Nanoparticles: applications in medicine and agriculture

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Abstract- Nanotechnology, is a rapidly evolving field with immense potential in diverse sectors catering to mankind. Nanomaterials, generated and engineered with the help of nanotechnology offer a multitude of applications in biomedicine as well as in agriculture, owing to the unique, size-based physical and chemical attributes they exhibit. Theranostics, a branch of nanomedicine, employs these small- sized nanoparticles, endowed with large surface area, for diagnosis as well as for treatment of diseases. Agriculture is another sector where nanomaterials have range of applications from acting as fertilizers, enhancing nutrient uptake by the plants from soil, to nanopesticides managing wide spectrum of agricultural pests including- phytophagous insects, fungi and several weeds, resulting into increment in food production. This has generated a lot of interest amongst researchers as agriculture is inextricably connected with food security of an ever growing human population. Agriculture, at present is facing numerous challenges as in one hand climate change is severely impacting the agricultural yield, exacerbating the water crisis and influencing insect pests' distribution range on the other hand it's under tremendous pressure to ensure food security for a mammoth human population despite of dwindling resources. Nanomaterials, therefore, have enormous potential in agricultural sector and researchers are actively engaged in this area but this dimension remains relatively unexplored. However, the very attributes of nanomaterials making them promising candidates for development of novel products in medicine and agriculture also pose challenges due to potential environmental and health hazards, demanding risk assessment studies. Green synthesis of nanomaterials not only offers an ecofriendly, environmentally safe and cost effective solution but may also reduce application of harmful agrochemicals, contaminating environment and penetrating into biological systems through food chain. This critical review attempts to highlight applications of nanoparticles in medicine and agriculture.

Index Terms- Agriculture, environment, food security, nanomedicine, nanoparticles, nanotechnology

Mention the abstract for the article. An abstract is a brief summary of a research article, thesis, review, conference proceeding or any in-depth analysis of a particular subject or discipline, and is often used to help the reader quickly ascertain the paper's purpose. When used, an abstract always appears at the beginning of a manuscript, acting as the point-of-entry for any given scientific paper or patent application.

I. INTRODUCTION

In 1974, Norio Taniguchi, a Japanese Scientist introduced the term Nanotechnology [1] that has turned today into one of the most leading and promising multidisciplinary field with enormous potential in medicine as well as in agricultural sector. Nanotechnology, is a technology that deals with understanding, designing and controlling the matter, approximately in the range of 1-100 nm. The technology relies on the unique properties of matter exhibited at the nanoscale, opening doorways to create materials with novel applications in various fields. Nanotechnology can be used to produce nanoparticles (NPs) that represent a whole class of tiny materials consisting of carbon, metal, metal oxides or organic matter, having at least one of the dimensions less than 100 nm [2]. They can be classified on the basis of dimensions – zero dimensional, one dimensional, two dimensional and three dimensional [3,4]. They can also be classified based on their composition, physical and chemical properties: Organic, inorganic and carbon based nanoparticles. The impact of size on physiochemical properties of matter allow researchers to fine tune a property of interest and thus makes these materials immensely interesting. Further, the large surface area to volume ratio of these materials endows them with high reactivity. Together these properties turn them into ideal candidates for development of novel products with applications in the field of medicine and agriculture. Nanomedicine, an altogether new branch of medicine applying nanotechnology for-detection, prevention, improved diagnosis and treatment of several diseases, has emerged in the past couple of decades. The already existing nanomedicine products display a wide range from applications in drug delivery and pharmaceuticals to bioimaging and diagnostics. A variety of nanomaterials are already serving as alternate tools for rapid disease diagnosis and molecular level disease management [5,6].

Agriculture, the backbone of most of the developing countries is another important sector where nanotechnology has made impact. To meet growing global food demand and protecting the crops agriculture heavily depends on chemical fertilizers and pesticides, that leads to environmental contamination and various health hazards. Nanotechnology has offered innovative practical applications to agriculture sector that seamlessly merge with traditional agricultural practices and promote sustainable agriculture. Nano- agrochemicals, a blend of nanotechnology and agrochemicals, has transformed agriculture with a range of innovative products such of nanofertilizers, nanopesticides, nanoinsecticides, nanofungicides and nanoherbicides. The enhanced efficacy of nanoagrochemicals translates into an eco-friendly and economic alternate to conventional agrochemicals. Further, the increased agricultural crop production in terms of quantity and quality leads to economic gains to farmers. Despite of several benefits, nanoagrochenicals are yet to achieve their actual potential and need to overcome the various obstacles, to reach to farmers. One of the major obstruction preventing nanoparticles from achieving a wider acceptance for application is environmental and human health safety concerns, associated with application of nanoparticles as they tend to accumulate in the living systems [7,8] and environment. Research studies have shown NPs can adversely affect living cells, inducing detrimental effects ranging from genotoxicity to cell death, hypertrophy, inflammation, metaplasia, and even carcinogenesis [9,10,11,12] primarily due to generation of range of reactive oxygen species (ROS) [13,14]. The critical review attempts to highlight the application of inorganic (metal and metal oxides based) nanoparticles in medicine and agriculture.

NANOPARTICLES AND MEDICINE

The field of nanotechnology is growing at a fast pace, leading to plethora of opportunities for advancements in medical science and is capable of revolutionizing disease treatment. Nanotechnology has enormous potential for application in biology and medicine as the materials designed are in the range exhibited by biomolecules and possess high specificity. These two features not only allow them to interact with biomolecules more efficiently but also endow them with target specificity at cellular level. Nanotechnology, therefore, has the potential to develop clinical applications aimed to achieve target specific treatments with increased efficiency and inflicting minimal damage to surrounding cells or tissues, an advantage over other available therapies. A large number of NPs have been synthesized using nanotechnology, with profound implications in diagnosis as well as treatment of various diseases.

Gold nanoparticles

Gold nanoparticles (AuNPs) have sparked a lot of research interest in the fields of biology and medicine. Gold NPS have a wide range of applications varying from bioimagining of tumor cells to microbial cells and targeted drug delivery. Gold nanoparticles have been of special interest for selective destruction of target cells [15] a property making them ideal candidate for cancer therapy [16]. AuNPs have been shown to possess antibacterial [17] as well as antifungal activity [18,19,20].

Silver nanoparticles

Silver nanoparticles have been widely used in the field of medical industry. Silver nanoparticles show antimicrobial activities against bacteria, virus and other organisms. Silver nanoparticles have shown potential antibacterial effects against infectious organisms such as *E. coli*, *Bacillus subtilis*, *Vibria cholerae*, *Pseudomonas aeruginosa*, *Syphillis typhus*, and *Staphylococcus aureus* [21,22]. Silver nitrate reacts with sulfonamide to form silver sulfadizin cream which is antibacterial in nature against many bacteria and also used for treatment of burns [23].

Zinc oxide nanoparticles

Zinc is present in various human body tissues like eye, liver, kidney, bones, muscles, brain etc. Zinc is also not only required for DNA and protein synthesis, cell division, immune function, wound healing but it also assists in enzyme catalysis and supports growth and development. Zinc also modulates several enzymes that maintain homeostasis [24]. Zinc nanoparticles (ZnO NPs) exhibit high bioavailability and solubility and are biologically compatible- thus get readily absorbed and able to mimic the action of biomolecules in the body [25]. All these factors clubbed together make ZnO NPs of much in biomedicine. Further, ZnO NPs in one hand are highly economic and much safer as compared to other metal oxide nanoparticles on the other hand display antibacterial, antimicrobial, anticancer activity and have applications in drug delivery and bioimaging [26,27,28].

Titanium oxides nanoparticles

Titanium dioxide nanoparticles (TiO2 NPs) have gathered much attention owing to their high potential in the field of medicine as they exhibit photoactivity. TiO2 NPs treated with ultraviolet light generate a range of reactive oxygen species (ROS) that can stimulate apoptosis via cell signaling pathways [29]. The photosensitizing ability of TiO2 NPs make them interesting candidates for photodynamic therapy (PDT) for treatment of diseases like cancer. Another application is to combat antibiotic-resistant bacteria- become a major challenge in medicine today, via photodynamic inactivation. [30,31]. Photoexited TiO2 NPs, engineered with folic acid are also known to kill cells [32].

Trimetallic nanoparticles

Trimetallic nanoparticles are group of emerging nanomaterials. Various ways have been used to synthesis these nanoparticles with appropriate size, shape, and composition based on their fundamental qualities related to surface morphology, colloidal stability, and usefulness. As compared to monometallic nanoparticles, bimetallic and trimetallic nanoparticles has superior biomedical application. When compared to other nanoparticles, trimetallic nanoparticles exhibit high catalytic activity, enhanced antimicrobial properties, diverse morphology, extremely selective and sensitive detection, improved drug

encapsulation efficiency, and high stability, among other characteristics [33]. These properties are due to presence of two to three metal compounds in it. Over the past decades, synthesis of nanoparticles in various shape and size with good yield remain interesting by the researcher. The interest in this topic has expanded to include the creation of complex and intelligent materials such as artificial cartilage, teeth, bones, and electronic equipment, among other things. The researchers were inspired by these trimetallic nanoparticles because of their outstanding involvement in identifying and curing illnesses, as well as its confirmation as a possible biological use [34].

NANOPARTCLES AND AGRICULTURE

Agriculture is the mainstay of the developing countries for their livelihood. Today, agriculture is under tremendous stress to meet the challenge of feeding the ever- increasing, mammoth human population. Agriculture as a sector leads to several global concerns such as environmental safety, sustainability and climate change as it struggles hard to enhance crop production. Nanoparticles have the potential to sustainably increase the agricultural production while mitigating existing unfavourable consequences. Nearly one third of global food production is lost each year, according to estimates [35]. Agriculture and agricultural practices may be made more organised and efficient by using nano-based agrochemicals. Application of nanomaterials in agricultural practices can bring a revolution in crop production as their small size, high surface: volume ration and different optical properties makes the nanoparticles ideal candidates for plant protection, nutritional improvement and managing better farm practices [6,36]. The potential applications of nanotechnological tools in agriculture management, has generated interest of researchers in this field [5,32]. In the past few years an array of promising agrochemicals has been developed. In comparison to conventional methods, the use of nanoparticles based fertilizers have been reported to induce faster germination [37,38], increase plant tolerance to biotic and abiotic stress, and increase plant growth while reducing environmental impact [39]. Nanotechnology is being used to develop next-generation fertilizers and pesticides which will aid in distribution of active chemicals to plants in a controlled and site-specific manner.

Nanoparticles –based fertilizers

Excessive chemical fertilizers application to enhance crop yield leads to decreased soil fertility, contamination of land and water and poses health risks to humans. To meet the challenge of ever increasing food demand, further rise in application of fertilizers is expected. Nanotechnology advancements offer major advantages in reducing chemical fertilizers application and the associated undesirable consequences on environment and health. Nanofertilizers are grouped into three main classes based on their formulation. The first class is referred to as nanoscale fertilizer, where conventional fertilizer size is reduced in the range of nanoparticles. The second class of nanoscale additive fertilizers represents traditional fertilizers supplemented with nanoscale additives and the third class comprising of nanoscale coating fertilizer, refers to nutrients coated with nanofilms or interposed in nanopores of a carrier material [40] forming nanocomposite structures that aid in controlled nutrient release [41]. Encapsulating fertilizers with the help of NPs have several advantages ranging from accelerating nutrients uptake by reducing nutrient loss to improvement in crop quality and yield, and mitigating environmental degradation. Several studies have demonstrated potential of NPs as fertilizers. Delfani et al. [42] reported foliar application of Mg and Fe NPs resulted in increased growth, seed weight and photosynthesis in *Vigna unguiculata* leading to increased production. Application of Ca NPs and humic acids resulted in 30% improvement in seedling growth in peanuts [43]. These improvements could be a result of enhanced nutrient use efficiency (NUE) as NPs based fertilizer are smaller as compared to size of pores, present on plant cell wall that are involved in uptake of nutrients. As NPs based fertilizers can be applied to soil or foliage, they can utilize both foliar and root entry routes that further enhances uptake of nutrients [44,45].

Nanoparticles -based pesticides

Agricultural crops are attacked by large number of disease causing organisms, including insects that inflict enormous damage to agricultural crops as phytophagous insect pests [46]. Synthetic chemicals in the form insecticides, are being applied as quickest and cheapest option to control these pests. However, this practice has arisen numerous issues due to non-judicious use of these synthetic chemicals, counted as severe effects on human health, pollinating insects, domestic animals, the ecological system, and the entry of these chemicals directly or indirectly into our ecosystems. Nanotechnology can help to diminish the toxic effects on non-target insects or other organisms This technology also allows the manufacturers to manipulate the properties of carrier substances for meticulous release of active components. In the techniques like nano-encapsulation, a protective layer of thin-walled shell, usually employed to protect the active compounds of a pesticide [47]. Silica NPs (Si NPs) have shown promising results against *Sitophilus oryzae* [48]. Application of SiO2 NPs on *Callosobruchus maculatus* resulted in digestive tract impairment or integument surface expansion [49]. Insecticidal properties were also reported for Ag and Ag-Zn nanoparticles against *Aphis nerii* [50].

Nanoparticles -based fungicides

A major loss of agricultural crops results from fungal diseases attacking field crops. The loss could be as high as 70% in case of some major crops [51] inflicting sever damage to both yield and economy. Conventional fungicides are available but due to non-specificity they pose threat to biodiversity. Therefore, an alternate solution with target specificity or precision is needed to address the issue of fungal diseases [52]. NPs have shown promising results in this area. Jo et. al [53] reported antifungal activity of Ag ions and AgNPs, against *Bipolaris sorokiniana* and *Magnaporthe grisea*. Sulfur nanoparticles (SNPs) have been found to be effective nanopesticides against the *Fusariaum solani* and *Venturia inaequalis* [54,55]. In another study Ouda [56] demonstrated antifungal property of CuNPs and AgNPs against *Alternaria alternata* and *Botrytis cinerea*. Antifungal

activity was also exhibited by ZnO NPs and MgO NPs against *Alternaria alternate, Rhizopus stolonifer, Fusarium oxysporum*, and *Mucor plumbeus* [57].

Thus, nanotechnology has immense potential not only to provide food security via increased agricultural production but also environment, ecological and economic gains - reducing frequency of application of pesticides and fertilizers and thereby decreasing the burden of these synthetic agrochemicals on environment, reducing impact of non-target organisms and increased agricultural production.

There exists a potential flip side also, associated with the application of nanomaterials as metals and nonmetals used to make nanomaterials have a hazardous effect on plants, human health, and the environment. The conventional methods of NPs synthesis utilize chemical compounds or organic solvents as reducing agents, which can be deleterious for environment and are also highly expensive. Therefore, an environmentally and biologically sound and cost effective production of nanomaterials, retaining their multifunctional nature intact, is desired. Green production of nanoparticles is leading the way in this direction. [6]. Green synthesis of nanoparticles harnesses various bacteria, fungi, algae, plant extracts and other biomolecules, therefore, this technology is environmentally benign, energy efficient [58] and lowers the risk of execution and other issues involving human health. Green nanotechnology based nanomaterials can contribute towards sustainable development, via reducing load of harmful, chemical based fertilizers and pesticides that have turned a necessity to sustain agricultural food production and preventing the generation of undesired and/ or harmful byproducts.

II. CONCLUSION

We conclude that nanotechnology has tremendous potential in health care and agricultural sectors. In the past few years we have witnessed a boom in studies establishing multitude of applications both in medicine and agriculture. Nanotechnology, beyond doubt, is turning what used to be considered by many as science fiction, into reality. It has the potential to revolutionize agricultural sector and significantly reduce the adverse impact of modern agriculture on environment and increase crop yields but the applications at present are not economically feasible. Thus, this technology needs to overcome challenges such as scaling up production at the same time reducing the cost and time involved to bring the products into market. There are high expectations from this technology, at the same time several safety concerns need to be overcome for a wider public acceptance of nanotechnology in both medicine and agriculture. We are yet to find answers to questions like is there a possibility that the highly reactive nanomaterials can be the carriers and facilitate cellular entry of toxins or is there a risk of accumulation of non- soluble nanoparticles? Further research studies are required to investigate the impact of nanomaterials on living systems. Risk assessment studies only can provide answers to raised safety concerns and ensure safety of a product before it gets approved for market. The risk assessment studies need to be in pace with advancements of nanotechnology to build reap the benefits it has to offer.

FUTURE PERSPECTIVES

Nanotechnology has enormously contributed towards health care. Despite being a relatively young branch of medicine, during past two decades nanomedicine has witnessed extensive material designing. For sustained development, this field requires clinical needs driven research, based on inputs coming from experts in the clinical field. This will translate into development of materials designed to meet specific clinical demands. Despite of the various advancements in the field a lot still needs to be achieved as potential of this nanotechnology based medicine seems immense. In future nanomedicine needs to develop low cost rapid tests for genetic screening for predisposition, microbial infections and early detection of diseases prior to setting of symptoms. It is expected is to deliver treatments or therapies to patients for various diseases, with minimal invasion as well as personalized medicine. The numerous studies reported in the review demonstrate a significant confidence that nanoparticles bio-pesticides based formulation and trimetallic nanoparticle have a bright future and potential for developing safer and more effective bio-pesticides formulation for pest control, leading to initial changes in this field. However, the latent toxicity of nanoparticles, demands closely monitored green synthesis of nanoparticle, with a focus on greater research into the material's environmental and human effects. The use of plant or plant extracts in the synthesis of trimetallic nanomaterials may be beneficial. Further, modifications in synthesis methods may result in changes in shape and dimension, and reduce the risk associated with their use. There is still a lot of work to be done on the formulation of green technology based nanoparticles for pest management, making the application more environmentally friendly.

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