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Nanotechnology in agriculture: Plants are green route for synthesis of nanoparticles

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Abstract
Nanotechnology is a new technology playing a vital role in different fields of science like medicine, engineering, electronic, pharmaceuticals, agriculture and food industry. Nanotechnology is highly interdisciplinary and important research area in modern science. The use of nanomaterials offers major advantages due to their unique size, shape and significantly improved physical, chemical, biological and antimicrobial properties. Physicochemical and antimicrobial properties of metal nanoparticles have received much attention of researchers.

Nanotechnology is the promising tool to improve agricultural productivity though delivery of genes and drug molecules to target sites at cellular levels, genetic improvement, and nano-array based gene-technologies for gene expressions in plants and also use of nanoparticles-based gene transfer for breeding of varieties resistant to different pathogens and pests. The nanoparticles like copper (Cu), silver (Ag), titanium (Ti) and chitosan have shown their potential as novel antimicrobials for the management of pathogenic microorganisms affecting agricultural crops. The nanotechnologies can be used for the disease detection and also for its management. The progress in development of nano-herbicides, nano-fungicides and nano-pesticides will open up new avenues in the field of management of plant pathogens. The use of different nanoparticles in agriculture will increase productivity of crop. Development of green nanotechnology is creating interest of researchers towards eco-friendly biosynthesis of nanoparticles. The synthesis of nanoparticles has become the matter of great interest in recent times due to its various advantageous properties and applications in various fields. Though chemical methods are costly, toxic and potentially dangerous to the environment. But biological approach of synthesis nanoparticles is eco-friendliness, cheap, low energy and time efficient. This reports the potential of plants *i.e.*, "green chemistry" to synthesize nanoparticles not only in the laboratory scale but also in their natural environment.

Keywords: Nanotechnology, nanoparticles, plants, biosynthesis, applications

Introduction

The term nanotechnology, buzzword of present-day science owes its origin from the Greek word 'nano' literally meaning 'dwarf'. When it is expressed in terms of dimension one nanometer equals to one billionth of a meter (1nm=10^{-9}m). The subject nanotechnology deals with manufacturing, study and manipulation of matter at nano scale in the size range of 1-100 nm which may be called as nanoparticles (Rajan, 2004) [25].

NT involves physics, chemistry, biology, engineering, medicines, agriculture and all other sciences. It is also considered as enabling technology since the property and activity of nanoparticles changes with change in size and shape (Satalkar *et al*., 2015) [30].

Different sectors of agriculture and food industry can be revolutionized by the use of nanotechnology using modern tools for the detection and treatment of diseases, increased capability of plants to take up nutrients etc. Nano-based crystals are in developing process that will increase the effectiveness of herbicides and pesticides with decreased doses. Smart delivery systems and sensors will increase the agricultural potential to fight with the pathogens and viruses (Rai and Ingle, 2012) [26].

Nanoparticles demonstrate unique targeted characteristics with elevated strength, high conductance of electricity and extra chemical reactivity (Nykypanchuk *et al*., 2008) [22]. The nanoparticles are of the size of 10^{-9} in diameter with distinctive chemical, physical and biological properties (Leiderer and Dekorsy, 2008; Bhattacharyya *et al*., 2010; Sabbour, 2013) [17, 6, 27]. Scientists are engaged in synthesizing different kinds of organic, inorganic and hybrid nanoparticles possessing physical, optical and biological properties. These targeted characteristics have increased the importance of nanoparticles in several fields including engineering, electronic, agriculture, pharmaceuticals and medicine (Salata, 2004; Rai and

Ingle, 2012; Dar and Soytong, 2013) [28, 26, 8]. From agricultural view point, nanotechnology has great potential to become a helping tool for pathologists in detection and treatment of plant diseases by the use of nano-based kits, detection of pests by the use of nano-sensors, enhanced capability of plants for nutrients absorption, maximized crop yield by nano-porous zeolites and insect pest management involving nano capsules (Chaudhry *et al*., 2008; Rai and Ingle, 2012) [7, 26]. It is also being supposed that efficiency of pesticides and insecticides will be increased due to the development of nanostructured catalysts in coming years with reduced doses.

Development of green nanotechnology is generating interest of researchers toward eco-friendly biosynthesis of nanoparticles. Among the recent advancement in agricultural sciences, metallic nanomaterials play a significant role in crop protection because of its unique physical and chemical properties, huge surface to volume ratio, structural stability and strong affinity to their target. The increased surfaces of nanoparticles are responsible for their different chemical, optical, mechanical, magnetic properties as compared to bulk materials (Mazur, 2004) [20]. Physical and chemical methods of synthesis of nanoparticles (NPs) are expensive, time consuming, labour intensive and also requires more energy. These methods are potentially hazardous to the environment and living organisms due to use of toxic reducing and stabilizing agents (Mittal *et al*., 2013) [21]. Therefore, there is a need to develop cost effective, non-toxic and eco-friendly method for synthesis of nanoparticles. Biological methods of synthesis would help to remove harsh processing conditions by enabling the synthesis at physiological pH, temperature, pressure and at the same time at lower cost. Biomolecules present in plant extracts can be used to reduce metal ions into nanoparticles in a single-step green synthesis process. This biogenic reduction of metal ion is quite rapid, readily conducted at room temperature, pressure and easily scaled up (Parikh *et al*., 2014) [23]. It is cost effective and main advantage is eco-friendly compared to other methods.

Plants - the green route for biosynthesis of nanoparticles

Nature has devised various processes for the synthesis of nano and micro- length scaled inorganic materials which have contributed to the development of relatively new and largely unexplored area of research based on the biosynthesis of nanomaterials. Synthesis using biological plant extract is compatible with the green chemistry principles. “Green synthesis” of nanoparticles makes use of environmental friendly, non-toxic and safe reagents. Figure 1 shows the general biosynthesis of metal nanoparticles from biological sources.

Phytomining is the use of hyper accumulating plants to extract a metal from soil with recovery of the metal from the biomass to return an economic profit [16]. Hyper accumulator species have a physiological mechanism that regulates the soil solution concentration of metals. Exudates of metal chelates from root system, for example, will allow increased flux of soluble metal complexes through the root membranes [36]. It has been observed that stress tolerant plants have more capacity to reduce metal ions to the metal nanoparticles [2]. Mechanism of biosynthesis of nanoparticles in plants may be associated with phytoremediation concept in plants [3, 10-11]. Biosilcification also results in nanoparticles in some higher plants as shown in figure 2 [18].

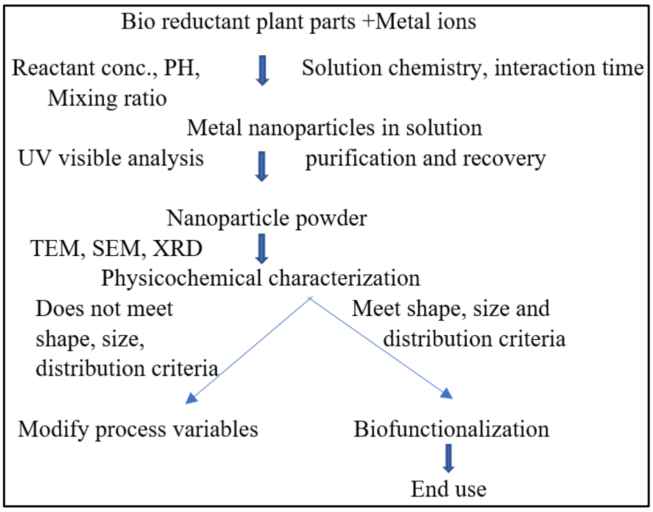

Fig 1: Generalized flow chart for Nano biosynthesis

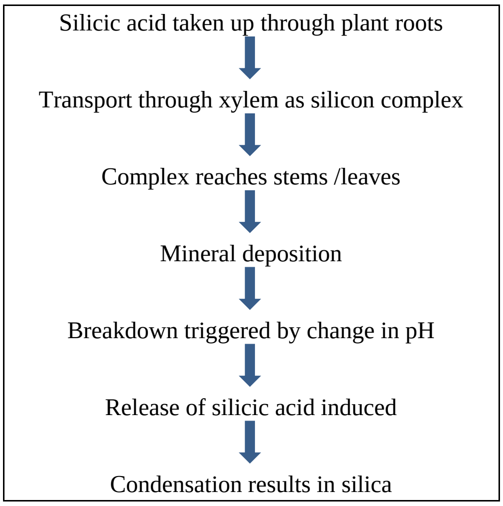

Fig 2: Flowchart for Biosilcification process

Nanoparticles synthesized by plants

Copper nanoparticles

The biosynthesis of copper nanoparticles from tulasi (*Ocimum sanctum* L.) leaves extract as reducing agent. For the synthesis of copper nanoparticles, 50 ml of tulsi leaf extract was mixed with 50 ml aqueous solution of 1mM copper sulphate (1:1 ratio of plant extract and copper solution) and stirred continuously for 2 min at 30 °C. Reduction takes place rapidly which is indicated by the change in colour of the solution. The mixture was incubated at room temperature overnight. Mixture was centrifuged at 3500 rpm for 10 min to get copper nanoparticles. The nanoparticles were washed and dried at room temperature [35].

Copper nanoparticles synthesized from *Areva lanata* leaves extract exhibited in 50 nm of size. The particles showed good bacterial activity against *E. coli*, *Staphylococcus aureus*, *Bacillus cereus* and *Pseudomonas aeruginosa* [9]. Biosynthesis of Copper Nanoparticles by *Vitis vinifera* Leaf aqueous extract used against *Escherichia coli*, *Staphylococcus aureus*, *Klebsiella pneumonia, Salmonella typhi and Bacillus subtilis* [12]. Copper bio nanoparticles were successfully synthesized using leaf aqueous extract of *Datura innoxia* from copper sulphate. FESEM analysis showed that the particles were spherical in shape with size ranging from 5 to 15 nm. The antimicrobial activity of copper bio nanoparticles revealed that they are effective growth inhibitors against *Xanthomonas* *oryzae* pv. *oryzae*, the causative organism of bacterial leaf blight of paddy [6].

Silver nanoparticles

Silver nanoparticles of 20-30 nm from leaves of *Acalypha indica* showed antimicrobial activity against *E. coli* and *Vibrio cholera*[20] while silver nanoparticles of 3-12 nm from peels of *Citrus sinensis* have been reported to show activity against *Bacillus subtilis* [19]. Particles of size 33.67 nm from *Allium cepa* stem show antimicrobial activity against *E. coli* and *S. typhimurium* [31]. Silver nanoparticles of size 8 nm from leaves of *Nicotiana tobaccum* inhibits *Pseudomonas putida*, *P. vulgaris*, *Escherichia coli* DH5α, *B. subtilis*, *P. aeruginosa* and *Salmonella typhi* [34].

Gold nanoparticles

Au particles are particularly and extensively exploited in organisms because of their biocompatibility[5]. Gold nanoparticles (Au) generally are considered to be biologically inert but can be engineered to possess chemical or photo thermal functionality. On near infrared (NIR) irradiation the Au-based nanomaterials, Au nanospheres, Au nanocages, and Au nanorods with characteristic NIR absorption can destroy cancer cells and bacteria via photo thermal heating. Au-based nanoparticles can be combined with photo sensitizers for photodynamic antimicrobial chemotherapy. Au nanorods conjugated with photo sensitizers can kill MRSA by photodynamic antimicrobial chemotherapy and NIR photo thermal radiation [21, 24].

Aggregated forms of nanoparticles like gold nanotriangles have been reported in lemon grass extracts and tamarind leaf extracts[1] and dead biomass of *Humulus lupulus* also produces gold nanoparticles [19]. Extra cellular synthesis of gold nanoparticles has been observed using *Emblica officinalis* fruit extract as a reducing agent.

Platinum nanoparticles

Nanoparticles ranging from 2-12 nm was the first to be reported in platinum and was synthesized using >10% *Diopyros kaki* leaf extract as reducing agent from an aqueous H(2) PtCl(6).6H(2)O solution at a reaction temperature of 95 °C [32]. Platinum nanoparticles of 23 nm size have been prepared using leaf extract of *Ocimum sanctum* as reducing agent from aqueous chloroplatinic acid at a reaction temperature of 100 °C that finds application in water electrolysis [33].

Zinc nanoparticles

To the best of our knowledge, biological approach using milky latex of *Calotropis procera* has been used for the first time as a reducing material as well as surface stabilizing agent for the synthesis of spherical-shaped ZnO-NPs. The structure, phase and morphology of synthesized product were investigated by the standard characterization techniques. Milky latex of *Calotropis procera* has been used for the synthesis of spherical ZnO NPS. Highly stable and spherical ZnO NPS have also been synthesized using *Aloe vera* extract [29].

Conclusion

In most of the countries in the world, agriculture is the backbone of the country. The adoption of new technology in different fields of agriculture and food industry by the proper monitoring systems, pest and disease detection, smart systems of chemicals and gene delivery in the crops, nano-pesticides and encapsulation, nano-formulations and many other applications will revolutionize the agriculture. It will increase the productivity and reduction in agricultural wastes will occur that will indirectly reduce the pollution from the environment.

The "green" route for nanoparticle synthesis is of great interest due to eco-friendliness, economic prospects, feasibility and wide range of applications in nanomedicine, catalysis medicine, nano-optoelectronics, etc. It is a new and emerging area of research in the scientific world, where day-by-day developments is noted in warranting a bright future for this field.

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