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Research Article

The Sustainable Development of Food Production in Agriculture Based on the Innovation in Nano-Science with Implication on Health and Environment

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Abstract

As the population of the world increases rapidly, the demand for agriculture and food products are increasing globally. Nanotechnology and the application of nanotechnology are the most promising solution for the transformation of conventional food and agricultural industries, aiming to improve the quality, safety and security of food and sustainable farming which revolutionizes the food and agricultural industries. Recent advancements in nanotechnology leads to new changes in the way of food perceived during farming, transporting, processing, packaging, storing, monitoring and consuming. The nanotechnology is given much importance in providing a better solution for food from farm to fork, which includes nutraceutical and functional foods, and improves nutritional status, efficiency, bio-availability, nano-additives, food texture, taste, color and package. In agriculture, various nano-products like nano-growth promoters, nano-pesticides, nano-fertilizers and several other products are available in developing and improving sustainable farming and crops. Rapid development is projected towards transforming several food and agricultural sectors, with increasing market stake and investment. Government, private and academic research centers are involved in exploring the advantages of nanotechnology to improve food security in upcoming years.

Keywords: *Nanotechnology, Nanomaterial, Agriculture, Food safety, Food Production.*

Introduction

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The nanotechnology gains the attention of in recent years due to its wide variety of applications in the field of medicines, drug development, catalysis, energy and development. The nanoparticles are of smaller in size and have potential towards industrial, medical and agricultural sectors. The nanoparticles are synthesized by several means such as the physical, chemical and biological methods [1]. There are several demerits in the synthesis of nanoparticles. This is because of the effort needed in scale-up, separation and its purification from microemulsion and the consumption of more surfactants [2]. The synthesize of nanoparticles by green methods like using the plant extracts, have more benefits such as, simple, convenient, ecofriendly and less reaction-time. Also, the nanomaterials formed by such method has several other applications such as the enhancement of fertilization, plant growth and also act as pesticides [3]. Moreover, it can reduce the usage of harmful chemicals that can pollute the environment and can cause adverse effect in human health [4].

The advancement in nanotechnology seems to provide substantial benefits in several sectors like food, agriculture and water. Emerging applications including water purification, rapid pathogen and chemical contaminant detection, and nano-enabled renewable energy technology applied over food chain are likely to provide new tools for several countries to overcome the challenges of sustainable development in agriculture and food safety and security.

The applications of nanotechnology in food and agriculture have some health effects in humans. It not only impacts the humans, but also have environment, social and ethical implications, need for adequate and immediate attention to global governance and challenges for developing countries [Nomani MZM, Alhalboosi AKK, Rauf M. (2020).Legal and Intellectual Property Dimension of Health and Access to Medicines in India. Indian Journal of Forensic Medicine & Toxicology, 14 (1),118-122.]. These are to be addressed globally, if the expected gains from nanotechnology in the food, agriculture and human and environmental health have to be realized.

Nanotechnology

Nanotechnology consists of a set of techniques, disciplines and devices to design, restructure and manipulate matter in nanoscale level i.e., 1 billionth of a meter. Nanomaterials are the materials with particles, aggregates or filaments of dimensions lesser than that of 100nm. Hence, nanotechnology can form various distinct new systems and structures namely the nanoparticles, nanowires, nanotubes, nanodispersions, nanolaminates, quantum dots, buckyballs and so on [5]. The basic factors that govern the properties of nanomaterials includes the size, distribution, chemical composition of constituent phases and number of interfaces or grain boundaries [6]. Agriculture and food production are directly linked to development and welfare of human and maintenance of ecosystem. As the population of world rises constantly, the change in climate, environmental hazards, shrinkage

in arable land and shortage in energy sources, the modern technologies are used to enhance the food production and improve its quality [Nomani ZM. (2020). Case Comment: Divya Pharmacy v. Union of India, Biotechnology Law Report, 39(2),122-128; https://doi.org/10.1089/blr.2020.29161.zmn]. Nanotechnology is used in the processing of food in all of the stages like food production, packaging, storing, transporting and value addition. There are several advantages in the usage of nanotechnology in the field of food production, disease detection in preventing loss, farm management, detection of environmental hazards and costs involved [7].

The nanoparticles are used in the detection of diseases in crop and its protection, smart delivery of pesticides, fungicides, fertilizers, bioactives, and chemicals with less harm in food chain, encapsulation of enzymes, food packaging and transporting by nanosensor, detection of food contamination by nanoparticles [8]. Food technology includes all the operations involved from farm to the moment at which the food reaches the fork. In agriculture, the use of light-weight and sophisticated machines and the design of nanoprocessor are the major advantages of nanotechnology [9]. Nanosensors are formed by combining nanotechnology and information technology. Nanosensors are used in packaging, storing and transporting the food products. This is because, the nanosensors can sense basic parameters of food safety like the quality, freshness, and physical, chemical and microbiological changes in food quality. The use of nanolaminates prevents deterioration of food from extreme exposure to light, dust, moisture, off-odors and off-flavors [10].

The nanofabricated tools can be used in the detection of diseases in animals and plants. The nanostructures can be used to control the development of novel diseases by studying the colonization of bacteria in plants and in drug delivery system [11]. The manufacturing of Nanosized functional ingredients as nutraceuticals and functional food consists of more nutrient absorption and retention which are formed into nanoemulsions for better bioavailability in the body. By using nanotechnology, the property, structure and interaction between various food components can be modified and can design novel food with better taste, flavor, stability, texture and freshness [12].

Nanotechnology in Food and Agriculture

Nanotechnology in agriculture has recently acquiring a greater attention due to its wide applications in food sector. Nanotechnology offers novel agrochemical agents and delivery systems to enhance the crop productivity and can be capable of reducing the usage of pesticides. The production of agricultural products can be increased by using nanotechnology. The applications of nanotechnology in the agriculture are, nanoformulations of agrochemicals to apply fertilizers and pesticides for crop enhancement, nanosensors in crop protection by detecting the diseases in crops and also the residues of agrochemicals, nanodevices for plant genetic engineering, diagnosis of plant diseases, poultry production, animal breeding, animal health and post-harvest management[Nomani MZM. (2019). The

access and benefit-sharing regime: An environmental justice perspective. Environmental Policy and Law, 49(4-5), 259-263; https://doi.org/10.3233/EPL-190172]. Precision farming needs some improvement in crops yield, but it won't damage the soil and water. Also, the loss of nitrogen can be minimized because of leakage and emission and microorganisms in soil. The application of nanotechnology emphasizes the DNA transfer in plants to develop insect resistant crops, food processing, food storing and enhances the shelf-life of the product. Also, the nanotechnology is supposed to develop biomass-to-production of fuel [13].

For better growth of plants, fertilizers are needed. The nanomaterials can be used as fertilizers which can enhance the crop production with reduced toxicity. Plants provide a most important way in the bioaccumulation in food chain. The recent advancement of agriculture includes the application and usage of nanoparticles in food production by a safe and effective way of using the chemicals in agriculture. Nanotechnology can also be used for effective control of virus attack in plants. The plant virus such as spherical virus is a most common virus that occurs naturally in the crops which can be easily controlled by using nanomaterials. Hence it is realized and believed that the use of nanotechnology in agriculture and food sector can revolutionize the whole industry including the farming, enhancement of the absorption of nutrients by plants, detection of plant diseases and in pest control.

Food business stakeholders and research scientists realized the applications and benefits of nanotechnology in food industry and their success depends on the cost and human perspective regarding the benefits and risks [14]. Nanotechnology has several benefits in the field of food and agriculture, but the market usage of it is still uncertain and marginal, but it is used widely in the field of biotechnology, medicine, physical science and information technology. This is because of the inadequate returns when compared to the large initial investment, different public perspective and scarcity in regulatory framework [15]. It is described in several researches, that the public perspective of nanotechnology is neutral, but the deflation in the direct application of nanoscience in food industry is huge. People also believe that the food processed via nanotechnology are similar to the genetically modified food products and hence the risks towards them are also similar and minimizes the use of food made through nanotechnology [16]. A study in [17] shows that the public perspective varies from person to person in the application of nanotechnology in food production, by examining a group of respondents and got the result as, around 30% of them supported the benefits of nanotechnology in food industry over its risks, 44% responds that the benefits and risks can coincide and around 26% respondents alleged that the benefits of nanotechnology is less when compared to its risks. Nanotechnology can be applicable in food industry in several

stages including the food packaging, food quality evaluation, food safety, food tracking and counterfeiting, functional food development and smart delivery system.

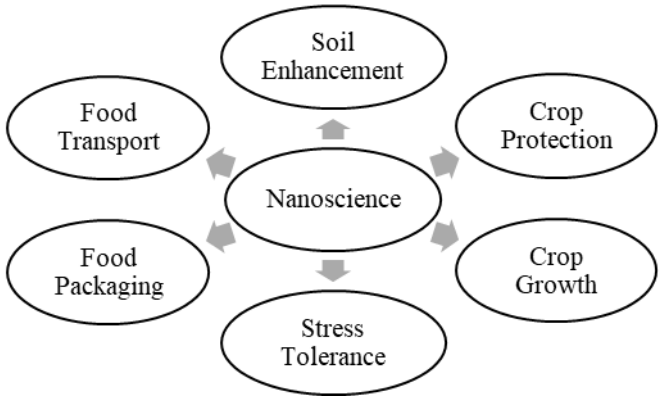

Fig 1: Applications and Perspectives of Nanoscience in Food and Agriculture

The proper food packaging should be a greater concern which relates to food spoilage and deterioration from environmental factors and food safety in storing and transporting the food. Different properties of packaging material can be formed using nanoparticles with distinct physical and chemical properties. Nanocomposites used for food packaging that are made from layered silicates and nanoclays can perform various functions, enhance the mechanical and barrier properties and are highly stable and degradable when compared to the conventional packaging materials. The carbonation of beverages can be maintained for around 30 weeks by manufacturing the polyethylene terephthalate (PET) bottles using clay nanoparticles, which can reduce gas permeation rate and oxygen ingress. Nanolaminates that are made of polysaccharides, lipids, proteins and colloidal particle have the ability to maintain the food acceptability and can used in the shelf-life period extension. This laminate is edible and can be used as an outer coat in various fruits, vegetables, meat, baked items, candies and chocolates to enhance the flexibility and rigidity by being an active barrier against oxygen and carbon dioxide. Nanocomposites are made from the starch with poly-β-hydroxyl octanoate and nanoclay. It can have higher barrier and strength over water vapor. It also can improve the shelf-life of several perishable vegetables and fruits by absorbing ethylene gas that are produced from respiratory food. Nanoscience can be involved in the manufacturing of biodegradable plastic materials for packaging which can be of light-weight and have more thermal stability and barrier protection.

Food preservation is an important factor in the prevention of food from getting spoiled. Nanosensors can be used to detect the physical, chemical and microbial contamination of food. There has been introduced low-cost nanosensors for the detection of variation in food

quality from food storage and transport. An electronic tongue has been introduced to detect visible change in color whenever there is an environmental change in the packaging. This electronic tongue is made from large number of nanoparticles which are of sensitive towards the variations in staling of fresh food in the sense that it is highly taste sensitive comparing with human tongue. The electronic nose made from nanowires are associated with gas sensors so as to detect variations in the odor of food inside the packages. Nanofabricated glucose biosensor is used to detect the quantity of glucose in food and the nanofabricated liposome nanoparticles is used to detect the quantity of allergenic protein in food. Microfluidic nanosensor is a device made with silicon is employed in the detection of food contaminated by pathogens. Detecting the pesticide and heavy metal residue are the crucial factors of food quality evaluation, as they can cause acute toxicity and adverse effects towards the health of humans and environment. Nanosized particles of TiO2 and methylene blue dye are applied to develop a fluorescent indicator ink that can detect the concentration of oxygen in food packages and can be applicable for detecting the changes in the condition of packages based on the atmospheric condition. Nanobeds with fluorescent dyes can detect changes in carbon dioxide inside the packaging in variable atmospheric conditions.

Product packaging is a coordinated system which safeguards the goods delivery and marketing to the consumers with a safe and acceptable condition and also ensures that no modification of products had been happened which leads to counterfeiting. Nanotechnology is now used in the tracking of food products inside a package so as to avoid tampering and to ensure the protection of the product, so as to prevent recalling from market. The nanobarcodes used in the products consists of each and every information regarding that product, which makes the produces to supervise the product supply chain and also the product can be tracked for infringements. The Radio Frequency Identification (RFID) also called as nanotag devices can be involved in reading the parameters like humidity, temperature and ambient gas concentration while transiting and storing a product, which can help the manufacturers, retailers, suppliers and consumers of the supply chain regarding the quality, safety and freshness of food[Nomani MZM. (2019). The access and benefit-sharing regime: An environmental justice perspective. Environmental Policy and Law, 49(4-5), 259-263; https://doi.org/10.3233/EPL-190172.]. The nanodisks made from gold and nickel integrating the chromophores, when hit by laser, reflects a light spectrum which can be able to detect the DNA and food adulteration. A technique called “Dip pen nanolithography” makes use of a scanning probe which when dipped in some modified ink, can encrypt the information about the processing conditions or batch number on food or its packaging. The information related to the climatic and soil conditions are also encrypted into the product so as to secure highly from recalling the product from markets that are with issues regarding the agricultural origin of a product.

The encapsulation of functional bioactive compounds, probiotics, antioxidants, flavors, ω-6 fatty acid, ω-3 fatty acid and phytochemicals with the help of nanoengineered materials

enhances the pace of development and processing nutraceuticals and functional food. These products consist of improved potency, texture, taste and aesthetical appeal. Also, this technology can maintain the stability and integrity of those sensitive compounds over degradation in processing and storing the food products. Lipid-based nanoencapsulation has more stability over environmental stress and higher bioavailability in gastrointestinal tract. Functional beverages consisting of vitamins A, D, D3 and K, phytosterols, lutein, lycopene and β-carotene are developed by sing Aquanova and Nutralease with more advantages and increased shelf-life. Liposomes are closed single or multi-layered vesicles made up of lipids/phospholipids and an aqueous phase are applied as carriers of the functional ingredients in food products. The nanoencapsulation made of lipophilic compounds like β-carotene, oil-soluble vitamins, flaxseed oil, citrus and coenzyme Q proves to be having better digestibility, since the nanoparticles are transported rapidly via epithelial cells and provides way for better absorption because of the improved solubility.

The food delivery systems based on nanotechnology, which includes nanoemulsions, nanocochleates, dispersions, associated colloids and micelles delivers encapsulated ingredients directly against the site of action, which in turn controls the rate of release under specified environmental triggers like variations in pH, charge and solubility. This system can offer protection against the physical and chemical degradation. The system called “Nanodrop” successfully delivers the functional components with enhanced absorption. Emulsions that are made with the help of nanoscience have much stability and novel properties of delivery of food, as it is of smaller size and possess more surface area in comparing with the conventional emulsions[Nomani MZM, Hussain Z. (2020). Innovation technology in health care management in the context of Indian environmental planning and sustainable development. International Journal on Emerging Technologies, 11(2), 560-564]. The nanoencapsulation can also benefit in masking and enhancing the color, taste and attractiveness of several food products. The nanoemulsions are made from a process of high-pressure homogenization to develop and adsorbed film of surfactant at the liquid-to-liquid interface of continuous and dispersed phases. the dispersed phase droplets of nanoemulsions with diameter from 50 to 100 nm are called as true emulsion. Associated colloids are involved in the encapsulation of non-polar ingredients into hydrophobic core made up of surfactant micelles or vesicles. Nanocochleates based delivery system can be applied in the encapsulation of hydrophobic compounds into lipid bilayers.

3 Implication of Nanoparticles in Human Health and Environment

Whenever any of the nanoparticle are taken into consideration, it would definitely have some adverse or contrasting or toxicological effects along with the benefits. This is because, after several researches, it is concluded that the nanoscale products differ drastically in its physical and chemical properties and has unexpected behavior. There are a lot to study about the interaction of living organisms, environment with engineering nanoparticles [18]. The nanotechnology used in food industry also has some adverse effects on social, environmental and health, since the nanoparticles are believed to enter into the ecosystem via pesticide delivery or via processed foods, which increases the toxicity of using it [19]. Nanoparticle migration from the food packaging materials and the behavior of entering nanoparticles into human body are not yet revealed completely and are still under the study [20].

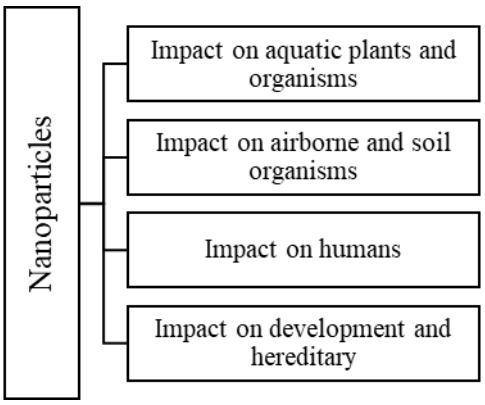

Fig 2: Safety and Challenges of Nanoparticles

The risk of nanoparticles is because of their high-reactivity and bioavailability, which in turn causes a long-term pathological effect. The entry of nanomaterials into the food chain is by its direct incorporation in food through nanocapsules, nanoemulsions and nanoantimicrobial films, and by using them in manufacture of food, food processing, preserving and tracking the food packages by using nanolaminates and nanosensors[Nomani MZM, Parveen P. (2020). Prevention of chronic diseases in climate change scenario in India. Environmental Justice,13(4),97-100; https://doi.org/10.1089/env.2019.0032]. The exposure of human to the nanoparticles will be based on the area in which the nanomaterials are used in food industry and its concentration with a higher risk if they are directly added in food products as the carrier of ingredients. Nanoparticles also increases the risk of humans being subjected to oxidative stress to body cells and can passes from lungs to blood, cell nucleus and central nervous system (CNS) which can cause inflammation in gastrointestinal tract, Alzheimer's disease, Parkinson's syndrome and DNA impairment. Also, nanoparticles when subjected long-term exposure results in adverse effects on kidney, liver and other vital organs. The interaction of nanoparticles with biomolecules and organells forms bio-corna which affects the cells negatively causing immunotoxicity, genotoxicity and cell death. It can also alter the epigenetics due to DNA methylation, histone modification and post-transcriptional changes of gene expression which are then transferred to future generations. The use of silver nanoparticle can damage the cell membranes, chromosomes, and DNA as they enter into intestinal mucus barrier and has an increase in the generation of ROS. The

silver nanomaterial even exposed in a low concentration also causes more toxicological effects and when exposed in a higher concentration, it results in damage of cells abnormally, apoptosis, shrinkage and skin cancer.

The increase in the use of nanoparticles in various sectors leads to extensive exposure of nanoparticles to environment, which will definitely traverse to the aquatic and terrestrial ecosystems. The nanoparticles can be released to the environment by any of the following ways, they are the natural way, unintentional way or intentional way, which are explained further[Nomani MZM, Rauf M. (2019). Legal policy for bio prospecting of natural resources in India. Indian Journal of Environment Protection, 39(11),1009-1015]. The natural way of releasing the nanoparticles into the ecosystem includes the volcanic eruption, soil erosion, forest fire, dust storm, clouds and ocean spray. The unintentional way of releasing nanoparticles into the ecosystem includes the welding, fossil fuel burning industrial waste, mining, smoking, vehicle exhaust and metal smelting. The intentional way of releasing the nanoparticles into the ecosystem are not yet documented. The ecotoxicity of nanoparticles are related to the physico-chemical properties of the nanoparticles.

Conclusion

It is well known that each and every invention or development has several benefits and also has its own shortcomings. But when they are related to food products, then it causes a serious issue. Eventhough the nanoparticles have many advantages and benefits; it also shows some adverse effects in the health of humans and in environment. As the health conscious and the knowledge towards health are going on increasing in the today's world, several studies have been carried out in finding the safer nanomaterial that can enhance the quality of the environment and human lives. Also, some of the nanoparticles are confirmed to have ho harmful effects of toxicity towards humans. In this paper, some of the studies that estimates the interaction of nanoparticles with agriculture and food systems are evaluated and contributed the effects of those nanomaterials towards food safety, security, packaging, storing, transporting and food tracking mechanisms. Also, in this paper, the implications of nanotechnology in human and environmental health are described.

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