Chapter 6
The Role of Plant-Mediated Biosynthesised Nanoparticles in Agriculture

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Abstract Different types of nanomaterials and different strategies could be used in the betterment of the overstressed agriculture. We have tried to focus on the different characterisation techniques involved in nanomaterial synthesis like UV-Vis spectroscopy, scanning electron microscopy (SEM), X-ray diffraction (XRD), transmission electron microscopy (TEM), atomic force microscopy (AFM) and Fourier transform infrared spectroscopy (FTIR). Further, the limitations of physical and chemical methods have also been discussed. We have talked about the organic strategies in detail, like microorganisms and plant-intervened biosynthesis of nanomaterials.

Keywords Nanotechnology · Green synthesis · Nanopesticides · Eco-friendly

6.1 Introduction

Nanotechnology is the link between physical and biological sciences. The plan and improvement of nanomaterials result from information on material designing and its exercises, explored by knowing natural science (Majeed et al., 2020). The

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rapidly growing field of nanotechnology is the interdisciplinary research and developmental field in physics, chemistry and biology. It explores the design, manufacture, assemblage and characterisation of materials that are more modest than 100 nanometres in size, just as the utilisation of scaled-down useful frameworks got from these materials (Nadaroglu et al., 2017). Nanotechnology has expected a colossal part in the agriculture industry, named nano-agribusiness, which infers that this advancement is regularly used to fabricate the yield (Duhan et al., 2017). Metal nanoparticles pulled in scientists due to their wide application and advances in various zones (Herlekar et al., 2014; Zhang et al., 2018). The main drawback of conventional methods is their environmental toxicity; therefore, the requirement for alternatives is increasing faster (Kaur et al., 2014). The nanoparticles synthesised through plants is a straightforward and eco-friendly approach to reduce toxicity, time and cost. There are various assessments subjected to plant-interceded biosynthesis of nanoparticles (Gupta et al., 2018), e.g. TiO_2 NPs impel spinach seed germination and plant improvement (Zheng et al., 2005), and ZnO nanoparticles significantly improve the transport and metabolic processes in plants (Jayarambabu et al., 2014). Similarly, Ag NPs obtained from neem (*A. indica*), dark tulsi (*Ocimum tenuiflorum*) and banana (*Musa balbisiana*) applied on mung bean (*Vigna transmit*) demonstrate a fundamental augmentation in shoot and root lengths (Banerjee et al., 2014). In this chapter, the main focus has been on collecting studies focused on plant-mediated nanomaterial synthesis and its essential function in agriculture.

6.2 Types of Different Nanoparticles (NPs)

The NPs can be categorised into different types:

(i) Inorganic-based nanomaterials.
(ii) Organic-based nanomaterials.
(iii) Carbon-based nanomaterials.
(iv) Composite-based nanomaterials.

6.2.1 Inorganic-Based Nanomaterials

The inorganic NMs consist of metal oxide and metal NPs. The metallic nanoparticles include Ag, Zn, Au, etc., while the metal oxide nanomaterials include TiO_2 and ZnO and semiconductors like ceramics and silicon.

6.2.2 Organic-Based Nanomaterials

These nanomaterials are made mainly from organic matter. The use of weak interactions (noncovalent) for design and molecular self-assemblage helps in turning organic NMs into structures such as liposomes, polymer, dendrimers and desired micelle NPs (Jaison et al., 2018).

6.2.3 Carbon-Based Nanomaterials

These NMs are found in different morphologies like hollow tubes, spheres or ellipsoids and contain carbon. The carbon-based NMs include MXene, carbon nanotubes (CNTs), graphene, fullerenes, carbon nanofibers and carbon black (C60). The methods for the preparation of carbon-based nanomaterials include laser ablation, chemical vapour deposition (CVD) and arc discharge (Kumar & Kumbhat, 2016; Paul et al., 2020; Syamsai & Grace, 2020).

6.2.4 Composite-Based Nanomaterials

Composite-based NMS are materials with at least one of the phases in the nanometre range. They comprise an assemblage of two materials of different types, allowing us to obtain a material of greater quality. Composite-based nanomaterials are a combination of carbon, organic or metal nanomaterials and some forms of polymer bulk, metal or ceramic materials (Jaison et al., 2018).

6.3 Techniques for the Readiness of Nanoparticles

Nanomaterials can be blended top-down and bottom-up methodologies, which are additionally partitioned into various strategies.

6.3.1 Top-Down Approach

This method involves the destruction of bulk materials into smaller molecules, which are later converted into NMs. Physical vapour deposition, milling or grinding are a few examples of the top-down approach.

6.3.2 Bottom-Up Approach

The bottom-up approach is a type of constructive strategy, opposite to that of the top-down approach. In this approach, NMs are obtained through simpler substances. Some examples of the bottom-up approach include sol-gel, pyrolysis and biological synthesis (Yadav et al., 2009).

6.4 Methods of Nanoparticle Production

6.4.1 Physical Methods

Physical methods for NM synthesis employ mechanical strain, high-energy radiations, electrical energy or thermal energy that leads materials to evaporation, condensation, abrasion or melting to produce nanoparticles. Based on physical procedures for NM preparation, they are usually divided into the following types:

6.4.1.1 Mechanical Attrition

Mechanical methods employ the technique of mechanical alloying that gained huge attention over a long time to manufacture various kinds of nanomaterials. Mechanical alloying is considered one of the novel techniques that can be carried out at room temperature. The strategy includes completed force plants, diffusive plants and vibratory industrial facilities (Dhand et al., 2015).

6.4.1.2 Condensation of Inert Gas

It is based on the application of inert gases like helium or argon and sometimes liquid nitrogen on the substrate to synthesise nanomaterials. The nanomaterials, after being evaporated, are transported along with the inert gases over the substrate, which gets condensed with liquid nitrogen. This method was first used by Ward et al. (2006) for the amalgamation of Mn nanomaterials.

6.4.1.3 Physical Vapour Deposition

The physical vapour deposition process is a group of techniques that are widely utilised for nanomaterial synthesis. They help in the formation of thin layers of nanomaterials of a few nanometres. Physical vapour deposition methods are environmentally safe and include three basic steps: vaporisation of materials, transport of vaporised materials and their nucleation to grow them into thin fibres.

6.4.2 Chemical Methods

These are the methods using certain chemical elements for the synthesis of nanomaterials. Different specialist substances like sodium borohydride, hydrazine and hydrogen are utilised for the synthesis (Egorova & Revina, 2000). In light of nanomaterials' compound union, they can also be isolated into two principle types: (i) gas-phase synthesis and (ii) liquid-phase synthesis.

6.4.3 Gas-Phase Synthesis

Gas-phase synthesis is a type of bottom-up approach of nanomaterial synthesis, and among this type of synthesis, gas pyrolysis and gas condensation are the most common types. In gas pyrolysis, the aerosol droplets resulting from metal salt are formed by flame heating. Droplets disperse in the gas, and dehydration decreases their size. Another method is gas condensation, which involves the evaporation of metal salts inside the chamber by different heat sources like laser beams, electron or radio frequencies, etc. The vapours are being pushed into the cooler chamber consisting of inert gases and after that collected from the chamber. The major drawback associated with this method is the agglomeration and amalgamates of nanomaterials (Naveed Ul Haq et al., 2017).

6.4.4 Liquid-Phase Synthesis

It is one of the precipitation methods in which inorganic alkalis act as reducing agents and is reacting with the metal salts to form an insoluble or soluble precipitated product. The product is washed and calcinated at a suitable temperature to produce a particular nanomaterial with variable morphology. With this method, the size can be tailored by optimising synthetic conditions. The liquid-phase synthesis can be divided into different types like sol-gel synthesis and colloidal, hydrothermal and solvothermal methods (Rai et al., 2013). Figure 6.1 shows the different physical and substance systems for nanomaterial synthesis.

6.5 Limitations of Chemical and Physical Methods

Though nanomaterials' physical and chemical syntheses are popular, they are also associated with a large number of risks. Using physical methods, we may obtain nanomaterials of high purity, but they typically require refined equipment, chemical materials, radiations and high energy consumption, leading to high operating costs.

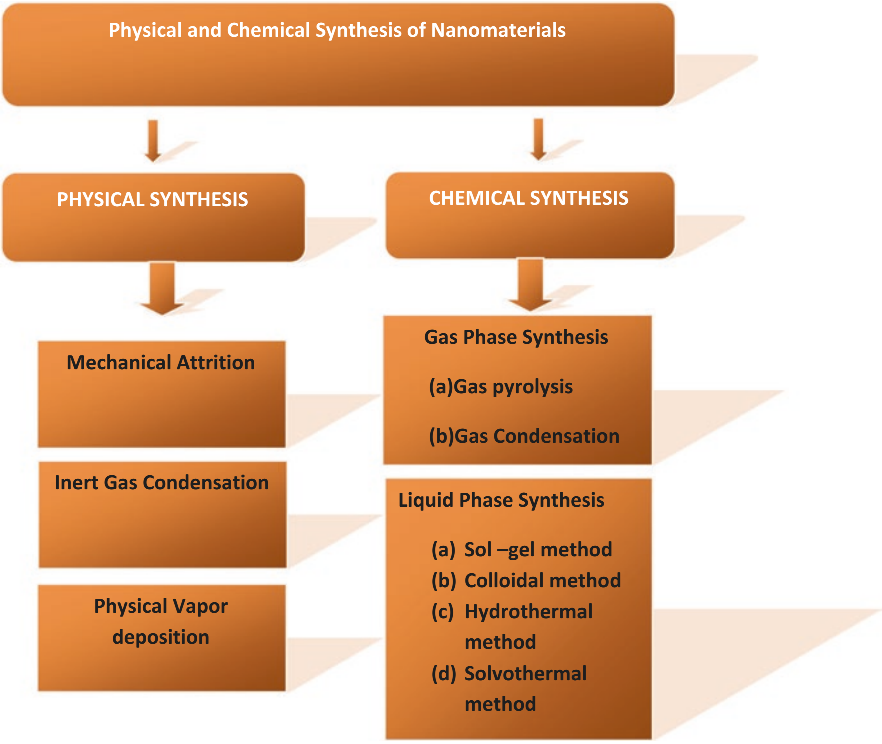

Fig. 6.1 Physical and chemical synthesis of nanomaterials

Again, the chemical synthesis generates many toxic chemicals that are non-biodegradable and harmful and can restrict the manufacturing process. In addition, certain toxic materials may contaminate the surface of nanomaterials and make them unsuitable for different applications. In this context the researcher's main focus is to formulate the alternate route for nanomaterial synthesis to defeat the restrictions of substances and actual strategies (Khandel et al., 2018).

6.6 Characterisation of Nanomaterials

Nanomaterials are characterised by different methods, including UV-Vis spectroscopy, X-ray diffraction (XRD), transmission electron microscopy (TEM), atomic force microscopy (AFM), scanning electron microscopy (SEM) and Fourier transmission infrared spectroscopy (FTIR).

6.6.1 UV-vis Spectroscopy

This is the most straightforward technique used to check the construction of nanoparticles. Different nanoparticles show different peaks, which confirm the structure of NPs in the aqueous medium. The UV-Vis spectroscopy works based on the intensity of light. It detects, analyses and investigates the nanomaterials' optical properties. This method is usually used to check the particles' distribution size (Rajasekaran & Raghavan, 2020; Velappan et al., 2020).

6.6.2 Scanning Electron Microscopy (SEM)

The SEM is one of the versatile techniques used to check the texture, morphology and size of nanoparticles. In this technique, electrons are used instead of light to scan the specimen surface to generate various signals, which give detailed information about the interaction, nature, composition and structure of materials (Raghavan et al., 2020; Sitaaraman et al., 2020).

6.6.3 X-Ray Diffraction (XRD)

The XRD is another technique for nanomaterial characterisation. It gives detailed information about the crystalline structure, crystalline size and lattice parameter of materials. However, this technique only uses the dried powder samples for characterisation. The data obtained from XRD analysis is compared with reference patterns from the Joint Committee on Powder Standards (JCPDS) (Krupa et al., 2019; Mourdikoudis et al., 2018).

6.6.4 Transmission Electron Microscopy (TEM)

Transmission electron microscopy is another quantitative technique used to characterise the morphology and homogeneity of nanomaterials. TEM gives the actual size of nanomaterials and accurate images of the nanoparticles. In TEM the uniform electron beam touches the samples and diffuses through them. The formation of images by TEM analysis is due to the interaction of samples with an electron, wherein the imaging device further magnifies the samples. We can get the maximum resolution through TEM than other characterisation techniques. The information about size, structure, shape, morphology and agglomeration is only possible through this technique (Chakravorty et al., 2020).

6.6.5 Fourier Transmission Infrared Spectroscopy (FTIR)

It is one of the analytical techniques used to study the different kinds of practical gatherings present in the biomolecules. During nanomaterials, the functional groups that act as capping and reducing agents are studied through this technique. It gives information about the molecular structure, nature of bonds and the functional groups involved in nanomaterial biosynthesis. It works on an electromagnetic absorption spectrum and wavelength ranging from 400 to 4000 cm^{-1} (Busó-Rogero et al., 2016).

6.6.6 Atomic Force Microscopy

Atomic force microscopy is one of the microscopic techniques that can produce three-dimensional pictures of the sample surfaces. The basic principle of atomic force microscopy is the interaction of forces involved between samples and fine probe. AFM gives the detailed size, shape and surface area of nanomaterials.

6.7 Biological Synthesis of Nanomaterials

The biological process of nanomaterial synthesis is the alternative to the physical and chemical methods (Fig. 6.2). It is a cheap, non-toxic, environmentally friendly option of nanomaterial synthesis compared to its physical and chemical counterparts. Nanomaterials with different sizes and shapes can be prepared through biological synthesis (Shah et al., 2015). The synthesis of nanomaterial through biological routes leads to safer, ecologically appropriate and non-toxic nanomaterial through the involvement of bacteria, fungi and plants (Nayantara & Kaur, 2018).

6.7.1 Bacteria-Mediated Biosynthesis of Nanomaterials

Research has been heavily based on prokaryotes as the easy and ideal ways to synthesise different nanoparticles. Because of their ability to adjust to extreme conditions and their abundance in the environment, microbes are decent contenders in nano-research. They can be handily controlled as they are fast-growing and inexpensive to cultivate in large quantities. Their growth conditions, including oxygen, incubation and temperature, can be easily monitored, and controlling such parameters can produce nanoparticles of different sizes (Pantidos & Horsfall, 2014). Different strains of bacteria like yeast, moulds and microalgae have been utilised to integrate metallic and non-metallic nanoparticles (Hulkoti & Taranath, 2014). Different types of nanomaterials like gold, silver and selenium with different

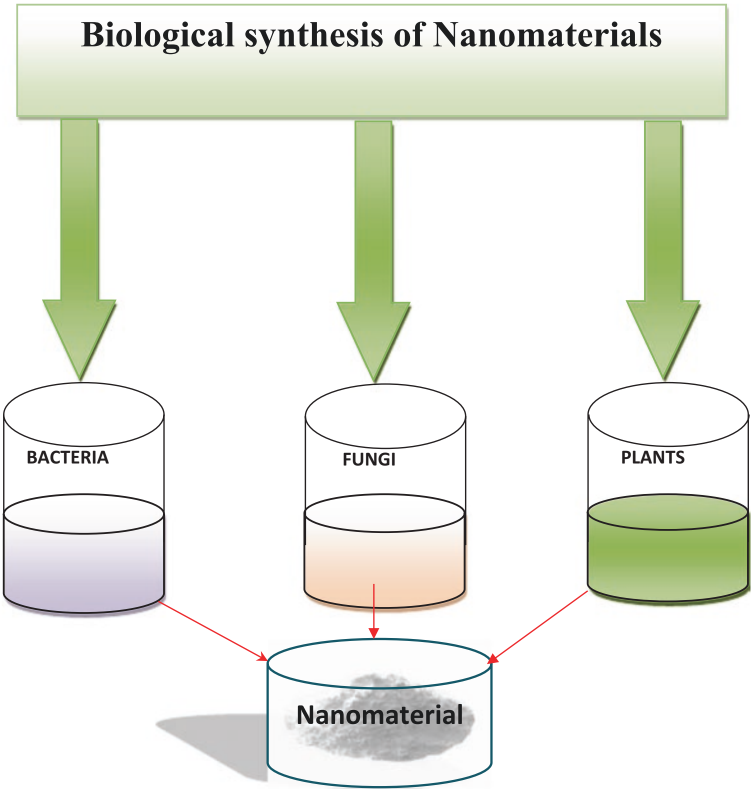

Fig. 6.2 Biological synthesis of nanomaterials

properties and different purposes like imaging, biosensors, in vitro antibacterial, anticancer, antioxidant and anticoagulant activities have been synthesised from bacteria over time (Grasso et al., 2019). *Bacillus* species have been widely considered because of their ability to bioaccumulate metals (Pantidos & Horsfall, 2014). Microbe-intervened amalgamation of nanomaterials can be classified into intracellular or extracellular by the guide of chemicals or proteins present in microorganisms which can go about as lessening specialists and convert metal salts into specific nanomaterials (Nadaroglu et al., 2017). Different bacteria like *Pseudomonas stutzeri*, *Pseudomonas aeruginosa*, *Escherichia coli* and *Vibrio cholera* have been utilised to combine diverse metallic nanoparticles through intracellular and extracellular strategies (Nayantara & Kaur, 2018; Srinath & Ravishankar Rai, 2015). Extracellular is the simplest method as it occurs outside the bacterial cells and does not involve the breakdown of the cell wall. It includes the usage of bacterial biomass, supernatant and cell-free extracts. The extracellular synthesis is preferred over intracellular synthesis as it does not involve complex downstream processes. The main challenge in microbe-based nanomaterials is the selection of choosing the right microbe, depending on its essential properties like replication, growth rate and biochemical pathways to be studied. Another aspect of microbe-interceded nanomaterials is reducing the temperature, which can control their size and mono dispersion (Ovais et al., 2018).

6.7.2 Fungal-Mediated Nanomaterials

Fungi have a great potential for the manufacture of different nanomaterials; around 6400 bioactive substances have been separated from the filamentous organisms and their connected species. Because of the substantial metal resilience and ability to disguise and bio-gather metals, organisms go about as significant balancing out and decreasing specialists. In addition, fungi can be quickly grown on a large scale and can produce size-controlled nanomaterials with definite morphologies (Guilger-Casagrande & de Lima, 2019). Fungus is a great contender for nanomaterial synthesis as it goes about as apparatus for a huge amount of proteins and quick and simple combination of nanomaterials (Alghuthaymi et al., 2015). The extracellular enzymes produced by several fungi are considered to play an essential role in nanomaterial biosynthesis. The enzymes include cellobiohydrolase D, glucosidase, acetyl xylan esterase and β-glucosidase. The enzyme nitrate reductase, released by fungi, acts as a reducing agent in nanomaterial production. Silver and gold nanoparticles have been produced from *Fusarium oxysporum* (Ovais et al., 2018).

Similarly, *Duggingyonia flagans* are used to synthesise silver nanoparticles by using insect carapaces as a source of substrate for fungi (Costa Silva et al., 2017). *A. alternata* can be used to synthesise silver nanoparticles (Ibrahim & Hassan, 2016). The microbial-assisted synthesis of nanomaterials has been found to be very easily scalable, co-friendly and consistent. Still, the production is more expensive because of extended time maintenance of cultures, and chances of contamination are very high. Moreover, microbial-based techniques require high aseptic conditions and maintenance that are not appropriate for nanomaterials' large-scale production, so plant-based nanomaterial production is preferred over microbial-based. The key advantage of bio-based methods over physical and chemical methods is that large-scale nanomaterials involve environmentally friendly, simple and one-step processes rather than chemicals, high temperature and pressure (Khandel et al., 2018).

6.7.3 Plant-Based Nanomaterials

Plants are the bio-factories for many active compounds like flavonoids, terpenes, alkaloids, enzymes and proteins, acting as capping and balancing out specialists for the nanomaterial synthesis (Fig. 6.3). The mechanism of nanoparticle synthesis

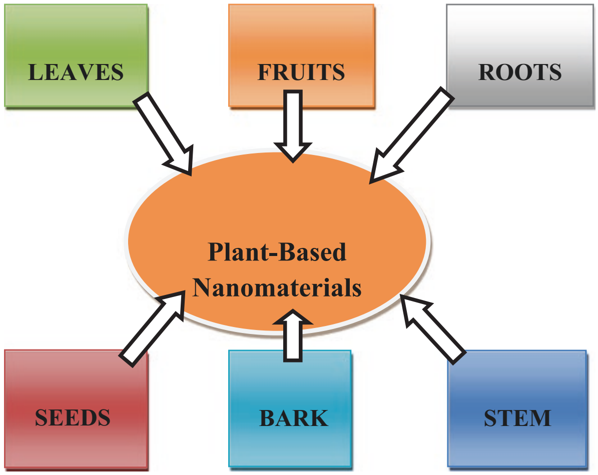

Fig. 6.3 Different parts of plants for nanomaterial biosynthesis

from plants is the same as that of microbial synthesis, but it's cheap, less costly and environmentally friendly (Khandel et al., 2018). Different parts of plants like leaves, roots, stem, bark, shoots, latex, seeds, peels, oils, natural products and so on can be utilised for the nanomaterial combination, as they can go about as great wellsprings of phytochemicals (Dauthal & Mukhopadhyay, 2016). Diverse metal oxide nanoparticles have been set up through a green approach. Zinc oxide nanoparticles use different plant extracts like *Cassia alata*, *Bauhinia tomentosa* and *Catharanthus roseus* (Happy et al., 2019; Gupta et al., 2018; Sharmila et al., 2018). Spherical-shaped nanoparticles were synthesised from various plant parts like *A. calamus* roots and *A. dentata* leaves (Kumar et al., 2014; Nakkala et al., 2014). Different types of plants like clove buds, cardamom, black pepper and saffron have been used for various types of nanomaterial synthesis (Chakravorty et al., 2020).

Plant-based selenium nanoparticles (SeNPS) have been carried out using different plant extracts like *Citrus reticulate*, *Catharanthus roseus*, *Leucas lavandulifolia*, *Allium sativum*, *Aloe vera* and *Asteriscus graveolens* (Anu et al., 2017; Deepa & Ganesan, 2015; Fardsadegh & Jafarizadeh, 2019; Kirupagaran et al., 2016; Sasidharan et al., 2014; Zeebaree et al., 2020). *Euphrasia officinalis* leaf extract mediated biosynthesis of gold nanoparticles (AuNPs) and silver nanoparticles (AgNPs) (Singh et al., 2018), and *Ziziphus* leaf extract mediated gold nanoparticles (Aljabali et al., 2018). *Indigofera tinctoria* leaf extract mediated silver (AgNPs), and gold nanoparticles (AuNPs) are a major highlight of the plant-based nanomaterials (Vijayan et al., 2018).

6.8 The Role of Nanoparticles in Agriculture

Human beings obtain their food directly or indirectly from the agriculture sector and keep in view the overgrowing world population. It is imperative to use new technologies like bio- and nanotechnology in the agricultural industry. In developing countries, the development of agribusiness is seen as a context for development. The field of nanotechnology has not just improved current horticultural practices by making them more secure, specialised and powerless yet, in addition, raised the nature of farming items by making them exceptionally nutritious and infection safe. The use of nanotechnology in horticulture has helped create work openings, new rural items, stockpiling/bundling techniques and the longer timeframe of realistic usability and, in a manner, has also improved the nature of water. The field of nanotechnology can improve the production and quality of food. A report published by Wheeler (2005) suggested that modern techniques can meet growing food demands and boost health, economic and environmental sectors as well. Lately, the significance of nanotechnology in the farming area has been acknowledged, although its examination started some 50 years back (Mukhopadhyay, 2014). In developing countries, more than 60% of the people earn their livelihood directly or indirectly from agriculture, thus acting as a backbone of their economy (b; Brock et al., 2011; Qamar et al., 2014; Rai & Ingle, 2012a). In the rural area, nanotechnology has arisen as one of the best basic instruments, and soon, it might turn into an anticipated thrust. To improve crop productivity, nanotechnology employs different approaches that involve the use of novel delivery systems and chemical agents posing a lesser threat to the welfare of living beings. Nanotechnology offers answers for the current issues in farming regions and gives trust in improving yield efficiency by better administration and protection programmes. Due to the extraordinary physicochemical properties of nanoparticles, nanotechnology offers incredible breadth to fulfil the food needs of the rising total populace. These nanoparticles control a broad scope of utilisations, essentially their utilisation in treating human sicknesses and in the agricultural area. In the rural area, nanoparticles have different applications as depicted in Fig. 6.4.

However, the most important aim of nanomaterials that is of a greater significance is to improve crop productivity and plant protection as discussed below.

6.8.1 Crop Productivity

Nanomaterials have been utilised to improve crop profitability and effectiveness. In the agricultural sector, a new strategy based on nanoparticle use has been commonly employed to address crop yield and efficiency problems. For supportable farming, nanotechnology can expand world food production, improve the nature of foods, screen plant development, distinguish sicknesses of plants/animals and give insurance to plants and capacity to decrease squanders (Biswal et al., 2012; Ditta, 2012;

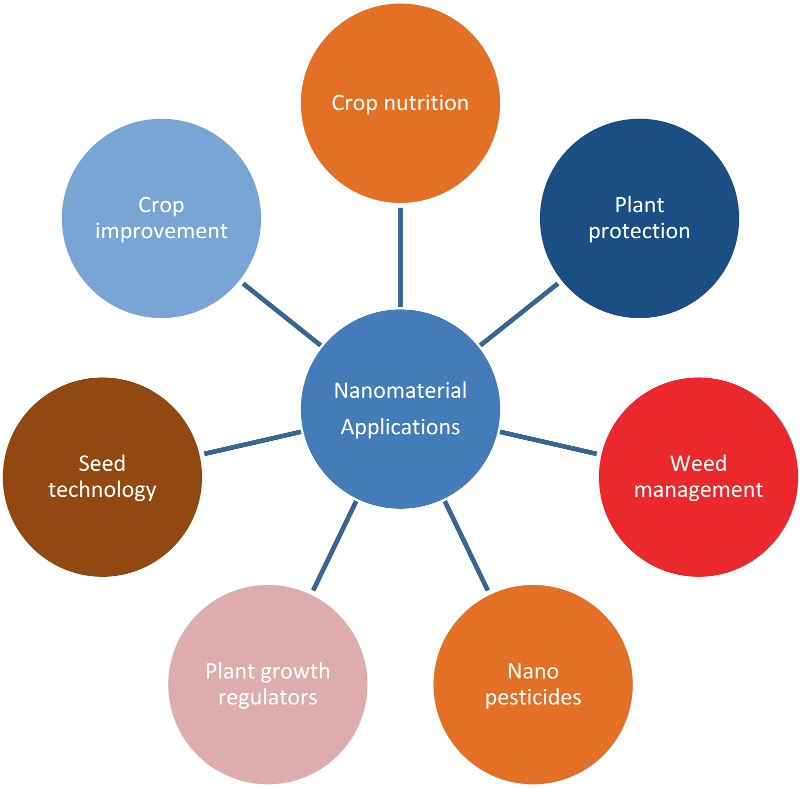

Fig. 6.4 Applications of nanomaterials in agriculture

Frewer et al., 2011; Gruere et al., 2011; Perez-de-Luque & Hermosín, 2013; Prasad et al., 2014; Sonkaria et al., 2012). The plants hereditarily incited by nanomaterial-based substances can assume a vital part in expanding agrarian efficiency (Kuzma, 2006; Scott, 2007). In plants and animals at cellular/molecular levels, the induction of molecules by gene delivery, site-specific drug delivery and nano-array-based gene modifications have been used (Maysinger, 2007). The factors that determine nanoparticle efficiency include size, chemical composition, reactivity and surface area. On plant development and improvement, nanoparticles may display both positive and negative impacts. A study on tomato seeds (Khodakovskaya et al., 2009) reported that the inserted carbon nanotubes (CNTs) increased their germination efficiency multiple times because CNTs improved the capacity of water take-up (Khodakovskaya et al., 2009). The growth of spinach increased with the use of TiO_2 nanoparticles, which enhanced the activity of the Rubisco enzyme and improved the absorbance of light (Hong et al., 2005; Yang et al., 2006). It was found that Tio_2 nanoparticles enhanced nitrogen metabolism, which ultimately improved spinach growth (Yang et al., 2007). A study reported by DeRosa et al. (2010) found that in corn and ryegrass, seed germination was inhibited by ZnO nanoparticles. The use of

Table 6.1 Significant nanoparticles for plant development and advancement

Nanoparticles	Plant	Effects	References
TiO_2	*Spinacia oleracea*	Induction of enzyme activity	Yang et al. (2006)
Alumina NPs	*Lemna minor*	Increased root length	Juhel et al. (2011)
Cerium oxide NPs	*Corn, soybean, alfalfa*	Increased growth of the stem and root	López-Moreno et al. (2010)
Iron oxide NPs	*Glycine max*	Improved quality and yield	Sheykhbaglou et al. (2010)
Iron oxide NPs	*Vigna radiate*	Biomass enhancement	Dhoke et al. (2013)
CuO NPs	*Triticum aestivum*	Increased biomass	Dimkpa et al. (2012)
CeO_2 NPs	*Arabidopsis thaliana*	Increased biomass	Ma et al. (2013)
G NPs	*Arabidopsis thaliana*	Early flowering and increased root and shoot length	Kumar et al. (2013)
TiO_2 NPs	*Triticum aestivum*	Increased chlorophyll content	Mahmoodzadeh et al. (2013)
CNTs	*Lycopersicum esculentum*	Enhanced seed germination and growth	Morla et al. (2011)
MWCNTs	*Lycopersicum esculantum*	Improved height of the plant along with an increased number of flowers	Khodakovskaya et al. (2013)
ZnO NPs	*Cicer arietinum* L.	Increased dry weight and shoot growth	Burman, Saini and Kumar et al. (2013)
ZnO NPs	*Arachis hypogea*	Increased yield, stem and root growth	Prasad et al. (2012)
AI NPs	Radish	Improved root growth	Lin and Xing (2007)
Au NPs	Lettuce, cucumber	Increased germination index	Barrena et al. (2009)

ZnO-based nanomaterial left some porous spaces in the roots of these plants, thus creating a potential route for nutrient delivery systems.

Other nanoparticles that have been discovered to be significant for plant development and advancement are listed in Table 6.1.

6.8.2 Plant Protection

In addition to enhancing crop productivity, nanoparticles are also known to protect plants from various diseases. Several approaches have been used to manage crop diseases, particularly genetic breeding, sanitation schemes, new pesticides and integrated pest management. New insights have been provided by nanotechnology for improving and modifying present crop management methods. Techniques such as spraying and broadcasting are conventionally used for applying plant protection chemicals and nutrients. However, the minimum required amounts of chemicals/nutrients do not reach the target site because of leaching, hydrolysis and microbial degradation. The conventional methods of crop protection generally involved the use of large-scale herbicides, insecticides and fungicides. Over 90% of the pesticides used for pest control were either lost in the environment or were unable to reach the target sites (Nuruzzaman et al., 2016). The utilisation of pesticides expanded the cost expenses and caused degradation of the general climate. In this regard, a better initiative that was needed in the agricultural sector to protect plants from microbial diseases was the development of nanoformulations or encapsulation of pesticides. These nanoformulations contain a small number of tiny particles with pesticides as active ingredients. Nanoparticles of carbon, silver, silica and alumina silicates have been used to control plant diseases caused by various phytopathogens. The epitomised nanoformulations encourage the controlled arrival of dynamic fixings into the objective zones of plants and hence give better outcomes. The pesticides of conventional origin have various limitations like limited solubility, increased resistance and nanoformulations; these problems are decreased (Dwivedi et al., 2016). Therefore, to accomplish higher harvest creation, the criticalness of nanotechnology has expanded dramatically. A study reported by Petosa et al. (2017) showed that the pesticide nanoformulations boosted crop yield by enhancing the efficacy of pesticides by regulating their transport potential. Their study combined polymeric nanocapsules with pyrethroid bifenthrin (Ncap-BIF), which ended up being a promising conveyance vehicle for plant security. The catalytic activity of trypsin, known as a viral protease, was reduced by fabricated bioactive AuNPs, thereby proving effective in controlling insects. This change in catalytic activity was believed to be due to the interaction of proteins with metallic nanoparticles (Patil et al., 2016). For instance, to control the growth of *Penicillium expansum*, *Alternaria alternate*, *Rhizopus stolonifer*, *A. flavus*, *Fusarium graminearum* and pathogenic bacteria, ZnO nanoparticles have proven to be effective (Dwivedi et al., 2016; Vanathi et al., 2016). Further, Si and TiO_2 have shown a promise in suppressing crop diseases through its antimicrobial activity. In sustainable agriculture development, nanomaterial-encapsulated pesticides, herbicides and fungicides have shown a tremendous scope.

6.9 Conclusions

Nanotechnology has emerged as the most innovative science with widespread applications. It has solved many agriculture-related issues like nutrient uptake efficiency, insect pest control and crop production. The synthetic pesticides available in the markets have negatively impacted the environment due to their toxic and persistent nature. To avoid the limitations of these synthetic pesticides, pest management could be done by involving nanotechnology-based nanopesticides. The nanopesticides are non-toxic and safe to use. To beat the impediments of biological or green synthesis methods, nanoparticles are favoured as eco-friendly, less toxic and healthy alternatives. In this regard, we will understand the role of green synthesised nanoparticles in agriculture management in this chapter.

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