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REVIEW ARTICLE

Nanotechnology and a Trend Towards Green Synthesis

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ABSTRACT

Since a decade ago, nanotechnology has become more advanced and promising technology due to its diverse applications in different fields of life. Nanotechnology has progressively emerged as an interesting field of science owing to its various uses in agriculture, genome manipulation, diseases diagnosis and treatment, manufacturing of drugs and medicines, cosmetics and packing industry. Nanoparticles as compared to their bulk counterparts have more effective properties due to their high surface to volume ratio and charges. Although nanoparticles are prepared by many physical and chemical methods but green synthesis i.e. using biological organisms for their synthesis is much more reliable due to cost effectiveness, being environment friendly and easy synthesis properties. Biological materials i.e. plants, algae, bacteria and viruses usually convert inorganic ions into nanoparticles with the help of metabolites by the reduction method. Of all other methods plants play more important and efficient role in the synthesis of green nanoparticles due to the presence of secondary metabolites which readily reduce ions of metal salts to nanoparticles. Green nanoparticles are being utilized in almost all fields of science at industrial and commercial level. This review describes some applications of nanotechnology in different areas of science with more emphasis on preparation of nanoparticles via green synthesis.

INTRODUCTION

Nanotechnology is a field of science which describes measuring, manipulation and manufacture of materials at atomic/ molecular level, usually ranging from 1-100 nanometers. Their most important feature is large surface area to volume ratio, the property responsible for their widespread uses in biotechnology, environmental remediation, medicine, microbiology, mechanics, optics, electronics, engineering and material science (Saif et al., 2016; Knopp et al., 2009; Melo et al., 2015). Therefore, nanoparticles have multifunctional characteristics to be employed in various fields of medicine, nutrition and energy. Since it is a multidisciplinary innovation, so, it covers wide ranges of physics, chemistry and life sciences. Also, it has made remarkable advantages in the pharmacological industry by curing various bacterial and viral diseases. Nano medicine makes a huge impact in health care sector for treating various chronic diseases. These are additionally being utilized as adjuvant material in the synthesis of drugs, vaccines for immunization, antibiotics, antimicrobial compounds, in production of new highly beneficial analytical tools and instruments. However, one limitation in moving from mainstream medicine to nanoparticle diagnostic and therapeutic approaches is the potential toxicity of the nanoparticles. Some nanoparticles are especially likely to accumulate in body tissues. For instance, unmodified copper or silver nanoparticles pose toxicity risks to the body and environment. Surface modifications of nanoparticles can create agents with very distinct chemical and/or biological properties from the "same" nanoparticles with unmodified surfaces (Parveen et al., 2016). The biogenic syntheses (e.g. from plant extracts) of the nanoparticles with specific sizes and shapes have been a challenge in biomaterial science. Environment friendly synthesis of nanoparticles is considered as a key factor for the coming generations to treat various diseases with minimum toxicity risks. The applications of nanoparticles in the fields of agriculture and commercial sector, for instance, use of nanoparticles in bioprocessing technology: conversion of agricultural and food wastes into energy and other valuable by-products, waste water treatment, cosmetics and food industry has developed strong trend for the biosynthesis of metallic nanoparticles from plant derivatives.

Physical properties of nanoparticles

The physical properties of nanoparticles are unique due to their large surface area to volume ratio. Nanoparticles have different colors like yellow, gold and grey. The gold ones melt at much lower temperatures (~300 °C) than the gold slabs (~1064 °C). Silver nanoparticles have distinct physico-chemical properties, for instance, high electrical and thermal conductivity, catalytic activity, chemical stability, and nonlinear optical behavior. Because nanoparticles are very small, absorption of solar energy is much higher in them than it is in continuous sheets of the bulk material (Parveen et al., 2016).

Green synthesis

The synthesis of nanoparticles/nanomaterials by using biological material for instance plants, microorganisms including bacteria, fungi, virus and algae is known as green synthesis. A schematic diagram of the preparation of green synthesized nanoparticles is shown in Fig. 1. The green synthesis has many advantages over other conventional methods. This method is less expensive and environment friendly. The conventional chemical methods can cause bioaccumulation and can add harmful materials to the environment. This particularly limits their use in health field due to the toxicity problem to living cells. The green synthesis route is considered safe, accurate and reliable alternative for nanoparticle fabrication (Patra and Baek, 2014). During green synthesis many metallic ions are reduced to nanoparticles in the presence of plant extracts. Different natural compounds including phenolics, alkaloids, steroids, flavonoids, tannins, amino acids, proteins and saponins can be obtained from plants and are then used as secondary metabolites (as stabilizing and reducing agents) for nanoparticle production. These compounds can easily be extracted from leaves, roots, stem, flowers, bark and seeds of the plants. Green tea (*Camellia sinensis*) leaves were used to prepare zinc oxide nanoparticles and their antimicrobial activity was observed against microbes (Shah et al., 2015).

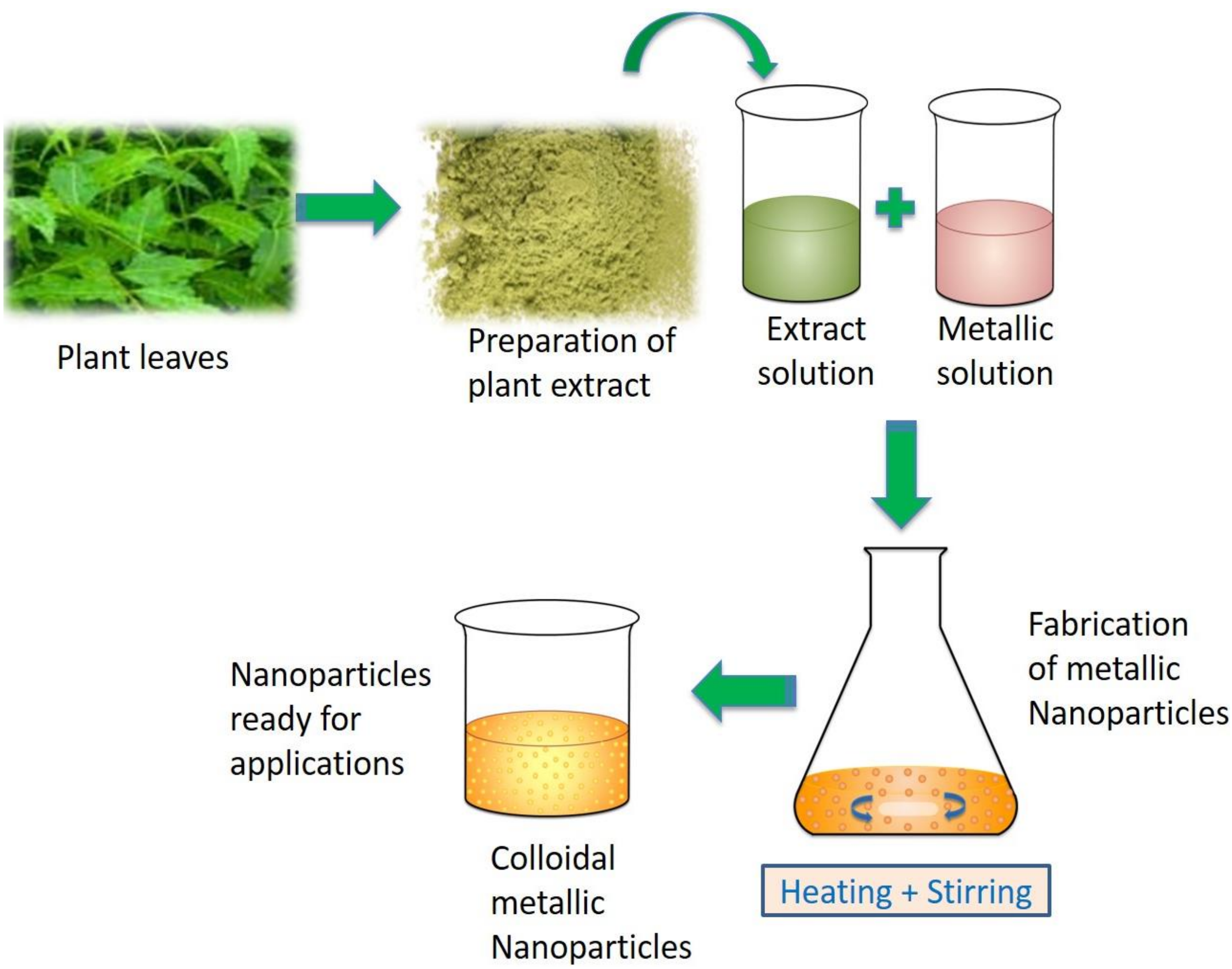

Fig. 1: Schematic diagram of the preparation of Green synthesized nanoparticles

a) Nanotechnology in medicine

Different nanoparticles including zinc, silver, magnesium, copper, gold, iron, cobalt, platinum, palladium and numerous more are being synthesized by using plant extracts. All these biosynthesized nanoparticles are being utilized for various applications with less to no side effects to the host. All these nanoparticles can control various chronic and acute illnesses such as hepatitis, HIV, malaria and cancer (Kuppusamy et al., 2016). These nanoparticles are also being utilized for site directed drug delivery. This strategy basically applies to use the desired dose of medicine with an aim that their resultant adverse effects on the host are minimum. This exceptionally specific approach can lessen expenses and are helpful in reducing the pain to the patients (Soni, 2016). Some important plants being used for the synthesis of nanoparticles are shown in Table 1.

Kathiravan et al. (2014) worked on synthesizing silver nanoparticles. *Melia dubia* plant extract was used for the synthesis of silver nanoparticles. Ultraviolet visible (UV–vis), Scanning electron microscopy (SEM), and X-ray diffraction (XRD) techniques were used to characterize these synthesized nanoparticles. The effectiveness of silver nanoparticles was tested against KB cell lines (human breast cancer). A remarkable cytotoxic activity of silver nanoparticles was recorded against KB cell lines, which revealed its significant therapeutic application. Sukirtha et al. (2012) biosynthesized silver nanoparticles from *Melia azedarach* and checked their cytotoxic activity against human epithelial carcinoma cell lines (HeLa cells) and Dalton's ascites lymphoma (DAL) in mice (*in vitro* and *in vivo*, respectively). Zeta potential analysis showed stability of silver nanoparticles at 24.9 mV. UV visible analysis showed surface Plasmon resonance (absorption peak) at 436 nm. These biosynthesized silver nanoparticles were dominatingly cubical and spherical with the size of approximately 78 nm. The cytotoxic activity of synthesized silver nanoparticles tested *in vitro* against HeLa cells demonstrated a dose depended response of silver nanoparticles, 300 μg/mL of silver nanoparticles was found to be lethal against HeLa cells.

More advance application of nanotechnology is nano-medicine that has significant role in the field of medicine and health. Nano-medicine has made the utilization of nanoscale materials, and nano-electronic biosensors. Development of nanodrugs has ultimately become beneficial to nanotechnology at molecular level. Application of nano-science in medicinal areas has many anticipated advantages and will profit all human communities. Nano drug applications assist in early recognition, diagnosis, control, prevention and appropriate treatment of diseases. It also made the follow up of outbreaks more convenient. Nano scale particles can also be utilized as labels and markers by making biological functions to be diagnosed rapidly. Testing of these nano drugs has turned out to be more flexible and more sensitive. Invention of nano devices further flourishes the application of nanotechnology in gene sequencing, for instance, the gold nanoparticles labeled DNA segments enhanced efficient detection of gene sequences. With the assistance of nanotechnology, the repair of damaged tissues of body has been made possible. Current utilizations of nanotechnology in stem cell research guarantees to provide new terms in regenerative drugs. The artificially stimulated cells are used in tissue engineering, which might change the transplantation of organs or simulated inserts. Nanotechnology becomes important to track and image the differentiation of stem cells into cell lines to understand their biological role. It will ideally prompt to stem cell-based therapeutic drugs and medicines for disease diagnosis, control and treatment (Soni, 2016).

b) Nanotechnology in environment

Nanotechnology is believed to play important roles in coming decades by securing nature and providing adequate energy to the developing world. More advance applications of this technology can be helpful in energy storage for future use, by its transformation from one to another useful form, synthesis of ecofriendly material and by the development of much better and improved sustainable power sources. Nanotechnology can be utilized for more affordable energy source production, in nano-catalysis, in solar technology and hydrogen technology. Carbon nanotube is being utilized as a hydrogen storage house. Nanotechnology is also being used in making photovoltaic more cheap, lighter and more effective, which lessens the combustion of engine pollutants by nano-porous filters and can clean the exhaust system mechanically. Nano scale noble metal particles are now frequently used to construct catalytic nanoparticles, catalytic converter and catalytic coated cylinders which help in cleaning of exhaust system. Nanotechnology can also help in growing new ecofriendly, green innovations that can limit undesirable pollution. Nano innovative methodologies can prompt lessening of energy utilization for enlightenment. Other than that nanotechnology can be utilized in the removal of dyes, waste water treatment, heavy metal removal, and reduction of pollutants in the environment and also in antibacterial activities. (Haverkamp, 2011) worked on a different aspect of nanotechnology that is basically the applications of phytoremediation in order to expel out most undesirable components from soils that later can be turned into an alternate application to produce nanoparticles with wide range of desired components. Similar procedures were already in use but the main objective to be achieved was different. In phytoremediation, the main purpose is to extract unwanted elements from soil, while in phyto-mining the main purpose is to concentrate for a

Table 1: List of different plants being used for the synthesis of nanoparticles along with their morphological features and uses/activities

Plants	Precursor	Size	Shape Range	Uses/ Activity	References
Carica papaya(CP) (papaya leaf) And *Catharanthus roseus*(CR) (sada bahar)	1mM Chloric acid ($HAuCl_4$)	15-28nm Size of spherical particles 2-29nm, From (CP) 3.5-9nm from (CR) 6-18nm from (CP+CR)	Spherical, Triangular, Hexagonal, CP (spherical, triangular) CR (Spherical triangular) CP+CR (spherical triangular, hexagonal)	Anticancer and antibacterial pathogenic bacteria *S. aureus* *E. coli* *B. subtilis* *P. vulgaris* Anticancer activity cell viability against MCF-7, HePG2 cell Lines MTT	Muthukumar et al. (2015)
Nerium Oleander (Kanair) (Highly stable at room temperature and no aggregation for several months)	($HAuCl_4$) Aliquots of Au(lll)	Mostly spherical shape particles 20-40 nm at low (concentration of plant) 5-10nm (high concentration)	Spherical, triangular, hexagonal, rod like particles at low concentration Flower like at (high concentration)	Anticancer activity against MCF-7 cell Lines MTT and catalytic activity against borohydrate reduction of 3-and 4 nitrophenol, Antioxidant property (DPPH)	Barai et al. (2018)
Garlic (*Allium Sativum*) (stable for 6 months)	($HAuCl_4 .3H_2O$) 99.99%	56.5 ± 13.6nm 34.2 ± 10.4nm 24.7 ± 8.2nm Varied size because of varying concentration of extract and (NH_4OH, NaOH)	Spherical particle	Antibacterial	Rastogi and Arunachalam (2013)
Nangifera Indica Seed (mango seed)	1 mM ($HAuCl_4 .4H_2O$)	46.8nm ~50nm	Spherical in shape	Antibacterial *S. aureus* *E. coli* Anticancer activity against human gastric cells	Vimalraj et al. (2018)
Rhizome parts of Ginger	1mM ($HAuCl_4$)	Greater then 20nm colloidal aggregation	Spherical and semispherical	Anticancer activity Cell culture, MTT Assay, lungs and liver cell cytotoxicity assay (ROS)	Babu et al. (2017)
Black cardamom (kali elichi) Ratio of concentration (1:1,1:0.5,1:0.1)	($HAuCl_4$) With ratio (1:1,1:0.5,1:0.1)	(1:1) 15-20nm (1:0.5) 20-30nm (1:0.1) 25-35nm Size depend on PH and ratio	Spherical, Triangular, Hexagonal Depends on ratio	Effects of PH on synthesis	Singh and Srivastava (2015)
Curcumin (haldi) ≥98% purity	Gold (lll) chloride trihydrate ($HAuCl_4.3H_2O$)	15nm with average diameter	Spherical (cur-AuNP)	Cytotoxic activity against human prostate cancer cell line	Nambiar et al. (2018)
Ethanol clove (*Syzygium aromaticum*)	1mM ($HAuCl_4$)	polydispersed 12-20nm	Mostly spherical particles	Anticancer activity Against human SU-DHL-4 Cells	Parida et al. (2014)
Gymnema Sylvestre (Gurmar)	Chloric acid ($HAuCl_4$)	72.8nm Spherical particles	Spherical particles	Anticancer activity against human colon adenocarcinoma cells	Arunachalam et al. (2014)

valuable element and for phyto-synthesis of specific molecules, for instance nanoparticles. The basic idea about the nanoparticles synthesis by different plants likewise is considered as accumulation and uptake of particular components by plants, which might be connected to phytoremediation and to phyto-mining in broad spectrum. Mehmood et al. (2014) worked on antibacterial efficacy of silver nanoparticles developed by a phyto-synthesis method. Crystalline and spherical shaped silver nanoparticles with the average size of about 30-45 nm were synthesized at the room temperature via bio-reduction of silver nitrate solution treated with bark extract of *Melia azedarach*. These bio-synthesized nanoparticles were examined for their antibacterial activity against *Escherichia coli* and *Klebsiella pneumonia* by analyzing the zone of inhibition formation on solid growth medium. Bio-synthesized silver nanoparticles demonstrated highly efficient inhibitory action against these bacteria. Thus, it is considered that all such green synthesis, eco-friendly and biocompatible techniques would promote the development and improvement of silver nanoparticles based novel biomedical products.

Hoag et al. (2009) used green tea to form iron nanoparticles and used them for degradation of an organic contaminant, bromothymol blue. It was seen that green synthesized iron nanoparticles had more activity than other Fe-EDTA and Fe-EDDS. Their experimental results showed that by enhancing nanoparticles concentration, more hydrogen peroxide (H_2O_2) catalyzed, as a result degradation of bromothymol blue enhanced.

Njagi et al. (2011) produced iron nanoparticles by using aqueous sorghum bran extracts and used them for degradation of bromothymol blue dye. Iron nanoparticles and H_2O_2 damages Bromothymol blue dye. The catalysis of H_2O_2 prompting the rate of reaction ultimately increased the rate of degradation of bromothymol.

c) Nanotechnology in textiles

With the advances in utilization of nanotechnology more up to date antibacterial cotton has been produced and utilized for antibacterial textile materials. With the use of nanotechnology in developmental work, new adjusted antibacterial textile material has been produced. Utilization of conventional antimicrobial agents in textiles for cleaning purposes has already been reported. The method has been progressed and became more advance technique by an emphasis on inorganic nano-structured materials that acquire great antibacterial efficiency and frequent utilization of such type of material to the textile (Fouda et al., 2013).

Ravindra et al. (2010) worked on cotton fibers which were mixed with plant based silver nanoparticles. They checked antimicrobial efficacy of these silver nanoparticles loaded cotton fibers. Their results showed very good antibacterial activity of the cotton fiber. It was observed that in infectious and other medical conditions and even after washing of the cotton fiber antibacterial activity was maintained.

d) Nanotechnology in agriculture

The development of nanotechnology has led to the formation of genetically modified crops (GMCs), enhanced animal and plant production, introduction of biocides and precise agriculture system. Nanoparticles not only enhance plant production but also activate rapid plant germination. Different types of nanoparticles are being used for agricultural purposes especially in plant protection and fertilization (Gogos et al., 2012). For example, silicon dioxide nanoparticles can be used against insect pests and are also useful in drug delivery as an effective element (Li et al., 2006); Zinc oxide nanoparticles can be used as insecticides (Goswami et al., 2010). However, low cost nanoparticle production and field applications are required to make their use more accessible for the farmers.

Nano agriculture is introduced which specifies the use of nanoparticles in plant and animal production for food and fuel enhancement. Plants can uptake and accumulate nanoparticles in their cells thereby, modifying their gene expression and associated biological pathways which will lead to plant growth and development. The effect of nanoparticles on plant growth depends upon the plant species, development stages, nanoparticles' shape, size, surface structure, chemical composition and duration of contact with the plant (Aslani et al., 2014).

Farghaly and Nafady (2015) described formation of silver nanoparticles with *Rosmarinus officinalis* leaves extract. Their toxic effect was seen on *Triticum aestivum* (wheat) and *Lycopersicum esculentum* (tomato). Effects on seeds were checked after 10 days of immersion (seedling growth), and 35 days of immersion (vegetative growth) in 100 mg/L of silver nanoparticles. Silver nanoparticles showed significant effect on germination percentage, lipid peroxidation, soluble proteins, antioxidant enzymes, dry weight and chlorophyll content in both plants. Moorthi et al. (2015) used *Sargassum muticum* plant extract to form silver nanoparticles. They characterized their nanoparticles by using energy dispersive X-ray (EDAX), XRD) and SEM. The insecticidal activity of silver nanoparticles against *Ergolis merione* showed more obvious alterations in the protein profile, cell morphology, hemolymph and deteriorated midgut incorporations, for example, basement membrane, lumen, fat body, and gastric caeca.

e) Nanotechnology in cosmetics

Nanoparticles are also being used in cosmetic industry. They are now available in toothpastes, conditioners, shampoos, anti-wrinkle and anti-cellulite creams, skin whitening creams, moisturizers, after-shaving astringent, anti-germ soap, cleansers, sunblock, foundation, lipstick, nail polish, perfumes and other wide range of beauty products (Baril et al., 2012; Neves, 2008; Fronza et al., 2007). The nano-emulsions, thus, constitute a class of emulsions with greater uniformity and droplet size of about 20 and 500 nm, which turn out to be progressively prominent as vehicles for the controlled release and advanced scattering of dynamic and active agents. The nanoscale cosmetic items planned for application to the body skin and face, with anti-aging activity and sun burn protection are fit for entering deeply into the skin layers, potentiating the impacts of the dynamic activity (Baril et al., 2012). Nano cosmetics are defined as “cosmetic formulations that carries active or other nanostructured ingredients, which has superior properties regarding its performance if compared with conventional products”. The more brightening advantages of utilizing nano beautifying agents originate from protecting ingredients from chemical and enzymatic degradation; control their release, particularly because of irritant factors at high concentrations, and the prolongation of residence of cosmetic actives or drugs in the deeper layers of the skin (Baril et al., 2012; Fronza et al., 2007; Neves, 2008). Lancôme the luxury division of L’Oréal was the first organization that presented nanotechnology-based cosmetic products in 1995, with the presentation of a face cream with an active ingredient, nano capsules of pure Vitamin Eto resist skin aging process. Thus, the cosmetic industry utilizes nanotechnology because of its wide range of beneficial applications, particularly with regards to their greater activity of being penetrant in an active form deep into the skin layers.

Pros and cons of nanotechnology

Nanoparticles produced by green synthesis (i.e. plants) have significant advantages over nanoparticles produced by conventional chemical methods. However, this method of producing nanoparticles is being utilized on smaller scale only. It is interesting to note that nanoparticles produced by plants have far better properties than other chemically or physically produced nanoparticles i.e. green nanoparticles cause little to no toxicity to cells, are environment friendly and biodegradable. Although green nanotechnology is a promising field and it has helped human beings in many fields of science but there are also certain contradictions associated with it. Also, the exact mechanism and long-term effect of green nanoparticles in living organisms is still not fully known. There is a need to research on these aspects of green nanoparticles too, so they can be utilized on a broader scale.

Authors’ contribution

All authors contributed equally to this work.

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