Biogenic Nanomaterials Using Moringa and Their Applications

13

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Abstract

Nanotechnology offers many potential advantages for agriculture such as enhancement of food quality and safety, reduction of agricultural inputs, enrichment of absorbing nanoscale nutrients from the soil, etc. Such nanotechnological applications reduce the amount of spread of chemicals, minimize nutrient losses in fertilization and increase the yield through pest and nutrient management. Besides, it also provides novel nanotools for rapid disease diagnostic and controlling measures using nanopesticides and nano-sensors for monitoring soil quality of agricultural field. This chapter covers the current status and challenges in the area of nanotechnology in the improvement of agriculture with a special emphasis given to Moringa.

13.1 Introduction

In recent days, great technological developments in the area of research and technology have been initiated by nano science and technology. Nanotechnology is the research and application of small structures that can be seen in all areas such as chemistry, biology, physics, material sciences and engineering. The idea of nanotechnology originated in the ninth century. For the first time in 1959, Richard Feynman gave a talk on the concept of nanotechnology and described molecular machines built with atomic precision, where he discussed nanoparticles and said, 'There's plenty of space at the bottom'. Nanotechnology is an increasingly growing research area that is an interdisciplinary field of science and technology that expands the scope of cell-level investment and control between synthetic material and the biological system (Sinha et al. 2009). Inorganic nanomaterials play an important role in various applications in different fields, such as optics, electronics, catalysis, drug delivery, atmosphere, environmental and biomedicine, in particular biomedicine, because of their special chemical,

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electrical magnetic and physical properties (Guo and Wang 2011). Different metal and metal oxide nanoparticles synthesized by biological methods have been shown to be useful in different applications over the last two decades. In addition, these biological approaches satisfy the green chemistry approach requirements defined as the design of chemical products and processes that avoid the use and processing of toxic/hazardous chemicals (Govindaraju and Tamilselvan 2020). In the last few decades, due to their cost-effective, non-toxic and eco-friendly nature, biological synthesis of nanomaterials using different bio-resources has gained a lot of interest in the field of nanotechnology. Researchers have turned their attention to the synthesis of nanoparticles, motivated by the abilities of green methodologies, using diverse biological materials such as actinomycetes (Manimaran and Kannabiran 2017), bacteria (Iravani 2014; Mukherjee and Nethi 2019; Ali et al. 2019), Cynobacteria (Hamouda et al. 2019), fungi (Dorcheh and Vahabi 2016; Guilger-Casagrande and de Lima 2019), plants and plant compounds (Govindaraju et al. 2011; Ashokkumar et al. 2014; Khaleel Basha et al. 2010; Venkatachalam et al. 2013; Uma Suganya et al. 2016a, b; Prabhu et al., 2014; Govindaraju et al. 2020a), seaweeds (Singaravelu et al., 2007; Govindaraju et al., 2009; Govindaraju et al. 2020b, c; Itroutwar et al. 2020), yeasts (Moghaddam et al., 2015; Eugenio et al., 2016) and even viruses (Thangavelu et al., 2020).

Among the various bio-resources, plants are also being used as a 'green bio-factory' for the production of metal and metal oxide nanomaterials. Further, plant-based genre of bio-reductants, have more advantages due to their high metal ion reduction, low cost and easy availability.

Moringa oleifera, originally discovered in India, is a member of the Moringaceae family and is generally referred as Drumstick tree, the Miracle tree or the Horseradish tree. There are 13 species, but *Moringa oleifera* is the most grown with a height of between 5 and 10 m. As the tree grows quickly and has drought tolerance properties, it can be cultivated in tropical, subtropical and arid regions of the world. It is exceptional and has tremendous promise, highlighted by the National Institute of Health, Bethesda, Maryland. The plant is highly regarded since nearly all pieces are used as a food source, as well as in the conventional treatment of various diseases and to encourage good health. These sections include but are not limited to the leaves, flowers, seed pods, nuts, stems, bark and gum. It is used for the prevention of bronchitis infections and fever. Further, it can also be used as antioxidant, antimicrobial, anti-diabetic, neuroprotective, cardioprotective and anti-inflammatory effects (Madi et al. 2016; Tiloke et al. 2018). In this sense, the approach to green chemistry for the synthesis of nanomaterials of metal and metal oxides by using various sections of *Moringa* is now under tremendous investigation and has thus become a groundbreaking gleam in the research arena.

13.2 Synthesis of Silver Nanoparticles and Its Applications

Due to its distinct properties such as catalytic activity, chemically stable, good conductivity and potent antimicrobial activity, silver nanoparticles have attracted and demanding research interest in the field of nanotechnology (Setua et al. 2007; Govindaraju et al. 2009). It is used as a substratum for surface-enhanced spectroscopy because of its colloidal nature, as it partly requires electrical conducting surface. Silver was used as an antimicrobial agent in this era. In order to increase the treatment of antibiotic resistance caused by the misuse of antibiotics, the recent focus is on silver nanoparticle synthesis (Panaek et al. 2006; Sandbhy et al. 2006). Several hypotheses have been identified for the antimicrobial activity of silver nanoparticles. The capacity of the silver nanoparticle inactivates the bacterial enzyme by releasing ionic silver that inactivates the thiol groups. Bacterial DNA replication, damage to cell cytoplasm, depletion of ATP levels and ultimately cell death are mediated by these silver ions (Feng et al. 2000; Uma Suganya et al. 2015a, b). As a nanoparticle of distinct surface-to-volume ratio, silver nanoparticle increases surface-to-surface interaction with bacterial cells that facilitate the dissolution of silver ion and enhance the efficacy of bacterial ion (Stobie et al. 2008). Among the various methods (physical, chemical) for synthesis of silver nanoparticles, biological methods particularly plant-based synthesis have highly stable and potent antimicrobial activity. Silver nanoparticles biosynthesis using *Moringa* leaf extracts has shown that this process generates a very sharp distribution. Further, it has shown that nonlinear optical absorption and optical limiting phenomena with an output comparable to particles prepared by other pathways can be added to the particles synthesized through this process (Sathyavathi et al. 2010). Prasad and Elumalai (2011) reported that the aqueous leaf extract of *Moringa* has been used for synthesizing spherical-shaped (average size 57 nm) silver nanoparticles and their antibacterial activity against *S. aureus, E. coli, K. pneumonia* and *B. cereus* and anti-fungal activity against *C. albicans, C. tropicalis* and *C. krusei.* Silver nanoparticles mediated by *Moringa* stem bark extract show excellent anti-cancer activity against the HeLa cell type. Green synthesized silver nanoparticles were stable and their modes of action were found to increase the generation of ROS and its subsequent action to inhibit cell replication by induction of apoptosis (Vasanth et al. 2014). Sunlight irradiation induced green synthesized silver nanoparticles using leaf extracts of Moringa and its antimicrobial potential against gram positive and gram negative bacterial species (*Staphylococcus aureus, Enterococcus faecalis, Escherichia coli, Pseudomonas aeruginosa* and *Klebsiella pneumonia* (Moodley et al. 2018)). Kalugendo and Kousalya (2019) reported the synthesis of silver nanoparticles using seed extracts of *Moringa* and their antibacterial activity against methicillin-resistant *Staphylococcus aureus*. Shousha et al. (2019) reported that Moringa leaves phyto-chemicals mediated synthesized silver nanoparticles showed potent in vitro antioxidant and cytotoxic activity. Recently, biogenic preparation and physico-chemical characterization of silver nanoparticles using *Moringa* flower extract and assessment of antimicrobial and heavy metal sensing properties have been studied (Bindhua et al. 2020).

13.3 Synthesis of ZnO and ZnS Nanoparticles and Its Applications

Semiconductor nanomaterials, particularly ZnO/ZnS wide band gap optically transparent semiconductor, can be widely used in photonics, optics and optoelectronics with diverse applications ranging from optical coatings, transistors, sensors, optoelectronic devices, drug delivery and agricultural applications. Bio-production and characterization of ZnO nanoparticles have been carried out using leaf, stem segments, flowers and fruit pods of the medicinal plant *Moringa* (Manokari and Shekhawat 2016). Preparation of ZnO nanoparticles was done using *Moringa* leaves as natural precursor via co-precipitation technique, and the nanoparticles were characterized using various spectroscopy and microscopy tools. Further, ZnO has been used for photocatalytic degradation of titan yellow dye and antimicrobial activity against *Bacillus subtilis* and *Escherichia coli*. Biosynthesized ZnS nanoparticles using the moringa leaves extract and its optical, dielectric, electronic property were studied. Morphology of ZnS was found to be mostly spherical in shape with average diameter ~30 nm (Sur and Ankamwar 2016).

13.4 Synthesis of Iron Nanoparticles and Its Applications

Katata-Seru et al. (2018) reported the biogenic preparation of iron nanoparticles using leaf and seed extracts of *Moringa* and their application in removal of nitrate from waste water and antibacterial activity against *Escherichia coli*. The removal percentage of nitrate is increased with a decrease in pH. Further, iron nanoparticles have dual properties of coagulant and antibacterial activities, which is ideal for treating contaminated water. Magnetic iron oxide nanoparticles were prepared and surface modified with *Moringa* seed proteins and characterization of functional groups responsible for adsorption, stability, morphology and surface interaction of nanoparticles was done. Batch adsorption technique has been used for recovery of precious metal ions Au(III), Pd(II) and Pt(IV) from aqueous solution (Amuanyena et al. 2019). Recently, Oliveira et al. (2020) reported that magnetite nanoparticles were prepared using co-precipitation technique and surface functionalized with *Moringa* seeds extract for magnetic coagulant MO-Fe_3O_4 application in effluent treatment plant.

13.5 Synthesis of Vanadium Nanoparticles and Its Applications

Recently, nanostructured vanadium compounds have attracted much interest due to their chemical and physical properties and their potential applications in catalysis, sensors, electrochemical capacitors, solar cells, biomedical devices (REF). Vanadium nanoparticles were synthesized by biogenic approach wherein *Moringa* leaf extract used as reducing and stabilizing agent. Antimicrobial activity of the biogenic vanadium nanoparticle was tested against bacteria and fungi.

13.6 Synthesis of Gold Nanoparticles

Gold nanoparticles have been used in a wide range of applications over the past few decades, such as biosensors, catalysis, drug delivery, biomedical and environmental applications. Gold core is inherently inert, biocompatible and very less toxic in nature due to its chemical stability and special properties, and hence, making it a perfect starting point for carrier construction. Nanoscale gold can be conveniently processed with controlled dispersity with a broad variety of core sizes, i.e. 1–150 nm. Different chemical and physical methods have been produced for nanoscale gold synthesis, but due to the use of a number of poisonous chemicals and high temperature in the preparation, these approaches have been found to be hazardous and detrimental to biological and environmental applications. Due to their easily reducible, quick, cost-effective, less toxic and environmentally safe nature, biological preparation of nanoscale gold is becoming dominant. Anirban et al. (2013) reported the *Moringa* leaf extract mediated green synthesis of spherical-shaped gold nanoparticles of size ranging between 20 and 60 nm at room temperature. Similarly, Ponnanikajamideen et al. (2016) used moringa gum for biological synthesis of gold nanoparticles for effective antibacterial activity.

13.7 Synthesis of Bismuth Nanoparticles and Its Applications

Das et al. (2020) reported the green synthesis of phyto-chemical encapsulated bismuth nanoparticles using a hydro-alcoholic extract of *M. oleifera* leaves. The size of the synthesized bismuth nanoparticles is in the range of 40–57 nm with amorphous morphology. Further, DPPH and phosphomolybdate assays revealed that the *M. oleifera* leaves extract and the synthesized bismuth nanoparticles possess antioxidant properties. Also, it was demonstrated that the *M. oleifera* leaves extract and the synthesized bismuth nanoparticles exert potent antibacterial activity against *Escherichia coli, Klebsiella pneumoniae, Staphylococcus aureus* and *Enterococcus faecalis* and anti-fungal activity against *Aspergillus niger, Aspergillus flavus, Candida albicans* and *Candida glabrata.*

13.8 Synthesis of NiO Nanoparticles and Its Applications

With several characteristics, such as surface area to volume ratio, electro-optical, magneto-optical, chemical and mechanical properties, nanoparticles differ from the bulk, serving as an effective instrument in this sense in the fight against bacteria. Due to high chemical stability, electro catalysis, super conductance characteristics and electron transfer capacity, NiO nanoparticles have attracted a lot of attention in recent study. Nickel oxide has a band gap of 3.6–4.0 eV and is a p-type semiconductor metal oxide. In addition, this paper documents that the NiO nanoparticles prepared from the green approach demonstrate improved cytotoxicity and antibacterial action.

Figure 13.1 describes the procedure involved in the development of nanoparticles using different parts of Moringa plant. Table 13.1 illustrates different applications of nanomaterials including development of nonlinear optics, nanomaterials with antimicrobial, antiviral and antioxidant capacity that were prepared using Moringa plant parts.

13.9 Future Prospects

Agriculture rapidly adapts newer technologies, modernization and increased use of nanochemicals. This warrant government policies need to be tailored to acclimatize these adaptations in order to maximize the production in agriculture and food industry, as nanotechnology possesses incredibly unique property and role in food supply chain (including crop production, use of agro-chemicals such as nanofertilizers, nanopesticides and nanoherbicides, precision farming techniques, intelligent feed, enhancement of food texture and quality, bioavailability/ nutrient values, packaging and labeling). From the above, it has been shown that Moringa has played several roles in formulating different nanotechnological strategies, and these areas may need more attention in near future to take the Moringa-based nanoproducts to the next level.

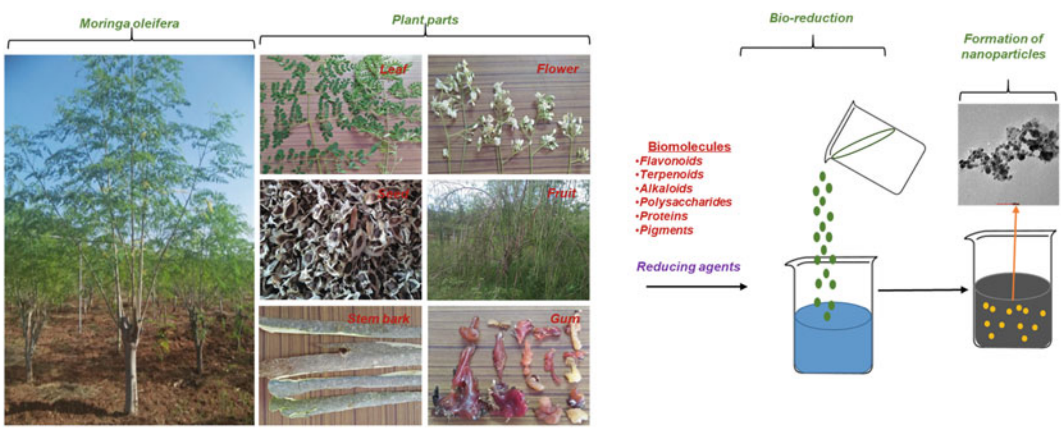

Fig. 13.1 Formation of nanoparticles using different Moringa plant parts

Table 13.1 Applications of nanotechnology that have employed Moringa plant parts

Moringa Plant parts used for synthesis	Nanomaterials	Size	Shape	Application	References
Leaves	Silver nanoparticles	46 nm	Spherical in shape	Nonlinear optics	Sathyavathi et al. (2010)
		57 nm	Spherical morphology	Antimicrobial activity	Prasad and Elumalai (2011)
		30 nm	Spherical morphology	Antimicrobial activity	Nilanjana et al. (2014)
		1–56.9 nm; 2–448.1 nm; 3–4705.0 nm	Polydisperse	Antimicrobial efficacy in packing materials	Narwade et al. (2018)
		5 and 10 nm	Irregular in shape	In vitro cytotoxicity and antioxidant activity	Shousha et al. (2019)
		9 and 11 nm	Spherical in shape	Antimicrobial activity	Moodley et al. (2018)
	Iron nanoparticles	3.4 and 7.4 nm	Spherical in shape	Removal of nitrate from water and antibacterial activity	Katata-Seru et al. (2018)
	ZnO nanoparticles	–	–	–	Manokari and Shekhawat (2016)
		52 nm	Hexagonal wurtzite structure	Photocatalytic and Antibacterial Activity	Pal et al. (2018)
	Vanadium nanoparticles	100 nm	Spherical in shape	Antimicrobial Activity	Aliyu et al. (2017)
	Copper nanoparticles	35.8–49.2 nm	Spherical in shape	Antioxidant and Antimicrobial Activities	Das et al. (2020)
	Bismuth nanoparticles	40.4–57.8 nm	Amorphous morphology	Antimicrobial and Antioxidant Activities	Das et al. (2020)
	NiO nanoparticles	–	Spherical in shape	Anticancer activity	Ezhilarasi et al. (2016)
	ZnS nanoparticles	30 nm	Spherical in shape	Optical, dielectric and electronic	Sur and Ankamwar, (2016)
	TiO_2 nanoparticles	100 nm	Spherical morphology	Wound healing activity	Sivaranjani and Philominathan (2015)
	Gold nanoparticles	20–60	Spherical morphology	–	Anirban et al. (2013)

(continued)

Table 13.1 (continued)

Moringa Plant parts used for synthesis	Nanomaterials	Size	Shape	Application	References
Seed	Iron oxide nanoparticles	–	–	Antibacterial action in wastewater	de Oliveira et al. (2020)
	Magnetite nanoparticles	–	–	Recovery of Precious Metal Ions from Aqueous solution	Amuanyena et al. (2019)
	Silver nanoparticles	–	–	Anti-Methicillin resistant Staphylococcus aureus activity	Kalugendo and Kousalya (2019)
Stem Bark	Silver nanoparticles	40 nm	Spherical- and Pentagon-shaped particles	Anticancer activity	Vasanth et al. (2014)
	ZnO nanoparticles	–	–	–	Manokari and Shekhawat (2016)
Flower	ZnO nanoparticles	–	–	–	Manokari and Shekhawat (2016)
	Silver nanoparticles	8 nm	Monodispersed spherical nanoparticles	Antimicrobial and Sensing application	Bindhua et al. (2020)
Fruit pods	ZnO nanoparticles	–	–	–	Manokari and Shekhawat (2016)
Gum	Gold nanoparticles	20–80 nm	Individually dispersed irregular-shaped particles	antimicrobial activity	Ponnanikajamideen et al. (2016)
Gum	Nanogels	–	Gel with 8% of mucilage was effective	Drug delivery	Panda et al. (2006)

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