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Nanotechnology a novel approach to enhance crop productivity

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ABSTRACT

Nanobiotechnology provides novel set of tools to manipulate and enhance crop production using nanoparticles, nanofibres, nanoemulsions, and nanocapsules. Nanomaterials provide a platform to deliver agrochemicals and various macromolecules needed for plant growth enhancement and resistance to stresses. Smart delivery of agrochemicals increases the yield by optimizing water and nutrient conditions. Another added advantage is controlled release and site-directed delivery of agrochemicals. Further enhancement in quality and quantity in agriculture can be achieved by nanoparticle-mediated gene transformation and delivery of macromolecules that induces gene expression in plants. Various types of nanomaterials have been tested so far and the results have been promising in terms of productivity and quality enhancement.

1. Introduction

The present century is facing a major challenge of how to feed the constantly growing human population. According to McCalla [1], world human population could reach eight billion by 2025. Most of the population of the world is directly or indirectly dependent on agriculture. A conventional method to enhance food production includes use of chemicals like pesticides and fertilizers. A great variety of pesticides are used to combat biotic stresses in agriculture but these have a major side effect on crop quality and soil health. Delivery of large amounts of fertilizers, in the form of ammonium salts, urea, nitrate or phosphate compounds leads to deterioration in the soil quality [2]. Much of the chemical fertilizers applied to plants are not absorbed by plants and lost as run-off causing water pollution. Indiscriminate use of fertilizers, pesticides, herbicide results in depletion of nutrients and fertility of the soil [3]. Agriculture sector is the backbone of developing countries. So, there is a dire need to develop a technology that can enhance the modern agriculture in a more productive, cost-effective and eco-friendly way. Various eco-friendly methods like biopesticides and bioinsecticides are already in use to control pests by non-toxic mechanism.

Nanotechnology is an innovative, novel and scientific approach that leads to design, manipulation and development of useful nanomaterials. Nanotechnology generates materials in nanometer scale ranging in size from 1 to 100 nm (nm). Due to the small size, the ratio between surface area and volume is increased in the nanomaterials (compared with bulk forms), improving the biochemical reactivity and conferring unusual and valuable physical properties. It is a potential rising field of science which has brilliant applications in basic and applied sciences (Fig. 1) [4]. The use of nanotechnology in agriculture is increasing rapidly to enhance food values, reduced agricultural inputs, improved nutrient contents and longer shelf life. Many nano-agricultural products are now developed to reduce the use of toxic chemicals. Nanotechnology includes many aspects of food security, disease treatment, new tools for pathogen detection, effective delivery systems and packaging materials [5]. A variety of nanomaterials like nanopesticides, nanoinsecticide, nanoemulsions, and nanoparticles were developed using nanotechnology (Table 1). A variety of materials are used to develop and coat nanomaterials, such as metal oxides, plant extracts, ceramics, silicates, lipids, polymers and emulsions (Fig. 2) [6]. Surface coated nanomaterials or nano-coated fertilizer particles hold the material more strongly to the plant due to higher surface tension than conventional surfaces. Moreover, nanocoatings provide surface protection for larger particles. A nanocapsule is composed of a shell that contains an active compound, like a chemical or biological agent for the protection of plant against pests and diseases. The shell consists of different elements, such as lipids, polymers, viral capsids or nanoclays.

The capsid of the virus is the protein coat protecting the nucleic acid inside and size of ranges from 30 to 140 nm in some viruses, so they are robust and show interesting features as carriers and delivery systems. In *in vitro* conditions capsid protein self-assemble into stable viral-like particles and can change their shape and size according to external factors, such as pH, leading to open or closed nanopores allowing for the

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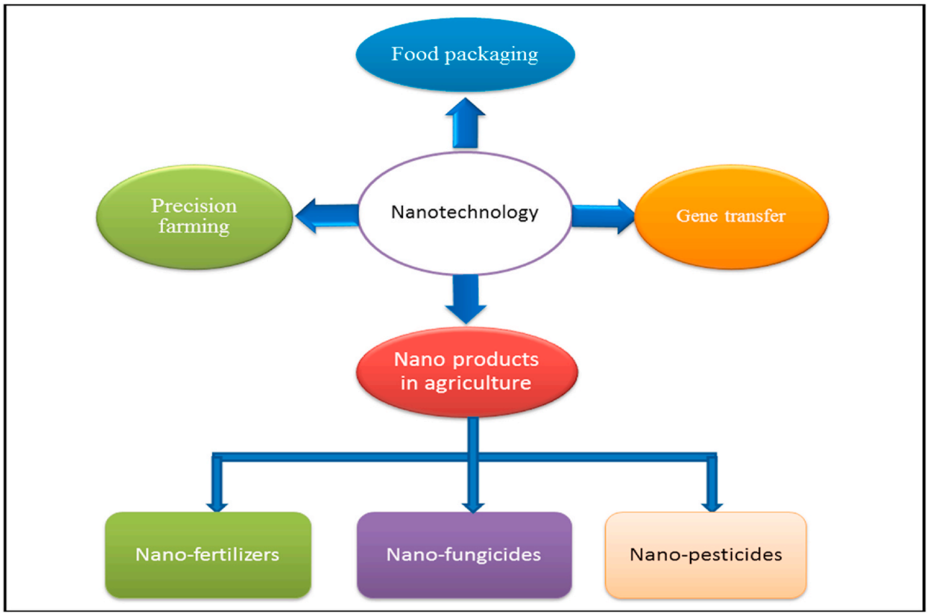

Fig. 1. Nanotechnology applications.

Table 1
Relevant agricultural applications of nanotechnology.

Products	Applications	Examples	References
Plant protection products Fertilizers	Nanocapsules, nanoparticles, nanoemulsions and viral capsids as smart delivery systems of active ingredients for disease and pest control in plants Nanocapsules and nanoparticles enhancement of nutrients absorption by plants and the delivery of nutrients to specific sites.	Neem oil (*Azadirachta indica*) nanoemulsion as larvicidal agent Macronutrient Fertilizers Coated with Zinc Oxide nanoparticles and NPK controlled delivery Nano-coating of sulfur using Chitosan Nanoparticles	[24] [25] [26]
Soil improvement	Water/liquid retention: Nanomaterials, e.g. zeolites and nanoclays, for water or liquid agrochemicals retention in the soil for their slow release to the plants	Soil-enhancer product, based on a nanoclay component, for water retention and release	[27]
Genetic material delivery	DNA	Gold (10–15 nm) Gold (5–25 nm) Starch (50–100	[28] [29] [30]
Nanosensors and diagnostic devices	Nanomaterials and nanostructures (e.g. electrochemically active carbonnanotubes, nanofibers and fullerenes) that are highly sensitive bio-chemical sensors to closely monitor environmental conditions, plant health and growth	Pesticide detection with a liposome-based nano-biosensor	[31]

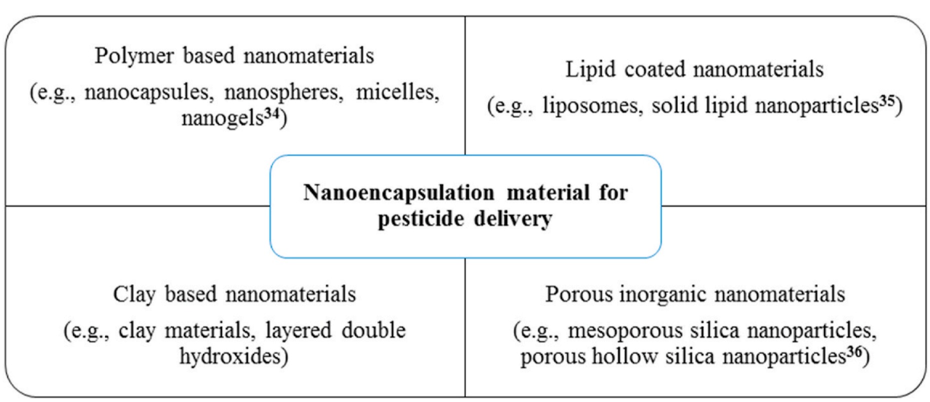

Fig. 2. Nano encapsulation Ref. [34–36].

entry or release of substances. Furthermore, alteration of the surface properties of the viral capsids can be used for coating agricultural chemicals in order to generate new nanomaterials [7]. The main function of nanocapsules is to protect the active compound until it is released; it also improves the solubility and the penetration of the compound into the plant tissues. Depending on the specific characteristics of the shell, the active compound can be released slowly and gradually or completely after the shell opens. The opening can be achieved by pH change or enzymatic degradation. Nanoparticles have a solid core or a matrix that is composed of different materials (such as metals or polymers) and is surrounded by linkers and biomolecules [8].

2. Nanotechnology potent applications

2.1. Nano-pesticides

Pesticides are compounds that are used to control pests and pathogens. The term pesticide includes the following chemicals like herbicides, insecticides, nematicides, molluscicides, rodenticides, bactericides, antimicrobials and fungicides to control biotic stress agents. They also include disinfectants, sanitizers and repellants [9]. These chemicals control pathogen, pests, weeds and herbivores. Pesticides can cause acute and delayed deleterious health effects in humans also. Pesticide exposure can cause irritation of skin and eyes in animals. It can also affect nervous system, mimic hormones causing reproductive problems and also cause cancer. Pesticide use raises a number of environmental concerns. About 95% of herbicides and 98% of insecticides are sprayed on crops that reach destinations other than their target species, including non-target species, air, water, and soil [10]. Thus causing loss of biodiversity, water pollution, air pollution and soil contamination [11].

Excessive use of pesticides leads to resistance against them (pesticide resistance), resulting in search of new pesticides which are more strong, potent and dangerous not just to the pest but to human and environment also. Nanotechnology has the potential to reduce the amount of use of these active compounds to save the environment and reduce the cost in crop production. "Nano-encapsulation" can be used to improve the insecticidal assessment. In nano-encapsulation method, the nano-meter size active pesticide ingredient is encapsulated by a thin-walled sac [12]. The successful approach in this regard is "controlled release of the active ingredient" that would greatly improve efficiency and reduce the amount of pesticide input and related environmental hazards.

2.2. Nano-herbicides

Continuous use of herbicides results in development of resistance in weed towards that particular herbicide [13]. Nanotechnology has the potential of targeted and concise delivery of nano-herbicides to weeds in an eco-friendly manner, without leaving any active compound in soil and environment. Carboxy methyl cellulose (CMC) nanoparticles have been reported as future nano-herbicides [14].

2.3. Nano-insecticides

Food is a basic need for rapidly growing human population and subsequent worldwide demand for food has urged for a better protection of agricultural crops from infestation by different insects. Compared to bulk substances, nano-insecticides have following advantages such as enhanced efficiency of natural and chemical insecticides by controlled release, less environmental contamination due to reduced rate of application, easy and safe handling, more susceptible to photo degradation and less toxic to non-target organisms compared with bulk. Polymer-based nano formulations have been exploited for the encapsulation of most of the insecticides.

Different kinds of polysaccharides such as chitosan, alginates, starch and polyesters (e.g., poly-ε- caprolactone and polyethylene glycol) have been considered for the synthesis of nano-insecticides [17]. Different forms of polymer and non-polymer based nanoformulations like nanoparticles [18], nanofibres, nanogels, nanosphere, micelles, nano-emulsions, and nanocapsule have been exploited for encapsulation of insecticides [12]. Among these, nanocapsules are by far the most widely used for controlled release of insecticides. Nanoformulation of many natural insecticides (e.g. neem oil) is also used [19]. Currently increasing awareness of environmental pollution leads to the sophisticated use of biodegradable and biocompatible polymers of natural origin over the synthetic ones for encapsulation.

Table 2
Nanobionics applications.

Nanoparticles in nanobinics	Applications	References
SiO_2 nanoparticles	Enhance the photosynthesis rates by improving activity of carbonic anhydrase (supplies CO_2 to Ribulose 1, 5-bisphosphate carboxylase-RuBisCo) and synthesis of photosynthetic pigments.	[32]
TiO_2 nanoparticles	Enhance the photosynthetic carbon assimilation by activating RuBisCo. Enhancement of RuBisCo carboxylation with high rate of photosynthetic carbon reaction as a result of nano-anatase induced marker gene for RuBisCo activase mRNA, enhanced protein level, and activities of RuBisCo activase.	[24]
Cerium oxide nanoparticles (nanoceria)	Inside chloroplasts (*in vivo)* augments ROS scavenging and photosynthesis of *Arabidopsis thaliana* plants under excess light	[33]

2.4. Nanobionics

A diversity of nanomaterials mostly metal-based and carbon-based are been exploited for their absorption, translocation, accumulation and promotory effects on growth and development in crop plants. A number of positive effects have been shown by many crop plants. Enhancement of various physiological parameters such as enhanced photosynthetic activity and nitrogen metabolism using metal-based nanomaterials has also been reported in soybean, spinach and peanut [15,16]. Photosynthesis is the process by which plants can convert solar energy into chemical energy in food supplies and carbon-based fuel. Approximately, 100 TW energy is captured by photosynthesis from sunlight that is six times higher than the power consumption need of human civilization [20]. Nanobionics or the application of nanoparticles for enhancement of functions of pant cell organs by studying the electronic interactions in biological systems is fast gaining momentum (Table 2).

The interaction of plant cell organelles and nanoparticles is endowing enhanced native functions to cell leading to a new field of nano-bioengineering. There have been a number of studies that have shown enhanced photosynthesis by use of nanomaterial like SWNTs (single-walled carbon nanotubes). SWNT-chloroplast assemblies have shown a higher rate of leaf electron transport *in vivo* through a mechanism consistent with augmented photo-absorption. Plasmon resonance of metal nanoparticles can increase the absorption of solar energy and lead to enhance carbon fixation [21]. However, the deleterious effect of nanomaterial's if any has to be assessed and taken care before their wide application for sustainable development.

2.5. Nanobiosensors

Nanotechnology has led to the development of nanoscale biosensors that have exquisite sensitivity and versatility. The sensors based on nanomaterials can be very versatile in terms of their sensing, detection, and monitoring. They allow the detection of contaminants such as pests, microbes and abiotic plant stresses due to drought, temperature or lack of nutrients [22,23]. These nanosensors could be distributed throughout the field where they can monitor soil conditions and crop growth. Nanoparticles or nano-emulsions can be engineered to trigger a chemical or electrical signal in the presence of a contaminant such as a bacterium. Ultimately, precision farming, with the help of smart sensors can lead to enhanced productivity in agriculture by providing accurate information, thus helping farmers to make better decisions. The ultimate goal of nanobiosensors is to detect any biochemical and biophysical signal associated with a specific stress at the level of a single molecule or cell.

3. Conclusion

21st century is facing many challenges in agriculture sector to produce more food to feed a growing population with a smaller rural labor force, changing climate and urbanization. These problems will further escalate when we would have feed over 9 billion population by 2050. Hence, it is essential to improve the yield of agricultural products in a sustainable way. Mainly in developing countries with higher populations, the raw materials from agriculture will soon be viewed as the foundation of commerce and manufacturing. To deal with this scenario, agriculture-dependent countries have to adopt more efficient methodologies, minimize labor force and sustainable production methods. Nanotechnology has the potential to increase agricultural efficacy to harvest higher yields in an eco-friendly way even in harsh environment. Worldwide many countries have predicted the potential of nanotechnology in agriculture. The adoption of nanotechnology would play an important role to nourish the growing population with declining natural resources. However, the deleterious effect of nanomaterial's if any has to be assessed and taken care before their wide application for sustainable development. If we overcome these considerations, the bright and beneficial future is at the doorstep of developing nations.

Declaration of competing interest

The Author declares no conflict of interest.

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