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Review on Agricultural Potentials of Nanotechnology

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ABSTRACT

Nanotechnology proved as a new hope of ray for almost every aspect of lifestyle of human being. Properties of nanomaterials are diverse in nature and significant for their functions. Advancement of nanotechnology is applicable for food, medicine, computer sectors. The remarkable properties of nanomaterials have enabled them to be used in agricultural sector too. To increase productivity at the same time disease management is important zone to be considered. In a given review paper it is considered regarding the crop management, crop protection pest control and utilization of nanotechnology based resources to achieve maximum production in an agricultural point of view.

Keywords: Agriculture, Crop protection, Nanomaterial's, Pest, Productivity.

I. INTRODUCTION

Nanotechnology is the manipulation or self-assembly of individual atoms, molecules, or molecular clusters into structures to create materials and devices with new or vastly different properties. Nanotechnology can work from the top down (which means reducing the size of the smallest structures to the nanoscale e.g. photonics applications in nanoelectronics and nanoengineering) or the bottom up (which involves manipulating individual atoms and molecules into nanostructures and more closely resembles chemistry or biology). The definition of nanotechnology is based on the prefix "nano" which is from the Greek word meaning "dwarf". In more technical terms, the word "nano" means 10^{-9}, or one billionth of something. For comparison, a virus is roughly 100 nanometres (nm) in size. The size of the double helix of DNA on the nanoscale is about 2 nm wide. The word nanotechnology is generally used when referring to materials with the size of 1 to 100 nanometres, however it is also inherent that these materials should display different properties from bulk (or micrometric and larger) materials as a result of their size. These differences include physical strength, chemical reactivity, electrical conductance, magnetism, and optical effects. Nanoscience and nanotechnology are the study and application of extremely small things and can be used across all the other science fields, such as chemistry, biology, physics, materials science, and engineering.

"Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nm, where unique phenomena enable novel applications." To this, it is useful to add two other statements to form a complete definition. First, nanotechnology includes the forming and use of materials, structures, devices, and systems that have unique properties because of their small size. Also, nanotechnology includes the technologies that enable the control of materials at the nanoscale.

Properties of Nanomaterials

a) Small particle size results in to new particle properties, which can also introduce new risks. Nanoparticles have a very large surface area which typically results in greater chemical reactivity, biological activity and catalytic behaviour compared to larger particles of the same chemical composition (Garnett and Kallinteri 2006; Nelet al. 2006).

b) Nanomaterials also have far greater access to our body (known as bioavailability) than larger particles, resulting in greater uptake into individual cells, tissues and organs. Materials which measure less than 300 nm can be taken up by individual cells (Garnett and Kallinteri 2006), while nanomaterials which measure less than 70 nm can even be taken up by our cells' nuclei, where they can cause major damage (Li et al., 2005).

c) Unfortunately, the greater chemical reactivity and bioavailability of nanomaterials may also result in greater toxicity of nanoparticles compared to the same unit of mass of larger particles of the same chemical composition (Oberdörsteret al. 2005a; Oberdörsteret al., 2005b). Other properties of nanomaterials that influence toxicity include: chemical composition, shape, surface structure, surface charge, catalytic behaviour, extent of particle aggregation (clumping) or disaggregation, and the presence or absence of other groups of chemicals attached to the nanomaterial (Brunner et al. 2006; Magrezet al., 2006; Sayeset al., 2004; Sayeset al., 2006). Some nanomaterials have proved toxic to human tissue and cell cultures in in vitro (test tube) studies, resulting in increased oxidative stress, production of proteins triggering an inflammatory response (Oberdörsteret al., 2005b), DNA mutation, structural damage to cell nuclei and interference with cell activity and growth, structural damage to mitochondria and even cell death (Li et al., 2005). Nanomaterials now in commercial use by the food industry, such as nano titanium dioxide, silver, zinc and zinc oxide have been shown to be toxic to cells and tissues in in vitro experiments and to test animals in in vivo studies. Nanomaterials have such diverse properties and behaviours that it is impossible to provide a generic assessment of their health and environmental risks.

d) The shape, charge and size of different particles can influence their kinetic (absorption, distribution, metabolism and excretion) and toxic properties. For this reason even nanomaterials of the same chemical composition which have different sizes or shapes can have vastly different toxicity (Sayeset al. , 2006).

The population is increasing and subsequent worldwide demand for food has urged for a better protection of agricultural crops from the infestation by different groups of insects. This initiated the intervention of modern techniques for the development of novel strategies of plant protection. Over the past decade, there has been a considerable amount of active research on the possible application of nanotechnology in the current agricultural practices including development of novel plant-protection products. In particular, designing of nanoformulation of different insecticides has emerged at high speed and which can be basically attributed to the fact that the composition of many conventional insecticides are feebly water soluble and require a delivery system for their application in the field.

Compared to bulk substances, nano-insecticides have added many advantages such as: (a) There is less environmental contamination due to reduction in rate of pesticides application. (b) Efficiency of chemical and natural insecticides is enhanced by controlled release. (c) Renders insecticides more susceptible to photodegradation. (d) Safe handling with reduced toxicity risks to animals. (e) Less toxicity towards non-target organisms compared with bulk. Among other benefits, nanoformulation of many natural insecticides (e.g. Neem oil) has protected them from premature degradation in the environment and thus helped in delivering maximum impacts on the target organisms. Polymer-based nanoformulations have been exploited for the encapsulation of most of the insecticides. Different polysaccharides like chitosan, alginates, starch and polyesters like poly-ε-caprolactone, polyethylene glycol have been considered for the synthesis of nanoinsecticides. The first formulation containing polymer for controlled release of biocides dates from the early 1970's. With the growing awareness for environmental pollution, application of biodegradable and biocompatible polymers of natural origin is preferred over the synthetic ones. The metabolites produced from the degradation of such polymers are of little concern. On the other hand, the growing general trend of preferring polymeric nanoformulations by researchers can be correlated to the manifestation of higher efficacy in insecticidal property of the encapsulated ingredient compared to commercial formulations. The efficacy tests have been confirmed from many field studies for different target organisms. Slow release, protection against degradation, and low solubility of the encapsulated insecticide are the most important features of polymeric nanoformulation making them first choice for nanoencapsulation. This valuable information has paved way to further development and practical application of polymeric nanoinsecticides with huge potential. Different form of polymer-based or non-polymer-based nanoformulations, such as nanosphere, nanocapsule, nanogels, micelles, nanofibers, nanometals and nanoemulsions has been proposed for encapsulation of insecticides. Among these, nanocapsules are by far the most widely used for controlled release of insecticides. Very recently, a novel concept of hybrid nanoformulation (encapsulation of nanoemulsion or liposome coating) has been suggested for the controlled release of some insecticides. However, the efficacy of the proposed novel approach needs to be tested for a broad spectrum line of insecticides. This is highly anticipated that application of nanoinsecticides for plant protection inevitably results in new benefits to human and environmental health. However, environmental safety issue on application of nanoinsecticides has been recently addressed. In order to ensure efficacy, most of the nanoinsecticides have been designed for slow release and allowing them persistence in the environment. Thus, it is important to investigate the environmental fate processes for both nanocarriers and the nanoformulated insecticides. Existing regulatory protocols for environmental risk assessment are mostly applicable to the bulk insecticides and cannot access the nanoformulated products because of different properties. For a fair risk assessment of the fate of nanoinsecticides, a new framework has to be developed and practiced in near future (Das et al. 2013).

Plant pathogens and pests are of the major factors limiting crop productivity. In crop sciences, nanotechnology can be used for the production of nanocapsules for delivery of pesticides, fertilizers, and other agrochemicals (Jhaet al., 2011). Nanotechnology for the control of plant diseases is a promising technique in plant pathology either by providing controlled delivery of functional molecules or as diagnostic tool for disease detection, an important step in plant disease treatment (Sharon et al., 2010). Encapsulation of herbicides could provide improvement in their application. For example Sulfonylurea herbicides are applied through the soil to control Orobanche spp., but several applications are needed to achieve effective control (Joel et al., 2007). Several studies were conducted using nanosized particles to control fungal pathogens such as Pythiumultimum, Magnaporthegrisea, Colletotrichumgloeosporioides, Botrytis cinereand, Rhyzoctoniasolani, as well as bacterial disease including Bacillus subtilis, Azotobacterchrococuum, Rhizobium tropici, Pseudomonas syringaeand, Xanthomonascompestrispv. Vesicatoria (Park et al., 2006). In Palestine, nanotechnology might be used for the control of several plant pathogens such as powdery mildews on grapevine and leaf spot on olive trees.

Nanotechnology and agricultural production developments

In the near future, nanostructured catalysts will be available which will increase the efficiency of pesticides and herbicides, allowing lower doses to be used. An agricultural system widely used in the USA, Europe and Japan, which efficiently utilises modern technology for crop management, is called Controlled Environment Agriculture (CEA). CEA is an advanced and intensive form of hydroponically based agriculture. Plants are grown within a controlled environment so that agricultural practices can be optimized. The computerized system monitors and regulates localised environments such as fields of crops and irrigated water. CEA technology provides an excellent platform for the introduction of nanotechnology to agriculture. Nanotechnological devices for CEA that provide "scouting" capabilities could tremendously improve the grower's ability to determine the best time to harvest the crop, the vitality of crop, and food security issues, such as microbial or chemical contamination.

Nanoparticles and plant disease control

Some of the nano particles that have entered into the arena of controlling plant diseases are nanoforms of carbon, silver, silica and alumina-silicates. At such a situation, nanotechnology has astonished scientific community because at nano-level, material shows different properties. The use of nano size silver particles as antimicrobial agents has become more common as technology advances, making their production more economical. Since silver displays different modes of inhibitory action to microorganisms (Young, 2009), it may be used for controlling various plant pathogens in a relatively safer way compared to commercially used fungicides. Silver is known to affect many biochemical processes in the microorganisms including the changes in routine functions and plasma membrane (Pal et al., 2007). The silver nanoparticles also prevent the expression of ATP production associated proteins (Yamankaet al., 2005). In a nutshell, the precise mechanism of bio-molecules inhibition is yet to be understood. Thus, use of nanoparticles has been considered an alternate and effective approach which is eco-friendly and cost effective for the control of pathogenic microbes (Kumar and Yadav, 2009; Prasad et al., 2011; Swamy and Prasad, 2012; Prasad and Swamy, 2013).

These nanoparticles have a great potential in the management of plant diseases compared to synthetic fungicides (Park et al., 2006). Zinc oxide (ZnO) and magnesium oxide (MgO) nanoparticles are effective antibacterial agents (Shah and Towkeer, 2010). The increased ease in dispensability, optical transparency and smooth-ness make ZnO and MgO nanostructures an attractive antibacterial ingredient in many products. Both have also been proposed as an anti-microbial preservative for wood or food products (Aruojaet al., 2009; Sharma et al., 2009). Properly functionalized nanocapsules provide better penetration through cuticle and allow slow and controlled release of active ingredients on reaching the target weed. The use of such nano-biopesticide is more acceptable since they are safe for plants and cause less environmental pollution in comparison to conventional chemical pesticides (Bariket al., 2008).

Silica nanoparticles a potential new insecticide for pest control

Application of nano-silica to the tomato plants may minimize the problems caused by Spodopteralittoralis. It provides a moderate degree of resistance, but presents the advantage of being feasibly integrated to other management tactics in controlling this pest. Nano-silica sprays affect the feeding preference of the Spodopteralittoralis, thus increasing the resistance of tomato plants. Concomitantly it affects biological parameters of the insect such as longevity and nymph production, thus reducing the reproductive potential of females on tomato plants and therefore reducing the insect population density, damages and yield losses to the crop. In conclusion, nano-silica is effective against Spodopteralittoralisand would therefore be a useful component of an integrated pest management strategy (El-Bendaryand El-Helady, 2013).

Pest Management

Insecticides are used in different ways, based on the physical-chemical characteristics of the each chemical substance, the area that needs to be covered and the target. Typical application of insecticides in crops is made by spraying a solution, emulsion or colloidal suspension containing the active chemical compound, which is made by a vehicle which may be a hand pump, a tractor or even a plane. This mixture is prepared using a liquid as a carrier, usually water, to ensure a homogenous distribution. Other methods for applying insecticides are through floggers or granule baits embedded with the active compound, among others that are less used. However, due to several degradation processes, such as leaching or destruction by light, temperature, microorganism or even water (hydrolysis), only a small amount of these chemical products reaches the target site. In this case, the applied concentrations of these compounds have been much higher than the required. On the other hand, the concentration that reaches its target might be lower than the minimum effective one.

Nanoparticles as pesticides

Nanoparticles are also effective against insects and pests. Nanoparticles can be used in the preparation of new formulations like pesticides, insecticides and insect repellants (Bariket al., 2008; Gajbhiyeet al., 2009). Torney, (2009) reviewed that nanotechnology has promising applications in nanoparticle gene mediated DNA transfer. It can be used to deliver DNA and other desired chemicals into plant tissues for protection of host plants against insect pests. Porous hollow silica nanoparticles (PHSNs) loaded with validamycin (pesticide) can be used as efficient delivery system of water-soluble pesticide for its controlled release. Such controlled release behaviour of PHSNs makes it a promising carrier in agriculture, especially for pesticide controlled delivery whose immediate as well as prolonged release is needed for plants (Liu et al., 2006b). According to Wang et al. (2007), oil in water (nano-emulsions) was useful for the formulations of pesticides and these could be effective against the various insect pests in agriculture. Similarly, essential oil-loaded solid lipid nanoparticles were also useful for the formulations of nano-pesticides (Liu et al., 2006b). Nanosilica, a silica product, can be effectively used as a nanopesticide.

Bariket al., (2008) reviewed the use of nano-silica as nano-insecticide. The mechanism of control of insect pest using nano-silica is based on the fact that insect pests used a variety of cuticular lipids for protecting their water barrier and thereby prevent death from desiccation. But here, the nanosilicaparticles when applied on plant surface, cause death by physical means of insects by being absorbed into the cuticular lipids.

It has been observed that the control efficacy against adult T. castaneumwas about 80%; presumably due to the slow and persistent release of the active components from the nanoparticles (Yang et al., 2009). The applications of diverse kind of nanoparticles viz. silver nanoparticles, aluminium oxide, zinc oxide and titanium dioxide in the management of rice weevil and grasserie disease in silk worm (B. mori) are caused by Sitophilusoryzaeand baculovirusBmNPV (B. morinuclear polyhedrosis virus, respectively (Goswamiet al., 2010). Teodoroet al. (2010) studied the insecticidal activity of nanostructured alumina against two insect pests viz. S. oryzaeL. and Rhyzoperthadominica(F.), which are major insect pests in stored food supplies throughout the world. Significant mortality was observed after 3 days of continuous exposure to nanostructured alumina-treated wheat. Therefore, compared to commercially available insecticides, inorganic nanostructured alumina may provide a cheap and reliable alternative for control of insect pests, and such studies may expand the frontiers for nanoparticle-based technologies in pest management.

Biological studies were performed on cotton plants infested with aphids to estimate the direct contact efficacy of nanosphere formulations on insects. The systemic effect of nanoformulation was studied from their ability to penetrate through the plant and reach the sap. The nanosphere formulations performed better than the reference to control the infestation at all the doses used due to their enhanced systemicity. The use of porous hollow silica nanoparticles (PHSN), with a shell thickness of nearly 15nm and a pore diameter of 4–5 nm, for providing shielding protection to pesticides from degradation by UV light was reported (Li et al., 2007). PHSN carriers improved the photostability of the pesticide, avermectin, loaded into the inner core and avermectin showed a typical sustained-release pattern from the carrier. Hence, such carriers have a promising future in the sustained-release pattern applications of various photosensitive components. The effects of slow/controlled-release fertilizers (for regulated, responsive and timely delivery) cemented and coated by nanomaterials; clay-polyester, humus-polyester and plasticstarch on crops were studied with wheat (Zhang et al., 2006).

II. CONCLUSION

Agricultural pest is serious problem which reduce the crop yield in every country. Increasing food demands of growing population need to increase the crop productivity. Unnecessary using of chemical pesticides cause problem to ecosystem and time consuming IPM programme, it is necessary and urgent to use alternatives to control pest. Nanotechnology is best approach against agricultural pests. Various authors studied the nanoparticles like carbon, silver, silicon, oxide of zinc and magnesium are effective against the various microorganisms and insect pests.

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