REVIEW ARTICLE

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Nanotechnology: A new frontier in Agriculture

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Abstract

Nanotechnology is science of manipulating materials at nano-scale. Among the latest technological advancements, nanotechnology occupies a central position. It has many applications in all stages of production, processing, storing, packaging and transport of agricultural products. The reduced use of herbicides, pesticides and fertilizers with increased efficiency, controlled release and targeted delivery will lead to precision farming. Dream of automated, centrally controlled agriculture can become reality now. Modern agriculture is need of hour because conventional agricultural will not be able to feed an ever increasing population with changing climate, depleting resources and shrinking landscape. But at the same time application of nano-materials in agri-food sector has to be evaluated for public acceptance so it does not come across a scenario as faced by GMOs in past. This article provides an overview of current and potential applications of nanotechnology in agriculture and food sector.

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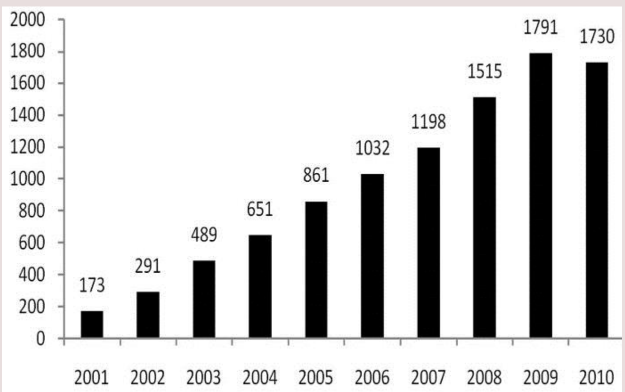
Introduction

Thanks to nanotechnology that the future food will be designed according to consumer's choice with a better taste, texture, nutrient contents and a longer shelf life. It can offer compelling value and prove to be the "the next big thing" in future agriculture. The food will be wrapped in "smart" safety packaging that can detect contaminants and spoilage agents.

Nanotechnology is a novel, innovative, interdisciplinary scientific approach that involves designing, development and application of materials & devices at molecular level in nanometre scale i.e. at least one dimension ranges in size from 1 to 100 nanometres [1], a billionth of meter. It is a broad spectrum emerging field of science which has brilliant applications in basic and applied sciences. It will leave no field untouched by its captivating scientific applications and agriculture sector is no exception. The first decade of 21st century witnessed an enormous increase in nano-food market. Science Citation Index Expanded through 2001-2010 shows that there is a steady growth in this field. Graph 1 indicates an exponential increase in research publications in field of nanotechnology [2].



Graph 1: number of scientific publications in the field of nanotechnology during the last decade (2001-2010) [2].

The use of nanotechnology in agriculture is getting importance because it is possible advantages vary from enhanced food values, reduced agricultural inputs, improved nutrient contents and longer shelf life.

For developing countries, agriculture sector is backbone of their economy including more than 60% of the population which depends upon agriculture to earn their livelihood directly or indirectly [3-5]. But even in 21st century it has to deal with concerns like sustainable use of natural resources, depleting nutrients in soil and environmental issues like runoff and accumulation of fertilizers and pesticides. So, the key is to adopt such a technology that can shape the modern agriculture in a more productive fashion that would ultimately lead to precision farming in a cost-effective way with the delivery of just the right amount of input at the right time [6]. Among the latest line of technological innovations in the field of agriculture, nanotechnology occupies a distinguished position in remodelling agriculture and food production to fulfil the demands in an efficient and cost-effective way [3,7].

Following is a glimpse of some potential applications of nanotechnology in agriculture and food production. There are numeral applications of nanotechnology in this particular field, but these are mostly at the bench-top exploration stage. However, it is very likely that in the near future these would be part and parcel of precision farming.

Methods

Search Strategy and Selection Criteria

A systematic search was carried out from, Google Scholar, Google Web Browser, PubMed Central and PubMed by providing key terms "bio-nanotechnology", "nano-herbicides", "nano-pesticides", "applications of nanotechnology in agriculture" "nano-encapsulation", and "nanotechnology in food packaging" with no filters. Found literature against these searches was further screened for inclusion according to their contents and year of publication. Mostly scholarly articles published during 2000-2011 were included in this review study. Exceptions were made for some papers not falling in the above mentioned category based upon their significant data and relevance to the topic. In this study, 60 peer reviewed research articles were selected.

Discussion

Nano scale carriers

These are "smart" nano scale devices which can be deployed for the efficient delivery of fertilizers, herbicides, pesticides and plant growth regulators etc. The nano scale carriers are designed in such a way that they can anchor the plant roots to the surrounding soil and organic matter. Hence leading to improve stability against degradation in the environment and ultimately reduce the amount to be applied [8,9].

Nano-pesticide

Plant pests are major factors in limiting crop yields. Conventional pest controlling methods include the use of over-the-counter pesticides in large quantity which consequently add an additional cost in crop production. Excess amount of pesticides also cause environmental and water pollution. There is a need to use as much as minimum amount of pesticides to save the environment and reduce the cost in crop production[10]. It can be achieved by increasing the retention time of pesticides with required efficiency. Persistence of pesticides in the initial stage of crop growth helps in bringing down the pest population below the threshold level, leading to an effective control for a longer period of time.

A nanotechnology approach, "nano-encapsulation" can be used to improve the insecticidal value. In nano-encapsulation technique the nano-sized active pesticide ingredient is sealed by a thin walled sac or shell (protective coating). The efficacious approach in this regard is "controlled release of the active ingredient" that would greatly improve effectiveness and decreased amount of pesticide input and associated environmental hazards. For example "Halloysite" (Clay nanotubes) have been developed as cost effective carriers of pesticides. These will greatly reduce the required amount of pesticides as having extended release time and better contact with plants, reducing the cost of pesticides up to a great extent with minimum impact on environment [11]. Another improvement in this sense might be the availability of nano-structured catalysts which will increase the efficiency of pesticides and insecticides and also reduce the dose level required for plants [12].

Liu *et al.,* has reported that Porous hollow silica nanoparticles (PHSNs) stacked with validamycin (pesticide) can be effectively used for controlled release of pesticide [13]. Nano-silica has already been experimented to control agricultural insect pests. Physiosorptipn is mode of action of nano-silica. It gets absorbed through insect cuticular lipids hence leading to insect's death by physical means [14].

Syngenta has launched a nano-encapsulated broad spectrum pesticide marketed under the name of Karate® ZEON to control insect pests of cotton, rice soybeans and peanuts.

The active ingredient of this product is a synthetic insecticide lambda-cyhalothrin which is released on contact with leaves. Another functional nano-insecticide under the name “gutbuster” releases its contents when exposed to alkaline environment such as insects stomach [15].

Nano-herbicides for effective weed control

Weeds are big hazard in agriculture, they reduce the yield up to a great extent. So there is no other option except eradicating them. Nanotechnology has potential to get rid of weeds by using Nano-herbicides in an eco-friendly way, without leaving any toxic residues in soil and environment [16]. Less amount of herbicide will be used if active ingredient is combined with a “smart” delivery system. Having size in nano dimensions, these will blend with soil particles and prevent the growth of weed species that have become resistant to conventional herbicides. Herbicides available in the market are designed to control or kill the above ground part of the weed plants. None of the herbicides inhibit activity of viable underground ground plant parts like rhizomes or tubers, which act as a source for new weeds in the ensuing season.

Developing a target specific herbicide molecule encapsulated with nano particle is aimed for specific receptor in the roots of target weeds, which enters into roots system of the weeds and translocated to parts that inhibit glycolysis of food reserves in the root system ultimately making the specific weed plant to starve for food and gets killed.

Detoxification of weed residues is necessary as excessive use of herbicides for longer period of times leaves residues in soil and causes damage to succeeding crops [17].As well as continuous use of same herbicide for persistent period of time leads to evolution of weed resistance against that particular herbicide. Up to 88% detoxification of a herbicide ‘’atrazine’’ by Carboxy Methyl Cellulose (CMC) nano particles has been reported [18].

“Smart dust” (Smart mini laboratories)

This is the future of agriculture, an army of nano-sensors will be scattered like dust across the farms and fields, working like the eyes, ears and noses of the farming world. These tiny wireless sensors are capable to communicate the information they sense. These are programmed and designed to respond various parameters like variation in temperature, humidity and nutrients [19]. The distributed intelligence of smart particles can be networked to respond immediately to any change in environment, hence giving an alert in advance to devise ways and means to deal with environmental variations [20]. By smart dust and gas sensors it is possible to evaluate the amount of pollutants in the environment [21]. The most efficacious approach in this sense is real time detection of parameters by the use of autonomous sensors connected to global positioning system (GPS) [15].

Disinfectants

It is estimated that 30 to 40% of the food produced on earth goes to waste before it can be consumed. The situation is even worse in case of fruits and vegetables. These losses can be reduced up to great extent by increasing the shelf life of perishable commodities. Nano- particles can also be used as disinfectants in food packaging and food engineering to increase the shelf life of food products.

The mechanism of action is as that extreme little size of nano particles causes emissions of excited electrons. These can be used as disinfectants for bacteria, the major agents in food contamination. These excited electrons from nano-particles are injected into bacterial bodies which results in bacterial removal from the concerned objects especially in food processing and packaging [22]. Studies have indicated that ENPs of C_{60} aggregates showed inhibitory effects for *Escherichia coli* and *Bacillus subtilis* [23]. ENPs of Ag were found toxic to *Staphylococcus aureus* and *Bascillus subtilis* [24]. The same Ag nanoparticles when biosynthesized by fungi showed toxic effects against fungal species like *Aspergillus niger* [25]. Presence of bacteria in food material can also be detected by using quantum dots (QDs). These have proven to be more effective as compared to conventional staining dyes with outstanding photostability and luminescence [26]. Initiative has already been taken in this regard as QDS were used as fluorescence marker for efficient detection of *E. coli* O157:H7 [41]. Also, *Bascillus* species labelled with nano-particles of ZnS and Mn2+ covered with 'chitosan' a linear polysaccharide gave an orange colour luminiscence under fluorescence microscope [9].

Nanoparticles in crop improvement

There are numerous reports revealing the use of nano-particles in crop improvement. Mostly carbon and metal-oxides based engineered nano-particles have been subject of studies [27]. Khodakovskaya (2009) has reported the effect of penetrated carbon nanotubes (CNTs) in tomato seeds as their germination efficiencies increased several times. The water uptake ability of CNTs enhanced the seed germination dramatically [28]. Ti02 nano-particles have been found to accelerate spinach growth by enhancing Rubisco activase activity and improving light absorbance [29,30]. Nano-particles of TiO2 improved spinach growth by enhancing nitrogen metabolism [31]. DeRosa *et al*, reported that ZnO nano-particles showed inhibition of seed germination in corn and rye grass. But these left porous domains in plant roots, hence letting a potential nutrient delivery system to be explored [32]. Silicon NPs are absorbed by plants and they lead to increased disease and stress resistance [33]. A product by Syngenta under the brand name Primo MAXX® is being used as plant growth regulator, it allows turfgrass to withstand against drought, heat and disease stress.

Nano lamination

Other significant factors include moisture, gases and lipids accumulation that cause the food to be perished. To protect the food from these agents, another workable option is nano-lamination. Nano-lamination is applied by coating foods with nano-laminates or simply by spraying it on the food surface. Along with preservation of food they can improve the texture, preserve flavour and colour of the food [34]. Nano-laminates are thin, harmless food grade protective films which are prepared from edible polysaccharides, proteins, and lipids [35]. These have proven to be a good barrier against carbon dioxide and oxygen. While against moisture lipid based nano-laminates are effective protectors. Predicala, (2009) has reported another improvement in this field as nano-coatings have been used to prevent fruits from weight loss and shrinkage [36].

Food packaging

It is always consumer's choice to demand fresh, safe and healthy food with longer shelf life, and easy to handle packaging material [17]. Conventional food packaging materials are difficult to degrade and cause serious waste problems as solid waste material. Although biomass based material has been deployed in food packaging but challenge is still there about their performance and cost effectiveness [37,38]. Incorporation of nano-materials in packaging biopolymers like cellulose and its derivatives polyesters [39], plant oils and gelatins [40,41] have proven to provide necessary mechanical strength, better reinforcement and barrier properties [42]. Choudalakis et al, (2009) has reported that polymer nano-composites have shown tremendous potential as barrier against gases (e.g., O2 and CO2) and water vapours [42]. The ground breaking in this field has already been made as Yano et al. and Rhim *et al.* have developed different kinds of clay composites with reduced water vapour transmission rate (WVTR) and relative permeability [42-45]. Thermoplastic starch (TPS)/clay nano-composite films have also been developed with remarkably fine dimensions and encouraging results [46]. Nanocomposites such as nylon 6 have also been prepared to obtain lighter, stronger plastics with better heat resistance and barrier properties[47]. Nano-clays and silicates like montmorillonite, hydrated alumina-silicate layered clay have been successfully used in food packaging [48]. Along with better mechanical and barrier properties nano-clays have shown increased thermal degradation temperature and glass transition [49-51]. Carbon nanotubes (CNTs) like polyamide [52], polyvinyl alcohol [53], polypropylene [54] are also being deployed in food packaging. An outstanding achievement is development of "electronic tongue" by Kraft foods. It is actually an array of nanosensors which change colour by the release of gases as the food spoils thus giving a clear indication whether the food is fresh or not. These nano-sensors are included in the food at the time of packaging [55] nano barcodes can also be used for monitoring and tracking of food [56]. Scientists at Cornell University developed fluorescent based nano barcodes containing probes for detection of various farm pathogens. A site detector can be used for pathogen detection even by non-trained individual [57]. Same is the concept of "electronic nose" (E-nose), operating like human nose in detection of odour and concentration of odorant in food. It contains nano-particles of gas sensors mainly ZnO. The mechanism of action is based on resistant pattern of different gases as each gives different detection signals [58].

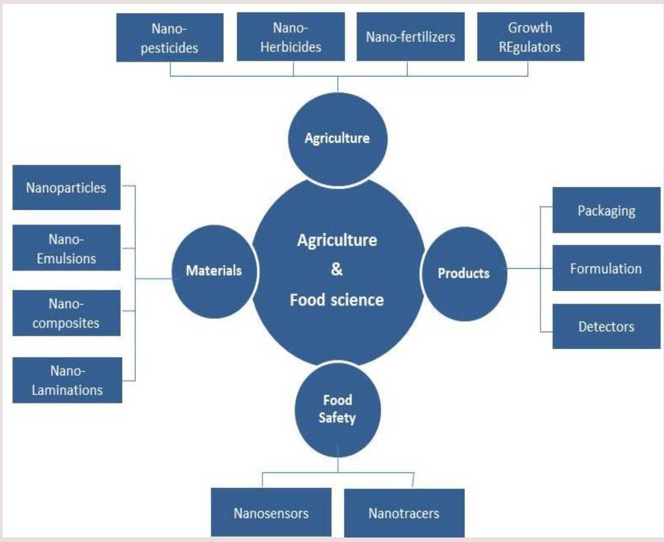


Figure 1: A pictorial demonstration of applications of nanotechnology in agri-food sector

Conclusion

Agriculture in 21st century faces diverse challenges to produce more food and fibre to feed a growing population with a smaller rural labour force, changing climate and urbanization. These problems will further get intensify when we would have to feed over 9 billion population by 2050. Hence, there will be an additional demand for agricultural products. Especially in developing countries with higher populations, the raw materials will soon be viewed as the foundation of commerce and manufacturing [59]. To deal with this scenario, agriculture dependent countries have to adopt more efficient methodologies, labour saving and sustainable production methods.

In agriculture sector, Nanotechnology has phenomenal potential to facilitate and frame the next stage of precision farming techniques. It will increase agricultural potential to harvest higher yields in eco-friendly way even in challenging environment [60]. Globally many countries have recognized the potential of nanotechnology in the agri-food sector and are investing a significant amount on it. The adoption of nanotechnology would play a crucial/ unparalleled role to feed the ever increasing population with declining natural resources.

But at the same time one has to be cautious about public acceptance of this novel technology. The outlook of nanotechnology in agri-food sector is still vague keeping in mind the unconstructive public response in case of GMOs. Whatever the impacts of nanotechnology are on the food industry and products entering the market, the safety of food will remain the prime concern. It is need of hour to inform public at large about its potential advantages at each step which will result in tremendous increase in public interest and acceptance. It is also critical to produce a trained future workforce in nanotechnology. Extensive studies are required to understand the mechanism for nano-materials toxicity and their impacts on natural environment. If we overcome these considerations, the bright and beneficial future is at doorstep of developing nations.

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