a range of existing disciplines—including chemistry, physics, biology, biotechnology, neurology, information technology and engineering—allowing a shift down to the nano scale (ETC Group, 2003). Nanotechnology can easily merge with other technologies and modify, endorse or clarify any existing scientific concept, which is why it is so called a "platform" technology (Schmidt, 2007). Nanotechnology is the most promising field for generating new applications in medicine, pesticide residue determination, water purification, increase in agricultural products quality and decrease in storage losses of agricultural products (Tavajohi, 2008). Nanotechnology is defined as any engineered materials, structures and systems that operate at a scale of 100 nanometers (nm) or less (one nanometer is one billionth of a meter) (Moraru *et al*., 2009).

To put this scale into perspective, a strand of DNA is 2.5 nm wide, a red blood cell is 7000 nm, while a human hair is about 80,000 nm wide (Friends of the Earth, 2008). Nanotechnology is the understanding and control of matter at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications… Unusual physical, chemical, and biological properties can emerge in materials at the nanoscale. These properties may differ in important ways from the properties of bulk materials and single atoms or molecules" (NSTC, 2011).

There are two basic forms of attaining nanomatarials "top-down" and "bottom-up". By this approach of arranging molecules one at a time, we can design complex systems by incorporating specific features which requires a good understanding of individual molecular structures and various molecular forces. The concept of arranging molecules with nanotechnology has the potential to impact diverse fields ranging from biology to materials science (Liu *et al*., 2003).

What nanotechnology offers for agriculture?

The use of nanotechnology in the future is expected to expand into numerous industrial applications and help decrease production costs by reducing energy consumption, attenuate environmental pollution and increase the production efficiencies in developed countries. Moreover, nanotechnology may be a useful tool to address different social problems of developing countries such as the need for clean water and the treatment of epidemic diseases (Fleischer and Grunwald, 2008). Nanoscience and nanotechnology may not provide all the solutions for the ever increasing problems of this planet but could help the sustainable development of many social communities. Many potential benefits of nanotechnology have already been identified by many researchers in the environmental and water sector , medicine , and in several industry applications but the future nanotechnology might bring innovations that can answer many existing scientific questions (Theron *et al*., 2008; Fleischer and Grunwald, 2008).

Hence, nanotechnology is going to play an important role in addressing fundamental issues such as health, energy and water (Binks, 2007). Major potential benefits of nanotechnology for agriculture and food sectors were reported in this review.

Food processing

Nanotechnology food applications include; smart packaging, on-demand preservation, and interactive foods. Building on the concept of on-demand food, the idea of interactive food, is to allow consumers to modify food, depending on their own nutritional needs and tastes. The concept is that thousands of nanocapsules containing flavour or colour enhancers or added nutritional elements (such as vitamins), would remain dormant in the food and will only be released when triggered by the consumer (Dunn, 2004). The main areas of application include food packaging and food products that contain nanosized or nano-encapsulated ingredients and additives. The main principle behind the development of nanosized ingredients and additives appears to be directed towards enhanced uptake and bioavailability of nanosized substances in the body, although other benefits, such as improvement in taste, consistency, stability and texture, etc., have also been claimed (Chaudhry *et al*., 2008). Some food companies are reported to be developing a nano-emulsion based ice cream with a lower fat content that retains a fatty texture and flavour (Renton, 2006). Industrial sausage and cured meat production requires the addition of numerous additives to speed up the production process, to stabilize colour and 'improve' taste. A nanotechnology-based carrier system using 30 nm micelles to encapsulate active ingredients such as Vitamins C and E and fatty acids which can be used as preservatives and processing aids. It offers considerable advantages for meat processors: faster processing, cheaper ingredients, higher colour stability, and ready to use liquid form (Fleischwirtschaft, 2006). Some food processing methods utilize enzymes to alter food components to improve flavor, nutritional value or other characteristics. These nanoparticles effectively hydrolyzed olive oil and were determined to have good stability, adaptability, and reusability (Bai *et al*., 2006). Nanotechnology is also being used to alter the properties and traits of food; including its nutrition, flavour, texture, heat tolerance and shelf life. For example, in the manufacture of low fat and low-calorie food that retains its rich and creamy taste and texture, applying this to a range of very low-fat ice-creams, mayonnaise and spreads (Daniells, 2008). Meanwhile, food companies are using microcapsules to deliver food components such as omega 3-rich fish oil. The release of fish oil into the human stomach is intended to deliver claimed health benefits of the fish oil, while masking its fishy taste (Friends of the Earth, 2008).

Food packaging

One of the earliest commercial applications of nanotechnology within the food sector is in packaging (Roach, 2006). Between 400 and 500 nano packaging products are estimated to be in commercial use now, while nanotechnology is predicted to be used in the manufacture of 25% of all food packaging within the next decade (Helmut Kaiser Consultancy Group, 2007; Reynolds, 2007). Conventional plastics, used widely in food packaging, are difficult to degrade thereby creating a serious problem of solid waste disposal. In this context, biomass based materials have been explored for the development of eco-friendly food packaging (Siracusa *et al*., 2008; Farris *et al*., 2009).

The challenge is to overcome performance related issues (e.g. poor mechanical strength, brittleness, poor gas and moisture barrier), processing problems (e.g. low heat distortion temperature), and high cost associated with biopolymer based packaging. Incorporation of nanomaterials in biopolymers (usually neutral polysaccharides such as starch, cellulose and its derivatives (Darder *et al*., 2007), polyesters such as polyhydroxyalkanoates, poly (lactic acid) (Bordes *et al*., 2009) as well as plant oils, gelatin, chitosan (Ray and Bousmina, 2005) provides the necessary reinforcement, improving both mechanical strength and barrier properties (Choudalakis and Gotsis, 2009); in addition, cost-price-efficiency is also improved (Sorrentino *et al*., 2007; Rhim and Ng, 2007).

Improvements in characteristics of food packaging materials, such as strength, barrier properties, antimicrobial properties, and stability to heat and cold, are being developed using nanocomposite materials. Electron microscopy shows that there is a strong adhesion between the clay nanoparticles and the polymer matrix and that there are exfoliated layers of clay that enhance the diffusion of gases through the composite membrane. This type of packaging may extend shelf life of food products (Lagarón *et al*., 2005). Polymer-silicate nanocomposites have also been reported to have improved gas barrier properties, mechanical strength, and thermal stability (Holley, 2005; Brody, 2006).

Food safety also requires confirmation of the authenticity of products. This is where application of nanobarcodes incorporated into printing inks or coatings has shown the potential for use in tracing the authenticity of the packaged product (Han *et al.*, 2001). Food quality indicators have also been developed that provide visual indication to the consumer when a packaged foodstuff starts to deteriorate. An example of such food quality indicators is a label based on detection of hydrogen sulphide, which is designed for use on fresh poultry products. The indicator is based on a reaction between hydrogen sulphide and a nanolayer of silver (Smolander *et al*., 2004). The nanosilver layer is opaque light brown, but when meat starts to deteriorate silver sulphide is formed and the layer becomes transparent, indicating that the food may be unsafe to consume. Other materials developed for potential food packaging applications are based on nanostructured silicon with nanopores. The potential applications include detection of pathogens in food and variations of temperature during food storage. Another relevant development is aimed at providing a basis for intelligent preservative packaging technology that will release a preservative only when a packaged food begins to spoil (ETC Group, 2004). Chemical release nano packaging enables food packaging to interact with the food it contains. The exchange can proceed in both directions. Packaging can release nanoscale antimicrobials, antioxidants, flavours, fragrances or nutraceuticals into the food or beverage to extend its shelf life or to improve its taste or smell (Del-Nobile *et al*., 2004; LaCoste *et al*., 2005; Lopez- Rubio *et al*., 2006; Nachay, 2007). In many instances chemical release packaging also incorporates surveillance elements, that is, the release of nano-chemicals will occur in response to a particular trigger event (Gander, 2007). Nano-based methods of detecting harmful pathogens are being developed for several pathogens: a nanobiosensor can identify the presence of *E. coli* and prevent the consumption of contaminated foods (Majid *et al*., 2008) similarly, nanosensors can indicate the deterioration of foods due to spoilage microorganisms or other factors. Biofinger, a portable nano detection tool could be used as a cheap and fast method in the diagnosis of diseases to detect any disease , as a pregnancy test ,it could be used to analyze chemicals ,detect bacteria in food or test water pollution (Kewal, 2008).

Most of us are familiar with the waxy coatings often used on apples. Now nanotechnology is enabling the development of nanoscale edible coatings as thin as 5 nm wide, which are invisible to the human eye. Edible nano coatings could be used on meats, cheese, fruit and vegetables, confectionery, bakery goods and fast food. They could provide a barrier to moisture and gas exchange, act as a vehicle to deliver colours, flavours, antioxidants, enzymes and anti-browning agents. Also increase the shelf life of manufactured foods, even after the packaging is opened (Renton, 2006; Weiss *et al*., 2006). A key purpose of nano packaging is to deliver longer shelf life by improving the barrier functions of food packaging to reduce gas and moisture exchange and UV light exposure (Lagarón, *et al*., 2005; AzoNano, 2007; Sorrentino *et al*., 2007). Nano packaging materials include barrier technologies, which enhance the shelf life, durability and freshness of food—or at least slow the rotting process. Nano packaging is also being designed to enable materials to interact with the food it contacts; emitting antimicrobials, antioxidants, nutraceuticals and other inputs. This 'smart' or 'active' packaging. For example, packaging may contain nanosensors that are engineered to change colour if a food is beginning to spoil, or if it has been contaminated by pathogens. Also nano magnesium oxide, nano copper oxide, nano titanium dioxide and carbon nanotubes are predicted for future use in antimicrobial food packaging (El-Amin, 2007). Barriers can reduce opportunity for microbial contamination by keeping bacteria away from food or preventing conditions that allow bacteria to grow. Nanocomposites used in food and beverage containers provide effective barriers to gas transmission (International Food Policy Research Institute, 2011). The new film is known as a "hybrid system" that is enriched with an enormous number of silicate nanoparticles. These massively reduce the entrance of oxygen and other gases, and the exit of moisture, thus preventing food from spoiling (Jha *et al*., 2011).

Nanolaminates is another viable option for protecting the food from moisture, lipids and gases. Moreover, they can improve the texture and preserve flavor as well as color of the food. Nanolaminates consist of two or more layers of nano-sized (1 – 100) thin food grade films which are present on a wide variety of foods: fruits, vegetables, meats, chocolate, candies, baked goods, and French fries (Rhim, 2004). E-Nose, its gas sensors that identify odors. These gas sensors are composed of nanoparticles e.g zinc oxide nanowires whose resistance changes when a certain gas is made to pass over it. This change in resistance generates a change in electrical signal that forms the fingerprint for gas detection. This fingerprint is used to determine the type, quality and quantity of the odor being detected (Hossain *et al.*, 2005). Nanotechnology is also enabling sensor packaging to incorporate cheap radio frequency identification (RFID) tags (Pehanich 2006; Nachay, 2007). Unlike earlier (RFID) tags, nano enabled (RFID) tags are much smaller, can be flexible and are printed on thin labels. This increases the tags' versatility (for example by enabling the use of labels which are effectively invisible) and thus enables much cheaper production. Such packaging can monitor temperature or humidity over time and then provide relevant information on these conditions, for example by changing colour (El-Amin, 2006; Gander, 2007).

Smart Delivery Systems and Sensor

Delivery of pesticides or medicines is either provided as "preventative" treatment or is provided once the disease organism has multiplied and symptoms are evident in the plant or animal. Nanoscale devices are envisioned that would have the capability to detect and treat an infection, Smart delivery system also can have the capacity to monitor the effects of the delivery of pharmaceuticals, nutraceuticals, nutrients, food supplements, bioactive compounds, probiotics, chemicals, insecticides, fungicides, vaccinations or water to people, animals, plants, insects, soils and the environment (Jha *et al*., 2011).

Since silver displays multiple modes of inhibitory action to microorganisms (Clement and Jarrett 1994). This capability of nano-silver is due to release of tiny particles of silver and so it is able to destroy not only the bacteria and fungus, but also the viruses (Sondi and Salopek-Sondi, 2004). it may be used for controlling various plant pathogens in a relatively safer way compared to synthetic fungicides (Park *et al*., 2006). Nano silver can exert effective antibacterial action at a considerably lower concentration than that of silver ions (Lok *et al*., 2006). The detrimental effects of nano-silver have been shown on more than six-hundred microorganisms (Abdi *et al*., 2008). The use of nanosized active ingredients has been suggested to offer improved delivery of agrochemicals in the field, better efficacy of pesticides, better control over dosing of veterinary products and pesticide formulation encapsulated in nanoclay for the slow release of growth stimulants and biocontrol agents (Friends of the Earth, 2008). Nanoparticles tagged to agrochemicals or other substances could reduce the damage to other plant tissues and the amount of chemicals released into the environment (Lez-melendi *et al*., 2008). Nano-silver eliminates the internal infections of ***in vitro*** explants and it is not toxic for the operator and for the environment (Rostami and Shahsavar, 2009). One of the potential applications of silver is to manage plant disease. Application of silver nanoparticles may lead to valuable discoveries in various fields such as pathogen control and antimicrobial systems (Lamsal *et al*., 2011).

A new composition of nano-sized Silica-Silver for control of various plant diseases has been developed by (Park *et al*., 2006) which consisted of nano-silver combined with silica molecules and water solublepolymer, prepared by exposing a solution including silver salt, silicate and water soluble polymer to radioactive rays. It showed antifungal activity and controlled powdery mildews of pumpkin. Nanosilica (~3–5 nm) could be successfully used to control a range of agricultural insect pests and animal ectoparasites of veterinary importance (Ulrichs *et al*., 2005& 2006; Barik *et al*., 2008).

(Wang *et al*., 2002) have shown that mesoporous Silica nano particles can deliver DNA and chemicals into Plants thus, creating a powerful new tool for targeted delivery into plant cells. There have also been reports that cellular 'injection' with carbon nanofibres containing foreign DNA has been used to genetically alter golden rice (AzoNano, 2003). Nanobiotechnology is already enabling scientists to rearrange the DNA of agricultural crops to develop Jasmine rice varieties that can be grown all year long, with shorter stems and improved grain colour (ETC Group, 2004). Nanobiotechnology now appears to offer a new suite of tools to manipulate the genes of plants or animals by using nanoparticles, nanofibres and nanocapsules, rather than using viral vectors, to carry foreign DNA and chemicals into cells (Vassaux *et al*., 2006; Torney *et al*., 2007). These nanomaterials can transport a much larger number of genes as well as the chemicals that trigger gene expression. Theoretically, the use of nanotechnology also offers greater control over the release of DNA at the target site. Nanopacticles can be used to carry and release effectors small molecule(_-estradiol) that induce the expression of genes within the plant cells in a controlled fashion (Jha *et al.*, 2011)

Nanosensors can be placed directly into the packaging material; alternatively, they could be stand-alone measurement systems based on microfluidics devices (Baeummer, 2004). Improved biosensor technology may be used to detect gases present in packaged foods as a measure of integrity of the packaging material, compounds released during food spoilage or deterioration, and the presence of pathogens or toxins in foods. Such sensors could be incorporated into packaging to alert consumers, producers, and distributers as to the safety status of foods or could be used to detect pathogens in processing plants. (Baeumner, 2004; Cheng *et al*., 2006*;* Helmke and Minerick, 2006). Several nano-based biosensors have been developed to detect contaminants, such as crystal violet or malachite green concentrations in seafood and parathion residues or residues of organophosphorus pesticides on vegetables (Amine *et al.*, 2006). The main advantage of nanosensors is that it significantly reduces detection time (Bhattacharya *et al*., 2007). Nano-based methods of detecting harmful pathogens are being developed for several pathogens: a nanobiosensor can identify the presence of *E. coli* and prevent the consumption of contaminated foods (Majid *et al*., 2008).

Precision farming

Precision farming is a management philosophy or approach to the farm and is not a definable prescriptive system (Dawson, 1997). This technology recognizes the inherent spatial variability that is associated with most fields under crop production (Thrikawala *et al*., 1999). Precision agriculture is defined as the art and science of utilizing advanced technologies for enhancing crop production while minimizing potential environmental pollution (Khosla, 2001).

Variable-rate technology (VRT) is another instrument, which uses the variability information and applies the inputs according to the requirement of the site, which includes fertilizer, pesticides and micronutrient application, liming, seed rate, irrigation and drainage (Fleischer *et al*., 1996: Schueller, 1997). Variable-rate technology (VRT) and yield monitors are an essential component of precision farming, which has mostly relied on the integration of geographical information system (GIS) and global positioning system (GPS) technologies, plus the implementation of (VRT) farm equipment. Precision farming technologies today are being studied and adopted for varied cropping systems. Besides the traditional crops, i.e., corn (*Zea mays* L.), soybean (*Glycine max* L.), wheat (*Triticum aestivum* L.), and barley (*Hordeum vulgare* L.), precision farming practices are now being implemented in potato (*Solanum tuberosum* L.), onion (*Allium cepa*), tomato (*Lycopersicon lycopersicum*), sugar beet (*Beta vulgaris* L.), forages, citrus, grape (*Vitis* spp.), and sugarcane (*Saccharum* spp.) (Heacox, 1998). It identifies the critical factors where yield is limited by controllable factors, and determines intrinsic spatial variability. It is essentially more precise farm management made possible by modern technology. The variations occurring in crop or soil properties within a field are noted, mapped and then management actions are taken as a consequence of continued assessment of the spatial variability With in that field. Development of geomatics technology in the later part of the 20th century has aided in the adoption of site-specific management systems using remote sensing (RS), global positioning system (GPS), and geographical information system (GIS). This approach is called Precision farming (PF) or site specific management (Carr *et al*., 1991; Brisco *et al*., 1998). Geographical information system (GIS) technology will help the farmers and scientists in decision making, as precise information on field will be readily available. GIS techniques make weed control, pest control and fertilizer application site-specific, precise and effective; it would also be very useful for drought monitoring, yield estimation, pest infestation monitoring and forecasting (Singh and Shekhawat, 2000; Reddy and Anand, 2000). Precision farming yields a threefold advantage. First, it provides the farmer useful information, that can influence their use of seed, fertilizer, chemicals, irrigation, and other farm inputs. Second, economics are optimized by enhanced efficiency of farm inputs. (Stombaugh and Shearer, 2000; Fleming *et al*., 2000). It is a paradigm shift from conventional management practice of soil and crop in consequence with spatial variability. It is a refinement of good whole field management, where management decisions are adjusted to suit variations in resource conditions. The agri-chemical and information technology industries have shifted down to the nano-scale to produce new agricultural chemicals, seeds, and livestock with novel functions and capabilities, as well as new systems of farm monitoring and management (Kuzma and Ver-Hage, 2006; Friends of the Earth, 2008). Practices of yield monitoring, variable-rate fertilizer and chemical application (VRA), variable-rate seeding, and parallel swath navigation, are being studied and used throughout a variety of crop production systems. These technologies offer opportunities for growers to increase both the production and environmental efficiencies of crop production and should be carefully evaluated (Grisso *et al*., 2011).

Animal Health

Today, application of antibiotics, probiotics and pharmaceuticals/ nutraceuticals is delivered through feed or injection system either as preventive treatment or when symptoms are evident. Nanoscale devices may have the capability to detect and treat infection and health problems. With the help of smart delivery system that poses multifunctional characteristics such as pre-programmed, time controlled, monitoring the effect of the delivery of probiotics, hormones, chemicals and vaccines is possible (Dutkiewicz and Kucharska, 1992). Management of breeding is an expensive and time consuming problem for culturing animals. One solution that is currently being studied is a nanotube implanted under the skin to provide real time measurement of changes in the level of estradiol in the blood. The nanotubes are used as a means of tracking oestrus in animals because these tubes have the capacity to bind and detect the estradiol antibody at the time of oestrus by near infrared fluorescence. The signal from this sensor will be incorporated as a part of a central monitoring and control system to actuate breeding (O'Connell *et al*., 2002). A novel method of DNA delivery has recently been described by using arrays of vertically aligned carbon nanofibers (VACNFs) to overcome the tedious microinjection involved in genetic manipulation and the temporal expression of genes that are not introduced into the inheritable genetic material of embryos but could affect them at crucial time (McKnight *et al*., 2003). This temporary expression could ameliorate the concerns that have accompanied genetic engineering livestock , including safety of genetic engineering animal food and products, cross-contamination of genetic engineering livestock with non-genetic engineering varieties and long –term effects on animal health and welfare from introduced genes (Thomas *et al*., 2003). The use of nanotechnology for DNA delivery could provide benefits to animals health and safety of animal derived products (Luo *et al*., 2004). Theoretically, any nanosized mineral, vitamin or other additive/supplement developed for a food application can equally be used for animal feed. There are a few examples of available products where a nanosized additive has been specifically developed (or is under development) for animal feed. An example is a feed additive comprising a natural biopolymer from yeast cell walls that can bind mycotoxins to protect animals against mycotoxicosis (YingHua *et al*., 2005). Nanoparticles can also remove food-borne pathogens in the gastrointestinal tracts of livestock (Qu *et al*., 2005). Nanomaterial that can be given to chicken to remove common poultry bacteria *Campylobacter*. The bacteria do not harm the birds but when ingested by humans, they can cause cramps and bloody diarrhoea. A nanoparticle to go into chicken feed which would latch on to *Campylobacter*, ensuring that it is excreted by chickens, so making the bird safer to eat. (Kannaki and Verma, 2006). Researchers have developed a nanoparticle that adheres to *E. Coli*. These nanoparticles are designed to be administered through feed to remove food-borne pathogens (Kuzma *et al.*, 2008). Nanoparticles have been designed to deliver vitamins or other nutrients in feed without affecting the taste or appearance. These nanoparticles encapsulate the nutrients and carry them via the gastrointestinal tract (GIT) into the bloodstream, increasing their bioavailability. Nanoparticles already reported to be incorporated into feeds include those engineered to provide encapsulation systems, e.g. micelles, liposomes, for delivery of feed ingredients, and those tailored for use in feed packaging such as biosensors, identification markers, shelf-life extenders and antimicrobials (Food Safety Authority of Ireland, 2008). Chicken feed containing nanoparticles that bind with harmful bacteria could help reduce food-borne pathogens (OECD, 2010).

Fisheries and aquaculture development

The fisheries and aquaculture industry can be revolutionized by using nanotechnology with new tools like rapid disease detection, enhancing the ability of fish to absorb drugs like hormones, vaccines and nutrients etc. Although much of development research is needed to enhance the potential use of nanotechnology in aquaculture, at present, there are numerous glimpses of the future application of this technology in fish health management, and water treatment in aquaculture (Rather *et al*., 2011).

The young carp and sturgeon exhibited a faster rate of growth (30% and 24% respectively) when they were fed nanoparticles of iron (ETC, Down of the farm, 2003). There is an immense opportunity to use the nanoparticles to deliver nutraceuticals in fish feed and neutrogenomics studies. Moreover, various nanoformulations of feed help to maintain better consistency and taste of feed (Freinds of the Earth, 2008). Research had demonstrated that different Selenium source (nano-Se and selenomethionine) supplemented in basal diet could improve the final weight, relative gain rate, antioxidant status as glutathione peroxidase activities and muscle Selenium concentration of crucian carp (*Carassius auratus gibelio)*. Moreover, nano-Se appeared to be more effective than that of organic selenomethionine in increasing muscle selenium content (Zhou *et al*., 2009). Similarly, the growth and performance of the experimented fishes have been assessed higher at nano level delivery of these nutraceuticals (Rather *et al*., 2011).

Outbreak of disease is one of the major stumbling blocks in the development and sustainability of aquaculture. Use of nanoparticles carrier like chitosan and poly-lactide-co-glycolide acid (PLGA) of vaccine antigens together with mild inflammatory inducers, one may achieve high levels of protection to fishes and shellfishes not only against bacterial but also from certain viral diseases with vaccine induced side effect (Rajeshkumar *et al*., 2009). Further the mass vaccination of fish can be done using nanocapsules which will be resistant to digestion and degradation. These nanocapsules contain short strand DNA are absorbed into the cell of fish when applied to water. The ultrasound mechanism is used to break the capsules which in turn release the DNA thus eliciting an immune response to fish due to the vaccination. (Ashraf *et al*., 2011; Rather *et al*., 2011). Radio frequency identification (RFID) is a chip with a radio circuit incorporating nanoscale component with an identification code embedded in it. These tags can hold more information, scanned from a distance and embedded in the product to identify any object anywhere automatically. These tags may be used as a tracking device as well as a device to monitor the metabolism, swimming pattern and feeding behaviour of fish. So it can detect pathogens and monitor temperature change, leakage etc., thus improving the product quality (Rather *et al*., 2011).

Nano-enabled technologies are available today for the removal of contaminants from water. Nonmaterial in the form of activated materials like carbon or alumina, with additives like zeolite and iron containing compounds can be used in aquaculture application for holding aerobic and anaerobic biofilm for the removal of ammonia, nitrites and nitrate contaminants (Gillman, 2006). Likewise, ultrafine nanoscale powder made from iron can be used as an effective tool for cleaning up contaminants such as trichloroethane, carbon tetrachloride, dioxins and polychlorinated biphenyls to simpler carbon compounds which are less toxic, thus paving the way for nano-aquaculture. It can use of NanoCheck in commercial fish farms, where algae and heavy metal removal and prevention. Besides, nanoscale delivery may be very useful for aquatic weed control in large water bodies (Rather *et al*., 2011; Ashraf *et al*., 2011).

Controlled environmental agriculture equal Green nanotechnology

Human beings depend heavily on Earth's natural capital—its biological resources and ecosystems—to live and prosper. Earth's biological resources are extraordinarily diverse. They include a myriad of species of plants, animals, and microorganisms, and they provide a significant fraction of mankind's food, agricultural seeds, pharmaceutical intermediates, and wood products (CBD, 2000). Currently, fossil fuels provide approximately 80% of the energy used worldwide. The world will continue to burn significant amounts of fossil fuels in the foreseeable future. Thus, carbon capture and storage (CCS) is emerging as a viable short- to medium-term alternative for reducing the amounts of anthropogenic CO_2 released into the atmosphere (IPCC, 2005). Earth also possesses a variety of ecosystems (e.g., wetlands, rainforests, oceans, coral reefs, and glaciers) that provide critical services such as (1) water storage and release; (2) CO_2 absorption and storage; (3) nutrient storage and recycling; and (4) pollutant uptake and breakdown. Preservation of the biodiversity of Earth's ecosystems is critical to human life and prosperity. During the last two decades, a consensus has gradually emerged that increasing emissions of carbon dioxide (CO_2) from the combustion of fossil fuels (e.g., coal and petroleum) are the key drivers of global climate change (IPCC, 2007). In rural areas, the energy should be reliable and affordable. The traditional energy sources like oil lamps, wood stoves, and diesel generators can be substituted with renewable off grid electricity (solar, wind), improved cooking, devices run on battery with off grid electricity charging. This should also be combined with local capability for manufacturing/ assembling, maintaining renewable based equipment and inexpensive solar cells would help provide electricity for rural areas. Nanotechnology has been used in solar photovoltaic (PV) applications to improve efficiency and reduce cost. Nanomaterials have been used in the next generation solar cells such as organic, thin film, dye sensitized and hybrid ones (The Energy and Resources Institute, 2009). Hybrid solar cells using polymeric layer covered with a thin film of nanocrystal PbSe has been developed to increase efficiency and protect the polymeric layer from UV radiation (Kim *et al*., 2009). Solar-powered electrochemical or photo-catalytic systems, which produce hydrogen via water splitting using organic pollutants as sacrificial electron donors, provide a possible solution to achieve two objectives: generation of energy and production of clean water (Silva *et al*., 2008; Park *et al*., 2009; Choi *et al*., 2010) Nanotechnology applications in the energy and environment sectors (such as increased use of renewable energy sources, remediation of polluted water and soils) would also contribute towards providing an improved environment for agricultural activities.

(Who, 2004) reported that one billion people are at risk because they do not have access to potable water and another 2.6 billion lack access to clean water. Seawater and brackish water from saline aquifers constitute ~97% of the water on Earth (Shannon *et al*., 2008). Lack of safe water and adequate sanitation facilities has an adverse impact on health in terms of (a) Waterborne diseases (diarrhea, typhoid, etc) that are transmitted through drinking contaminated water and (b) Water-washed disease (skin and eye infections, for instance) which occur due to lack of water for washing and personal hygiene. There are nearly 4 billion diarrheal cases per year causing around 1.8 million deaths. Contaminated surface water sources also affect inland fisheries, which is a major food source in some parts of the world (The Energy and Resources Institute, 2009).Approximately 70–90% of the water used in agriculture and industry and for human consumption is returned to the environment as wastewater (Shannon, 2010).

Nanomaterials can be used to adsorb or sequester pollutants and remove them from water. Various chemical groups can also be added to nanoparticles to improve their specificity in removing certain pollutants. Carbon nanotube filters can effectively remove bacteria and viruses from water. Gram-positive and -negative bacteria can be killed by nanoparticles of silver compounds and magnesium oxide which disrupt bacterial cell membranes (Savage and Diallo, 2006). Magnetic nanoparticles could be used to filter water at the point of use to remove nanocrystals and arsenic (Yavuz *et al*., 2006). Nano-enabled water treatment techniques incorporating carbon nanotubes, nanoporous ceramics, and magnetic nanoparticles can be used to remove impurities from drinking water and could potentially remove bacteria, viruses, water-borne pathogens, lead, uranium, and arsenic, among other contaminants (Hillie and Hlophe, 2007). Water purification membranes produced from nanmaterials:1) nanostrcutured membranes from nanomaterials such as carbon nanotubes , nanoparticles and dendrimeres, 2) nanoreactive membranes from metal nanoparticles and other nanomaterial (Theron *et al*., 2008). Polysulfonate ultrafiltration membranes impregnated with silver nanopraticles were found effective against *E.coli* K12 and *P.mendocina* bacteria strains and showed a significant improvement in virus removal (Zodrow *et al*., 2008). Nanoscale zero-valent iron and other nanomaterials (nanoscale zeolites, metal oxides, carbon nanotubes, and fibers) can be used to remediate pollutants in soil or groundwater (Karn *et al*., 2009). Apply nanotechnology and particularly nanoparticles in cleaning up soil contaminated with heavy metals. The particle flow along with the ground water and decontaminate in route, which is much less expensive than digging out the soil to treat it (Jha *et al*., 2011).

Carbon nanotube

It is now known that carbon molecules at nanoscale can form cylindrical tubes, called carbon nanotubes (CNTs), Carbon nanotubes (CNT) can be formed as single-wall carbon nanotubes (SWCNTs), or multi-wall carbon nanotubes (MWCNTs). CNTs have very high tensile strength, and are considered to be 100 times stronger than steel, and conduct electricity neither of which is possible with the carbon found in coal or diamonds (FAO/WHO, 2009).

Carbon nanotubes (CNTs) have acquired an important status in nanotechnology due to their unique mechanical, electronic and thermal properties, which have led to their exploitation in diverse applications such as sensors, energy and gas storage (Ohashi and Dai, 2006). Recently, studies have revealed the capacity of single walled carbon nanotubes (SWNTs) to traverse across both the plant cell wall and cell membrane (Liu *et al*., 2009). This study also pointed out that SWNTs can serve as effective nano transporters to deliver DNA and small dye molecules into intact plant cells. Compared to plant cell walls and membranes, the penetration of nanoparticles into seeds is expected to be difficult due to the significantly thick seed coat covering the whole seed. In spite of this anticipated hurdle (Khodakovskaya *et al*., 2009) demonstrated that CNTs could effectively penetrate seed coat, thereby influencing the seed germination and plant growth more than twice as much as the untreated plants.

These desirable effects possibly reason suggested for the higher water uptake was that new pores were generated during penetration of seed coat by CNTs. Another possible cause could be the efficient gating of the water channels by the CNTs in the seed coat.

CONCLUSION

Food security has always been the biggest concern of the mankind. Nations, communities and Governments have been struggling with the issue since long. Recent decades have seen even bigger challenges on this front. The future looks even bleaker with food shortage issue looming large. The challenge is how to feed the growing population by producing more on a stagnant or shrinking landscape; with lesser input costs and with lesser hazards to the eco-system. Another adjunct to this problem is how to add to the income of agricultural producers so as to sustain their motivation to grow crops. This also leads to the question as to how to add value to what is being produced. Value for the producer as well as the consumer! And how to make the transaction in agro products smooth, safe and reliable. Thus, all across the world, an urgent need is being felt for more scientific and targeted management of the agriculture and food sector. Nanotechnology has answers to many of these challenges. Applications of nanotechnology have the potential to change the entire agriculture sector and food industry chain from production to conservation, processing, packaging, transportation, and even waste treatment. Strategic applications of nanoScience can do wonders in the agriculture scenario. NanoScience concepts and Nanotechnology applications have the potential to redesign the production cycle, restructure the processing and conservation processes and redefine the food habits of the people. Nanoscience and nanotechnology are still in their infancy. At present, new exciting results and, sometimes, disappointments alternate on the scene, as always happens in fields that have not yet reached maturity. Surely, as Feynman said, "*when we have some control of the arrangement of things on a molecular scale, we will get an enormously greater range of possible properties that substances can have*", and these new properties will lead to a wide variety of applications which we cannot even envisage today. Hopefully, nanoscience and nanotechnology will contribute in finding solutions for the four big problems that face a large part of the earth's population: food, health, energy, and pollution. The new technology may be able to harness several newer possibilities in managing the farm sector precisely. These vignettes are not science fiction, but real, and developed countries reaped benefits from it. These technologies should be used to complement the traditional methods for enhancing productivity and quality, rather than to replace conventional methods. In the light of today's urgent need, there should be an all out effort to use new technological inputs for the development of our society, as well as to make the 'Green Revolution' an 'Evergreen Revolution'. Now what we require is the development of a symbiotic relationship between man and nature to harmonize the ecological balance. Nanotechnology may present new opportunities to improve the poor. And that could have significant impacts on rural populations in developing countries. Nanotechnology promises to reduce pesticide use, improve plant and animal breeding, create new nano-bioindustrial products, environmental protections, disease treatment, and delivery methods. It promises higher yields and lower input costs by streamlining agricultural management and thereby reducing waste and labour costs. It also offers the potential to employ less skilled and therefore cheaper, farm machinery operators. Nanoscience is leading to the development of a range of inexpensive nanotech applications to increase fertility and crop production. Nanotechnology will enable making high quality products at very low cost and at a very fast space. Food. science and technology should take advantage of the powerful tools of nanotechnology, for the benefit of humankind. The experience gained from this could be used to revolutionize the food and agriculture systems. It is very difficult to predict the long-term impact of any technology, nanotechnology in particular. As in the case of almost every nonconventional technology, e.g., genetic engineering, some fear that nanotechnology can give people too much control. We believe that this control can be wisely used, and that the huge contributions that nanotechnology can make are very strong arguments in favor of using this revolutionary science to its fullest potential. As with any new technology that offers significant benefits to humankind, there are also risks of adverse and unintended consequences with nanotechnology. Technological advances have always been a two-edged sword; offering both upsides and downsides. Sometimes, even when technology has been used for good, it has had unexpected negative results. But the history of human progress is the story of our ability to exploit the benefits of technology while effectively identifying, addressing and minimizing its downside. Nanotechnology applications must comply with the requirements for high level of public health, safety, consumer and environmental protection and ethical considerations in terms of impact on livelihoods and economic resilience. Scientific education is producing many people who are able to make science, and this is good. Even more important, however, would be to produce people who are able to distinguish what is worth making with science. As scientists and citizens we have a great social responsibility. We must teach and check that science and technology are used for peace, not for war; for alleviating poverty, not for maintaining privileges; for reducing, not for increasing the gap between developed and underdeveloped countries; for protecting, not for destroying our planet that, even after the development of nanoscience and nanotechnology, will most likely remain the only place where mankind can live. So Investment in nanotechnology by governments as well as careful attention to consequences to human health and the environment are both necessary for the public to accept and benefit from commercial products with nanomaterials Nanotechnology will present opportunities to integrate science and technology with social science and humanities**.** Education must provide mechanisms for updating scientists and engineers on new technologies as well as making all students critical thinkers capable of intelligent debates about societal effects of nanotechnology. Whatever the impacts of nanotechnology on the food industry and products entering the market, the safety of food will remain the prime concern. Science is not only an art but also big business. Today's science is tomorrow's technology. So we need scientists, engineers and researchers who can perform the cutting–edge research that will keep them competitive globally. No organization can promote and sustain science in respective countries except the governments and scientific community themselves working together with civil society and regional and international partners. Scientific knowledge must be fully exploited to increase national productivity and bring prosperity. This is a portent of hope; hope that possibly within the next few years, the region may achieve socio-economic growth and prosperity through greater investment in building science capacity. So it is not only the time for solution the challenges in agriculture sectors but also it is the time for cooperative all scientists to benefit mankind.

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REFERENCE

Abdi, G., Salehi, H. and Khosh-Khui, M. (2008): Nano silver: A novel nanomaterial for removal of bacterial contaminants in valerian (*Valeriana officinalis* L.) tissue culture. Acta Physiol. Plant., 30: 709-714.

Anane-Fenin, A. (2008): Nanotechnology in Agricultural Development in the ACP Region, Technical Centre for Agricultural and Rural Cooperation: Knowledge for Development.

Amine, A., Mohammadi, H., Bourais, I. and Palleschi, G. (2006): Enzyme Inhibition-Based Biosensors for Food Safety and Environmental Monitoring, Biosensors and Bioelectronics 21, no. 8:1405–1423.

Ashraf, M., Aklakur, Md., Sharma, R., Ahmad, S. and Khan, M. (2011): Nanotechnology as a Novel Tool in Fisheries and Aquaculture Development: A Review KhanIranica Journal of Energy & Environment 2 (3): 258-261.

AzoNano (2003): Nanofibers To Be Used In Drug Delivery, Gene Therapy, Crop Engineering and Environmental Monitoring. Available at: http://www.azonano.com/details.asp?ArticleID=114 (accessed 24 December 2007).

AzoNano (2007): Advanced Nanotechnology gets grant for food packaging.

Nanotechnology News Archive. Available at: (accessed 18 January 2008) http://www.azonano.com/news.asp?newsID=3177.

Baeumner, A. (2004): Nanosensors identify pathogens in food. Food Technol 58:51–55.

Bai, Y.X., Li, Y.F., Yang, Y. and Yi, L.X. (2006): Covalent immobilization of triacylglycerol lipase onto functionalized nanoscale SiO2 spheres. Process Biochem 41:770–777.

Barik, T. K., Sahu, B., Swain, V., Res, P. (2008): Nanosilica—from medicine to pest control 103:253–258.

Bhattacharya, S., Jang, J., Yang, L., Akin, D. and Bashir, R. (2007): Biomems and nanotechnology based approaches for rapid detection of biological entitities. Journal of Rapid Methods & Automation in Microbiology 15 :1–32.

Binks, P. (2007): Nanotechnology & water opportunities and challenges. Victorian Water Sustainability Seminar, may 15 2007.(This presents approaches to the study of nanotechnology for water issues).

Bordes, P., Pollet, E., Avérous, L. (2009): Nano-biocomposites: Biodegradable polyester/nanoclay systems Progress in Polymer Science 34 (2) 125-155.

Brisco, B., Brown, R.J., Hirose, T., McNairn, H. and Staenz, K., Can. J.(1998): Remote Sensing, 24, 315–327.

Brody, A.L. (2006): Nano and food packaging technologies converge. Food Technol 60:92–94.

Carr, P.M., Carlson, G.R., Jacobsen, J.S., Nielsen, G.A. and Skogley, E.O., (1991): J. Prod. Agric., 4, 57–61.

Chaudhry, Q., Scotter, M., Blackburn, J., Ross, B., Boxall, A., Castle, L. Convention on Biological Diversity (CBD) (2000): How the Convention on Biological Diversity promotes nature and human well-being. Sustaining life on earth. Montreal, Quebec, Canada: Secretariat of the Convention on Biological Diversity. ISBN 92-807-1904.

Chaudhry, Q., Scotter, M., Blackburn, J., Ross, B., Boxall, A., Castle, L., Aitken, R. and Watkins, R. (2008): Applications and implications of nanotechnologies for the food sector. Food Add. Contam.,25(3): 241–258.

Cheng, M.M.C., Cuda, G., Bunimovich, Y.L, Gaspari, M., Heath, J.R., Hill, H.D., Mirkin, C.A., Nijdam, A.J., Terracciano, R., Thundat, T. and Ferrari, M. (2006): Nanotechnologies for biomolecular detection and medical diagnostics. Curr Opin Chem Biol 10:11–19.

Choi, J., Park, H. and Hoffmann, M.R. (2010): Effects of single metal-ion doping on the visible-light photoreactivity of TiO_2. J. Phys. Chem. C 114(2):783.

Choudalakis, G. and Gotsis, A.D. (2009): Permeability of polymer/clay nanocomposites: A review European Polymer Journal 45 (4) 967-984.

Clement, J.L and Jarrett, P.S (1994): Antibacterial silver. Met Based Drugs;1: 467-82.

Daniells, S. (2008): Unilever Breakthrough Could Take Food Foams to New Level. <www. foodnavigator.com> (12 Mar. 2008).

Darder, M., Aranda, P. and Ruiz-Hitzky, E. (2007): Bionanocomposites: A new concept of ecological, bio-inspired, and functional hybrid materials. Advanced Materials 19: 1309–1319.

Dawson, C.J. (1997): in Precision Agriculture (ed. Stafford, J. V.), BIOS Scientific Publishers Ltd, vol. 1, pp. 45– 58.

Del-Nobile, M., Cannarsi, M., Altieri, C., Sinigaglia, M., Favia, P., Lacoviello, G. and D’Agostino, R. (2004): Effect of Agcontaining Nano-composite Active Packaging System on Survival of *Alicyclobacillus acidoterrestris*. Journal of Food Science 69(8):379.

Dunn, J. (2004): “A Mini Revolution”, Food Manufacture, 1 septemper ,49,accessed at www.foodmanufacture.co.uk/news/.

Dutkiewicz, J. and Kucharska, M. (1992): Advances in Chitin and Chitosan (Brine CJ, Sandford PA, Zikakis JP, eds). Elsevier Science, 54–60.
ElAmin, A. (2006): Nano ink indicates safety breach in food packaging. Available at: http://www.foodnavigator.com/news/ng.asp?id=72022 (accessed 23 January 2008).
ElAmin, A. (2007): Carbon Nanotubes Could be New Pathogen Weapon, Food Production Daily. Com Europe. Error! Hyperlink reference not valid. (13 Nov. 2008).
ETC Group (2003): The Big Down. Atomtech: Technologies Converging at the Nano-scale. Canada.
ETC Group (2004): Food Packaging Using Nanotechnology Methods: an Overview of 'Smart Packaging' and 'Active Packaging'. http://www.azonano.com/Details.asp?ArticleID=1317.
ETC, Down on the Farm, (2003): The Impact of Nanoscale Technologies on Food and Agriculture Available http:// www.etcgroup.org/ en/ materials/publications.html, Last Accessed February 15, 2003.
FAO-WHO (World Health Organization). (2009): FAO/WHO Joint Expert Meeting on the Application of Nanotechnologies in the Food and Agriculture Sectors: Potential Food Safety Applications. Rome: FAO-WHO,http://www.fao.org/ag/agn/agns/files/FAO_WHO_Nano_Expert_Meeting_Report_Final.pdf.
Farris, S., Schaich, K.M., Liu, L.S., Piergiovanni, L. and Yam, L.K. (2009): Development of polyion-complex hydrogels as an alternative approach for the production of bio-based polymers for food packaging applications: a review Trends in Food Science & Technology 20 (8) 316-332.
Fleischer, S.J., Weisz, R., Smilowitz, Z. and Midgarden, D. (1996): In The States of Site-Specific Agriculture (eds Pierce, F. J., Robert, P. R., Sadler, J. and Searcy, S.), Soil Science Society of America, pp. 213–218.
Fleischer, T., Grunwald, A. (2008): Making nanotechnology developments sustainable. A role for technology assessment Journal of Cleaner Production, 16:889-898. (This presents approaches to study of the sustainability of nanotechnology applications).
Fleischwirtschaft (2006): Available at: http: //www. aquanova. de/ media/ public/publikationen2006/Fleischwirtschaft_ProfWeber_NovaSOL_060502.pdf (accessed 24 December 2007).
Fleming, K.L., Westfall, D.G., Wiens, D.W. and Brodahl, M.C. (2000): Evaluating farmer defined management zone maps for variable rate fertilizer application. Precision Agriculture 2: 201-215.
Food Safety Authority of Ireland (2008): The relevance for food safety of applications of nanotechnology in the food and feed industries. Dublin, Food Safety Authority of Ireland. 88 pp.
Friends of the Earth (2008): Out of the Laboratory and on to our Plates. Nanotechnology in Food and Agriculture. Australia.
Gillman, G.P. (2006): A simple technology for arsenic removal from drinking water using hydrotalcite. Science Total Environmental, pp: 336.

Gander, P. (2007): The smart money is on intelligent design. Food Manufacture UK. (Accessed 17January 2008). Available at: http: //www. Food manufacture.co.uk/news/fullstory.php/aid/4282/The_smartmoney_is_on_intelligent_design.html

Grisso, R., Alley, M., Thomason, W., Holshouser, D. and Roberson, G.T. (2011): Precision Farming Tools: Variable-Rate Application Virginia cooperative Extension. Publication 442-505.

Han, M., Gao, X., Su, J.Z. and Nie, S. (2001): Quantum-dot-tagged microbeads for multiplexed optical coding of biomolecules. Nat. Biotechnol., 19: 631–635.

Heacox, L. (1998): Precision Primer. American Vegetable Grower 46(6):24.

Helmke, B.P. and Minerick, A.R. (2006): Designing a nano-interface in a microfluidic chip to probe living cells: challenges and perspectives. Proc Nat Acad Sci USA 103:6419–6424.

Helmut Kaiser Consultancy Group (2007): Nanopackaging Is Intelligent, Smart And Safe Life. New World Study By Hkc22.com Beijing Office. Press Release 14.05.07 Available at http://www.prlog.org/10016688 nanopackagingisintelligent- smart-and-safe-life-newworld-study-byhkc22-com-beijing-office.pdf (accessed 17 January 2008).

Hillie, T. and Hlophe, M. (2007): Nanotechnology and the Challenge of Clean Water, Nature Nanotechnology 2: 663–664.

Holley, C. (2005): Nanotechnology and packaging. Secure protection for the future. Verpackungs- Rundschau 56:53–56.

Hossain, M.K., Ghosh, S.C., Bootongkong, Y., Thanachayanont C. and Dutta, J. (2005): Growth of zinc oxide nanowires and nanobelts for gas sensing application, Journal of Metastable and Nanocrystalline Materials, Vol.23,27-30.

Intergovernmental Panel on Climate Change (IPCC) (2005): Carbon dioxide capture and storage. Eds., Bert Metz, Ogunlade Davidson, Heleen de Coninck, Manuela Loos and Leo Meyer (Eds.) Miller.Cambridge, Cambridge University Press, U.K.

Intergovernmental Panel on Climate Change (IPCC) (2007): Climate change: The physical science basis, Biopolymerbased antimicrobial packaging: Review. Crit. Rev. Food Sci. Nutr. 44:223-237.

International Food Policy Research Institute (2011): Agriculture, Food, and Water Nanotechnologies for the Poor: Opportunities and Constraints.http://www.ifpri.org/publication/agriculture-food-and-water nanotechnologies-poor.

Jha Z. , Behar, N., Sharma, S.N, Chandel, G., Sharma, D.K. and Pandey, M.P. (2011): Nanotechnology: Prospects of Agricultural Advancement. Nano Vision, Vol.1 (2), 88-100.

Kannaki, T.R. and Verma, P.C. (2006): The Challenges of 2020 and the Role of Nanotechnology in Poultry Research (P. 273-277), Poultry Research Priorities to 2020. Proceedings of National Seminar (November 2-3,). Central Avian Research Institute, Izatnagar-243 122 (India).

Karn, T. Kuiken, and M. Otto (2009):“Nanotechnology and In Situ Remediation: A Review of Benefits and Potential Risks,” Environmental Health Perspectives 117, no. 12: 1823–1831.

Kewal K. J. (2008): The Hand Book of medicine, MD, FRACS, FFPM. ISBN:978-1-60327-318-3. Library of Congress control Number: 2007940762.

Khodakovskaya, M., Dervishi, E., Mahmood, M., Xu, Y., Li, Z., Watanabe, F. and Biris, A. S. (2009): ACS Nano, 3,3221.

Khosla, R. (2001): Zoning in on Precision Ag. Colorado State University Agronomy Newsletter 21(1):2-4.

Kim, T.W., Kim, I.Y., Im, J.H., Ha, H.W. and Hwang, S.J. (2009): Improved photocatalytic activity and adsorption ability of mesoporous potassiumintercalated layered titanate Journal of Photochemistry & Photobiology, A: Chemistry 205 (2): 173-178.

Kuzma, J. and VerHage, P. (2006): Nanotechnology in agriculture and food production: anticipated applications. Project on Emerging Nanotechnologies. Washington DC, Woodrow Wilson International Center for Scholars, September 2006.

Kuzma, J., Romanchek, J. and Kokotovich, A. (2008): Upstream oversight assessment for agrifood nanotechnology. Risk Anal., 28: 1081–1098.

LaCoste, A., Schaich, K., Zumbrunnen, D. and Yam, K. (2005): Advanced controlled release packaging through smart blending. Packag Technol Sci 18:77-87.

Lagarón, J.M., Cabedo, L., Cava. D., Feijoo, J.L., Gavara, R. and Gimenez, E. (2005): Improving packaged food quality and safety. Part 2: Nanocomposites. Food Additiv Contam 22: 994–998.

Lamsal, K., Kim1, S.W., Jung, J. H., Kim, Y.S., Kim, K.S. and Lee, Y.S. (2011): Application of Silver Nanoparticles for the Control of *Colletotrichum* Species *In Vitro* and Pepper Anthracnose Disease in Field Mycobiology 39(3): 194-199.

Lez-melendi, P.G., ´ Ndez-pacheco, R.F., Coronado, M.J., Corridor, E., Testillano, P.S., Risuen˜ o, M.C., Marqulna, C., Ibarra, M.R., Rubiales D. and Pe ´ rez-de-luque A., (2008): Nanoparticles as Smart Treatment-delivery Systems in Plants: Assessment of Different Techniques of Microscopy for their Visualization in Plant Tissues Annals of Botany 101: 187–195.

Liu, P., Zhang, Y.W. and Lu, C.(2003): Finite element simulations of the self-organized growth of quantum dot superlattices. Phys.Rev.B 68,195314. Liu, Q., Chen, B., Wang, Q., Shi, X., Xiao, Z., Lin, J. and Fang, X., (2009): Nano Lett., vol.(9): 1007.

Lok, C.N., Ho, C.M., Chen, R., He, Q.Y., Yu, W.Y., Sun, H., Tam, P.K.H., Chiu, J.F., and Che, C.M. (2006): Proteomic analysis of the mode of antibacterial action of silver nanoparticles. J. Proteome Res. 5, 916-924.

Lopez-Rubio, A., Gavara, R. and Lagaron, J. (2006): Bioactive packaging: turning foods into healthier foods through biomaterials. Trends Food Sci. Technol 17: 567-575.

Luo, D., Han, E., Belcheva, N. and Saltzman, W.M. (2004): A self-assembled, modular DNA delivery system mediated by silica nanoparticles. J. Controlled Release, 95: 333-341.

Majid, E., Male, K.B. and Luong J.H.T. (2008): Boron Doped Diamond Biosensor for Detection of Escherichia coli, Journal of Agriculture and Food Chemistry, 56 : 7691–7695.

McKnight, T.E., Melechko, A.V., Griffin, G.D. and Guillorn, M.A.(2003): Intracellular integration of synthetic nanostructures with viable cells for controlled biochemical manipulation. Nanotechnol., 14: 551-556.

Moraru, C., Panchapakesan, C., Huang, Q., Takhistov, P., Liu, S. and Karn, B., Kuiken, T. and Otto, M. (2009): Nanotechnology and In Situ Remediation: A Review of Benefits and Potential Risks, Environmental Health Perspectives 117, no. 12: 1823–1831.

Nachay, K. (2007): Analyzing nanotechnology. Food Technology 61(1): 34 36.

NSTC. (2011): The National Nanotechnology Initiative Strategic Plan. Arlington, VA: National Science and Technology Council (NSTC).

O'Connell, M.J., Bachilo, S.M., Huffaman, C.B., Moore, V.C., Strano, M.S., Haroz, E.H., Rialon, K.L., Boul, P.J., Noon, W.H., Kittrell, C., Ma, J., Hauge, R.H., Weisman, R.B. and Smalley, R.E. (2002): Band gap fluorescence from individual singlewalled carbon nanotubes. Sci., 297(5581): 593-596.

OECD (Organisation for Economic Co-operation and Development),(2010): Report of the Questionnaire on Regulatory Regimes for Manufactured Nanomaterials, OECD Environment, Health and Safety Publications Series on the Safety of Manufactured Nanomaterials No. 22 (Paris: Environment Directorate, OECD, 2010).

Ohashi, T. and Dai, L. (2006): Carbon Nanotechnology (ed. Dai, L.), Elsevier, The Netherlands.

Park, H.J., Kim, S.H., Kim, H.J., Choi, S.H. (2006): A new composition of nanosized silica-silver for control of various plant diseases. Plant Pathol J; 22: 295-302.

Park, H., Vecitis, C.D. and Hoffmann, M.R. (2009): Electrochemical water splitting coupled with organic compound oxidation: the role of active chlorine species. J. Phys. Chem. *C* 113(18):7935–7945.

Pehanich, M. (2006): Small gains in processing, packaging. Food Processing. com. Available at: http: //www. Food processing. com/ articles/ 2006/ 228.html (accessed 8 August 2007).

Qu, L., Luo, P. G., Taylor, S., Lin, Y., Huang, W., Anyadike, N., Tzeng, T.R., Stutzenberger, F., Latour, R.A., Sun, Y.P. (2005): Visualizing Adhesion-Induced Agglutination of *Escherichia coli* with Mannosylated Nanoparticles, Journal of Nanoscience and Nanotechnology 5, no. 2(4): 319–322.

Rajeshkumar, S., Venkatesan, C., Sarathi, M., Sarathbabu, V., Thomas, J., Basha, A.K. and Sahul-Hameed, A.S. (2009): Oral delivery of DNA construct using chitosan nanoparticles to protect the shrimp from white spot syndrome virus (WSSV). Fish and Shellfish Immunol., 26(3): 429-437.

Rather, M.A., Sharma, R., Aklakur, M., Ahmad, S., Kumar, N., Khan, M. and Ramya, V.L. (2011): Nanotechnology: A Novel Tool for Aquaculture and Fisheries Development. A Prospective Mini-Review. Fisheries and Aquaculture Journal, Volume FAJ-16:1-5. http://www.astonjournals.com/faj.

Ray, S.S. and Bousmina, M. (2005): Biodegradable polymers and their layered silicate nanocomposites: In greening the 21st century materials world Progress in Materials Science 50 (8): 962-1079.

Reddy, G.P. and Anand, P.S.B. (2000): Yojana, June 35–36.

Renton, A. (2006): Welcome to the world of nanofoods. Guardian Unlimited UK (accessed 17January 2008).

Reynolds, G. (2007): FDA recommends nanotechnology research, but not labelling.

Rhim, J.W. (2004): Increase in water vapour barrier property of biopolymerbasededible films and coatings by compositing with lipid materials. Trends Food Sci.Technol. 10: 254-260.

Rhim, J.W. and Ng, P.K.W. (2007): Natural biopolymer-based nanocomposite films for packaging applications. Critical Reviews in Food Science and Nutrition 47(4) 411–433.

Roach, S. (2006): or b in part 3 animal) Nanotechnology passes first toxicity hurdle. Available from Error! Hyperlink reference not valid..

Roco, M.C. and Bainbridge, W.S. (2001): Societal implications of nanoscience and nanotechnology. Boston, Kluwer Academic Publishers. pp. 3–4.

Rostami, A. and Shahsavar, A. (2009): Nano-Silver Particles Eliminate the *in vitro* Contaminations of Olive ‘Mission’ Explants. Asian Journal of Plant Sciences, 8: 505-509.

Savage, N. and Diallo, M.S. (2006): Nanomaterials and water purification: opportunities and challenges. J. Nanoparticle Res 7:331–342.

Schmidt, K.F. (2007): Nanofrontiers, visions for the future of nanotechnology . Project on Emerging Technologies, Woodrow Wilson International Center for Scholars, national Institutes of Health, Washington, D.C., USA.(This presents approaches to the study of the future of nanotechnology).

Schueller, J. K. (1997): in Precision Agriculture (ed. Stafford, J. V.), BIOS Scientific Publishers Ltd, vol. 1, pp. 33–44.

Shannon, M.A. (2010): Net energy and clean water from wastewater. ARPAE Workshop. Available online: Error! Hyperlink reference not valid..

Sharon, M. and Ajoy, K.. (2010): Choudhary and Rohit Kumar Nanotechnology in Agricultural Diseases and Food Safety Journal of Phytology , 2(4): 83–92.

Shannon, M.A., Bohn, P.W., Elimelech, M., Georgiadis, J.G., Mariñas, M.J, and Mayes, A.M. (2008): Science and technology for water purification in the coming decades. Nature 452:301–310.

Silva, L.A., Ryu, S.Y., Choi, J., Choi, W. and Hoffmann, M.R. (2008): Photocatalytic hydrogen production with visible light over Pt-interlinked hybrid composites of cubic-phase and hexagonal-phase CdS. J. Phys. Chem. C 112(32):12069–12073.

Singh, K. K. and Shekhawat, M. S., 2000Farmer and Parliament, 10– 13.

Siracusa, V., Rocculi, P., Romani, S., Rosa, M.D. (2008): Biodegradable polymers for food packaging: a review Trends in Food Science & Technology 19 (12) 634-643.Searcy, S.W.(1995): In Proc. Site-Specific Management for Agric. Syst., Minneapolis, MN, ASA-CSSA-SSSA, Madison, WI, pp. 603–608.

Smolander, M., Hurme, E., Koivisto, M. and Kivinen, S. (2004): PCT International Patent ApplicationWO 2004/102185 A1.

Sondi, I. and Salopek-Sondi, B. (2004): Silver nanoparticles as antimicrobial agent: A case study on *E. coli* as a model for Gram-negative bacteria. J. Colloid Interface Sci., 275: 177-182.

Sorrentino, A., Gorrasi, G. and Vittoria, V. (2007): Potential perspectives of bio-nanocomposites for food packaging applications. Trends Food Sci Technol 18:84-95.

Sozer, N., Kokini, J.L. (2009): Nanotechnology and its applications in the food sector Trends in Biotechnology, 27 (2): 82-89.

Stombaugh, T.S. and Shearer, S. (2000): Equipment technologies for precision agriculture. Journal of Soil and Water Conservation 55:6-11.

Tavajohi, S. (2008): Nanotechnology and Its Application in Safety and Health. Iran. Nano, Nanotechnology, Islamic Republic of Iran.14.

The Energy and Resources Institute (2009): A review of NT developments as applicable to developing countries. TERI project: Capability, Governance, and Nanotechnology Developments - a focus on India (Project Report No. 2006ST21:D2). The International Development Research Centre, Canada.

The Royal Society and Royal Academy of Engineering (RS-RAE). (2004): Nanoscience and Nanotechnologies: Opportunities and Uncertainties. London: RS-RAE.

Theron, A., Walker, J.A., Cloete, T.E. (2008): Nanotechnology and water treatment : Applications and Emerging opportunities Critical Reviews in Microbiology, 34, 43-69.(This presents approaches to the application of nanotechnology for water remediation).

Thrikawala, S., Weersink, A., Kachanoski, G. and Fox, G. (1999): Economic feasibility of variable-rate technology for nitrogen on corn. American Journal of Economics 81:914-927.

Thomas, C.E., Ehrhardt, A. and Kay, M.A. (2003): Progress and problems with the use of viral vectors for gene therapy. Nature Reviews Genetics 4: 346-351.

Torney F, Trewyn B, Lin V, Wang K. (2007): Mesoporous silica nanoparticles deliver DNA and chemicals into plants. Nature Nanotechnol 2:295-300.

Ulrichs C, Mewis I, Goswami A (2005): Crop diversification aiming nutritional security in West Bengal—biotechnology of stinging capsules in nature's water-blooms. Ann Tech Issue of State Agri Technologists Service Assoc. ISSN 0971-975X, pp 1–18.

Ulrichs, C., Entenmann, S., Goswami, A., Mewis, I. (2006): Abrasive und hydrophil/lipophile Effekte unterschiedlicher inerter Stäube im Einsatz gegen Schadinsekten am Beispiel des Kornkäfers Sitophilus granarius L. Gesunde Pflanze 58:173–181.

Vassaux, G., Nitcheu, J., Jezzard, S., Lemoine, N. (2006): Bacterial gene therapy strategies. J. Pathol 208: 290-298.

Wang, Y.A., Li, J.J., Chen H.Y. and Peng, X.G. (2002): Stabilization of inorganic nanocrystals by organic dendrons. J. Am. Chem. Soc.;124:2293-8.

Weiss, J., Takhistov, P., and McClements, D.J. (2006): Functional materials in food nanotechnology. J. Food Sci., 71(9): R107–R116.

WHO, A. (2004): Guidelines for Drinking-water Quality. Geneva. World Health Organization Vol. 1 : 3 rd ed.

Woodrow Wilson International Centre for Scholars. (2009): The Nanotechnology Consumer Inventory. www. nanotechproject. org/inventories/consumer.

Yavuz, C.T., Mayo, J.T., Yu, W.W., Prakash, A., Falkner, J.C., Yean, S., Cong, L., Shipley, H.J., Kan, A., Tomson, M., Natelson, D. and Colvin, V.L. (2006): Low-Field Magnetic Separation of Monodisperse Fe3O4 Nanocrystals, Science 314 : 964–967.

YingHua, S., ZiRong, X., JianLei, F., CaiHong, H. and MeiSheng, X. (2005): *In vitro* adsorption of aflatoxin adsorbing nano-additive for aflatoxin B1, B2, G1, G2. Scientia Agricultura Sinica, 38(5): 1069–1072.

Zhou, X., Wang, Y., Gu, Q. and Li, W. (2009): Effects of different dietary selenium sources (selenium nanoparticles and selenomethionine) on growth performance, muscle composition and glutathione peroxidase enzyme activity of crucian carp (*Carassius auratus gibelio*). Aquac., 291(1-2):78-81.

Zodrow, K., Brunet, L., Mahendra, S., Li, D., Zhang, A., Li, Q., Alvarez, P.J.J. (2008): Polysulfone ultrafiltration membranes impregnated with silver nanoparticles show improved biofouling resistance and virus removal. Water Research , In press, Corrected proof, Available online 24 November 2008.(This presents approaches to the study of silver imperegnated ultrafiltration membranes efficiency for virus removal and biofouling resistance).

Nesreen Ahmed Sabry Helal

NANOTEHNOLOGIJA U POLJOPRIVREDI: PREGLED

SAŽETAK

Kretanja u oblasti biohemije, fizičke hemije, mikroskopije i inženjeringa tokom protekle decenije, rezultirala su ogromnim porastom interesovanja kada je riječ o osobinama veoma malih čestica i njihovoj mogućoj primjeni u industrijskom i potrošačkom sektoru. Širokoj javnosti je predstavljen potencijal nanotehnologije za pokretanje radikalnih promjena u zdravstvu, tehnologiji tekstila i materijala, informacionoj i komunikacionoj tehnologiji i energetskom sektoru. U stvari, nekoliko proizvoda nastalih primjenom nanotehnologije već se nalazi na tržištu. Kao i u drugim sektorima, pojava nanotehnologije obećava revoluciju u razvoju proizvoda i primjeni u poljoprivredi. Istraživači na univerzitetima sada ispituju mogućnosti primjene nanotehnologije u poljoprivredi. Ovaj aspekt je još uvek u povoju i zahtijeva pažnju naučnog kadra kada je riječ o njegovoj širokoj primjeni i efektivnoj upotrebi njegovih potencijalnih prednosti. U ovom radu dat je pregled primjene nanotehnologije u poljoprivredi.

Ključne riječi: nanotehnologija, poljoprivreda, primjena