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GREEN SYNTHESIS OF NANOPARTICLES AND THEIR EFFECT ON PLANT GROWTH AND DEVELOPMENT: A REVIEW

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ABSTRACT

Nanotechnology permits advance research in several areas and opens a large scope in the field of biotechnology and agriculture industry due to unique physiochemical properties. To fulfill the increasing demand of world population higher agricultural productivity is needed to boost the yield. This review presents the current literature and key role of nanoparticles on plant growth, development and yield. The synthesis of nanoparticles by green method with the use of plant extract which is nontoxic, cost effective, ecofriendly over physical and chemical methods. Phytochemical constituents in the plant extract such as phenols, proteins, flavonoids, carbohydrates, alkaloids and amino acids is responsible for the reduction of size of nanoparticles.

***Keywords* :** Nanoparticles,Green method, Phenols, Proteins, Flavonoids, Carbohydrates, Alkaloids and Amino acids

Introduction

In science and technology, huge amount of development has been brought by nanotechnology in the recent years (Kalpana and Rajeswari, 2018). Nanotechnology brings revolution in all over the world (Arora *et al*., 2012).Particles within the size range of 1-100 nm are considered as nanoparticles (NPs) (Chung *et al*., 2016). Important properties of NPs have a large surface area, high surface energy and quantum confinement (Nel *et al*., 2006). It has become important to increase crop production to feed the growing world population, to meet the increasing demand. Nanotechnology, in the current technological innovations, obtained an important position in transforming agriculture and food production (Nair *et al*., 2010). Although fertilizers are very important for plant growth and development, most of the applied fertilizers are rendered unavailable to plants due to a variety of factors such as leaching, photolysis, hydrolysis, and decomposition (Siddiqui *et al*., 2015). Thus, it is critical to advance research in order to minimize nutrient losses in fertilization and increase crop yield through the use of new applications enabled by nanomaterials and nanotechnology (Singh *et al*., 2015). Nanotechnology has enormous potential in terms of high reactivity, agricultural uprising, improved bioavailability, bioactivity, and NPs surface effects (Gutierrez *et al*., 2011). Engineered nanoparticles have the ability to enter plant cells and leaves, as well as transport DNA and chemicals into plant cells (Galbraith 2007 and Torney *et al*., 2007).Nanomaterials have ability to engineer plant function but the mode of transport, absorption and distribution of nanoparticles within plant word is still remaining poorly understood. Nanobionics to engineer plant function opens a gate in the new research field at the interface of nanotechnology and plant biology (Giraldo *et al*., 2014).

Harmful impact of solvents and synthetic reactants on environment due to intensive use, for this reason need an alternative 'green' method application which is environment friendly reactants for the preparation of nanomaterials (Leon *et al*., 2013). In the synthesis of NPs medicinal plants were preferably choose that already reported for biomedical properties and having wide range of natural products (Kumar and Kumar, 2017). Bioactive phytochemicals constituents reacted to reduce metals into metal oxide and showing good stability in the formation of NPs (Mishra and Sharma, 2015).

Green synthesis of Nanoparticles

The method generally used for producing nanoparticles is top down approach and bottom up approach (Sepeur, 2008). In top down approach various physical and chemical methods are used for size reduction of material to producing nanoparticles (Meyers *et al*., 2006). The major limitation of this method is the imperfection of the surface structure of nanoparticles because physical properties and surface chemistry are highly dependent on surface structure (Thakkar *et al*. 2010). In Bottom up approach, small entities are joined e.g. molecules, atoms and small particles of nanometer range by using chemical and biological method (Mukherjee *et al*., 2001). Biological method, synthesis of nanoparticles involved microorganisms, plants or plant extract and enzyme, it is more ecofrienldy over physical and chemical methods (Nair *et al*. 2002 and Schultz *et al*., 2000). Plant or plant extract reduces the complexity of maintaining cell culture of biological method for biosynthesis of nanoparticles (Wilner *et al*., 2006). Biological entities carry capping and stabilizing agents. Enzymes, sugar, proteins and phytochemicals like flavonoids, terpenoids, phenolics, cofactors acts as stabilizing and reducing agents (Kaushik *et al*., 2010 and Khiarissova *et al*., 2013 Figure 1& Table1).

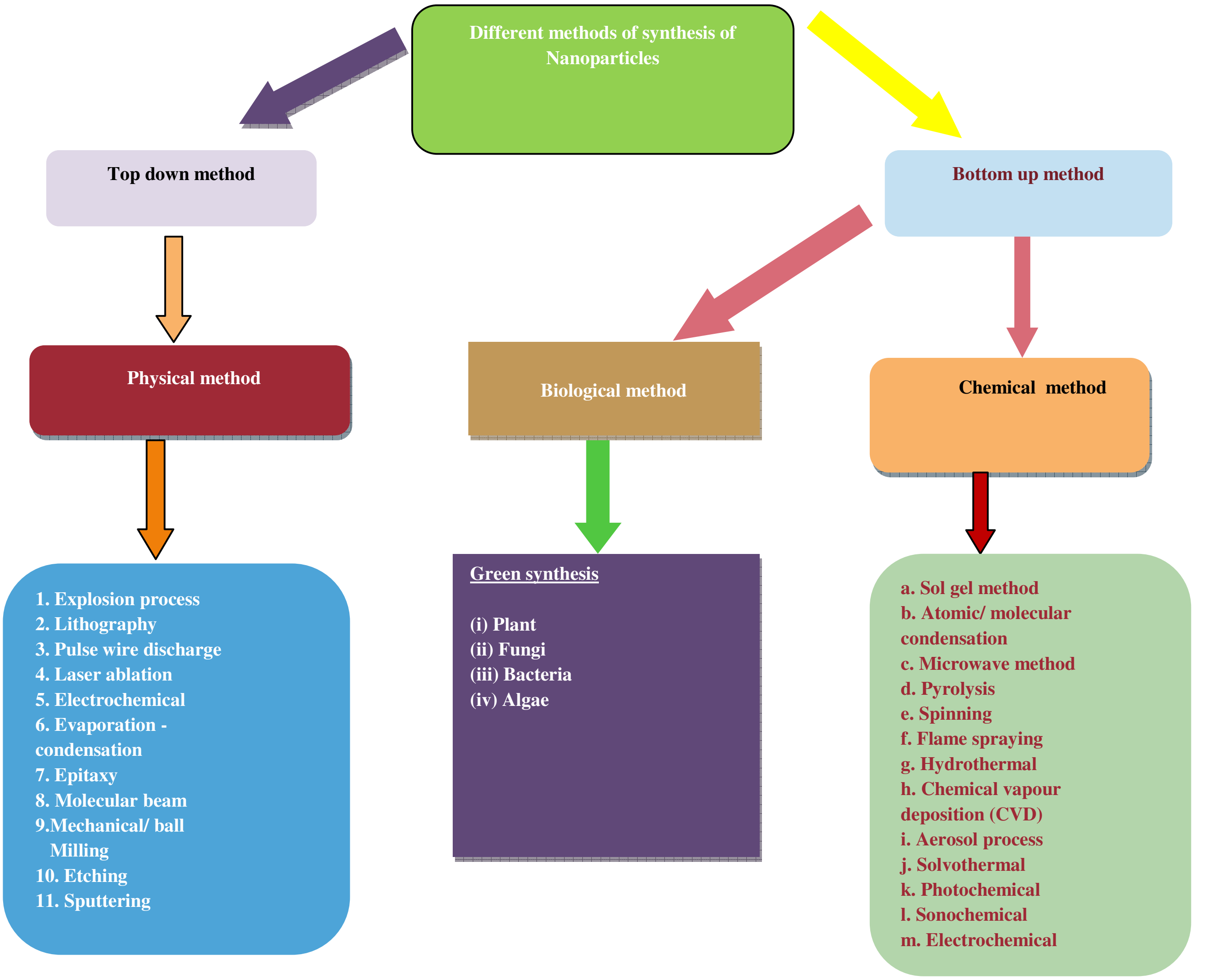

Fig. 1 : Schematic representation of various methods for synthesizing nanoparticles

Table 1 : Synthesis of nanoparticles via different plant parts

Plant	Biosynthesis of nanoparticles	Size of nanoparticles (in nm)	Precursors	References
Cynodon dactylon	Bio silica	7 -80	-	Babu *et al*. (2018)
Croton sparsiflorus	Ag	22–52	$AgNO_3$	Kathiravan *et al*. (2015)
Euphorbia condylocarpa	Pd/ Fe_3O_4	Less than 39	$PdCl_2$ & $FeCl_36H_2O$	Nasrollahzadeh *et al*. (2015)
Cocos nucifera	Pb	47	$Pb(COOH)_2$	Elango and Roopan (2015)
Gloriosa superba	CeO_2	5	$CeCl_3$	Arumugam *et al*. (2015)
Malva sylvestris	CuO	14	$CuCl_2.2H_2O$	Awwad *et al*. (2015)
Catharanthus roseus	Pd	38	Pd(OAc)	Kalaiselvi *et al*. (2015)
Cassia alata	CuO	110-280	$CuSO_4$	Jayalakshmi and Yogamoorthi (2014)
Olea europaea	Ag	20-25	$AgNO_3$	Khalil *et al*. (2014)
Camellia sinensis	ZnO	16	$Zn(O_2CCH_3)_2(H_2O)_2$	Senthilkumar and Sivakumar (2014)
Phyllanthus amarus	CuO	20	$CuSO_4$	Acharyulu *et al*. (2014)
Oryza sativa	TiO_2	13	$TiO_2(OH)_2$	Ramimoghadam *et al*. (2014)

Gum karaya	CuO	4.8-7.8	$CuCl_2.2H_2O$	Velora *et al.* (2013)
Chenopodium album leaf extract	Silver and gold	10-30	$AgNO_3$, Auric acid	Dwivedi and Gopal (2010)
Parthenium hysterophorus leaf	Ag	30-80	$AgNO_3$	Parashar *et al.* (2009)
Mentha piperita leaf	Ag	10-25	$AgNO_3$	Parashar *et al.* (2009)
Capsicum annum	Ag	10-40	-	Li *et al.* (2007)
Pelargoneum graveolens	Ag	16-40	$AgNO_3$	Shankar *et al.* (2003)
Medicago sativa	Gold	2-20	-	Torresday *et al.* (2002)

Role of different NPs on Plant Physiology and Biochemistry

In present years, plant interactions with nanoparticles have resulted in a variety of morphological and physiological changes, depending on the properties of the NPs. The chemical composition, size, surface area, reactivity, and dose at which they respond positively determine the adequacy of NPs (Khodakovskaya *et al.*, 2009). This review deals with the possible roles of different types of NPs in seed germination, photosynthesis and plant growth etc.

(i) Silicon dioxide nanoparticles

Lower concentration of SiO_2 (10 & 20 ppm) NPs significantly increased the percentage of seed germination in *Sorghum bicolor* (Bhatia *et al.*, 2014). Under salt stress, silicon significantly helps in recovery at growth stages, including germination in wheat (Ahmad *et al.*, 1992). By increasing gas exchange and chlorophyll fluorescence parameters such as net photosynthetic rate, transpiration rate, stomatal conductance, PSII potential activity, effective photochemical efficiency, actual photochemical efficiency, electron transport rate, and photochemical quench, nano-SiO_2 promotes plant growth and development (Siddiqui *et al.*, 2014 and Xie *et al.*, 2011). Exogenous application of nano-SiO_2 and nano-titanium dioxide (nano-TiO_2) improves soybean seed germination by increasing nitrate reductase (Lu *et al.*, 2002) and improving the seeds' ability to absorb and utilise water and nutrients (Zheng *et al.*, 2005).

(ii) Zinc Oxide nanoparticles

Studies suggested that zinc oxide NPs induces plant growth and development. Zinc deficiency can lead to disorders in factors regulating growth in plants (Luomg and Kim, 2015). It decreases grain yield, plant protein percentage and the nutritional value of products (Taheri *et al.*2015). Laware and Raskar (2014) found that at the concentration of 20 and 30μg ml^{-1} better growth and flowering occurred with higher values of seeded fruit per umbel, seed weight perumbel and 1000 seed weight, it overall reduce the photoperiod in onion. Hafizi and Nasr (2018) found varied concentrations as beneficial nanoparticles on the level of enzymes in safflower. Munir *et al.* (2018) reported that ZnONPs induced a significant improvement in wheat growth characteristics, photosynthesis and biomass by seed priming method, Zn were found to be in higher concentration in the roots, shoot and grains of wheat than the control reduce the Zn deficiency in plants. Three different physical forms of ZnO particles (ZnO nanocolloid, ZnO nanoparticles, and micrometric ZnO particles)were analyzed in irrigation water supplied to mineral poor soil. Taheri *et al.* (2015) found that all the three helps in improving shoot dry matter and leaf area index while the best result given by ZnO nanoparticle treatment so they concluded that zinc nanoparticles can improve corn growth and yield in mineral-depleted soils. Siddiqui *et al.* (2018) reported that a foliar spray of ZnO NPs to plants lacking *Rhizobium* resulted in significant improvements in lentil growth, pod number, chlorophyll, carotenoid content, and NR activity in both inoculated and uninoculated plants. Thunugunta *et al.* (2018) observed positive impact of ZnO nanoparticles to the seedling growth of eggplant under greenhouse conditions while negative impact has been seen under tissue condition. ZnO and $ZnSO_4$ NPs were examined at 1000 and 2000 mg L^{-1} concentration ZnO NPs at a concentration of 1000 mg L^{-1} positively affected plant height, stem diameter, and chlorophyll content, increased fruit yield and biomass accumulation compared to $ZnSO_4$ treatments and could be used habanero pepper production to improve yield, quality, and nutraceutical properties of fruits (Lopez *et al.* 2019)

(iii) Silver Nanoparticles

Salama (2012) studied the effect biologically synthesized AgNPs of different concentrations 20, 40, 60, 80 and 100 ppm on (*Phaseolus vulgaris* L.) and corn (*Zea mays* L.) and discovered that biosynthesized AgNPs had a significant impact on the growth of plantlets. Sadak (2019) analyzed the different concentration of AgNPs among the 40mg/l concentration showed the best results in improving the growth parameters and as well in biochemical parameters such as shoot length, number of leaves/plant, shoot dry weight, photosynthetic pigment (chlorophyll a, chlorophyll b, and carotenoids), indole acetic acid (IAA) contents thus enhance the yield quantity (number of pods/plant, number of seeds/pod, weight of seeds/plant, and seed index) quality (carbohydrate%, protein%, phenolics, flavonoids, and tannins contents) of the yielded seeds as well as increasing antioxidant activity of the yielded seedsof fenugreek plant. Recently, Krishnaraj *et al.* (2012) investigated the effect of biologically synthesised Ag NPs on the growth metabolism of hydroponically grown *Bacopa monnieri* and concluded that biosynthesized AgNPs have a significant effect on seed germination, induced protein and carbohydrate synthesis, decrease total phenol contents, and catalase and peroxidase activities.

(iv) Titanium dioxide Nanoparticles

Number of studies has been done to understand the impact of titanium dioxide nanoparticles (TiO_2NPs) on bacteria, algae, plankton, fish, mice, and rats but less work has been done on plant (Siddiqui etal. 2015). TiO_2NPs have the capability to affect the food chain, processing and economics of barley (Mattiello and Marchiol, 2017). Dehkourdi andMosavi (2013) reported that parley seeds treated by nano-anatase showed a rise in the percentage of germination, the germination rate index, the root and shoot length, the fresh weight, the vigor index, and the chlorophyll content of the seedlings. TiO_2NPs enhanced seed germination, radicle and plumule growth of canola seedlings (Mahmoodzadeh *et al*., 2013). Jiang *et al*. (2013) studied the combined effects and physiological mechanism of high-CO_2 and TiO_2 NPs on wheat and gives the better understanding of the joint effects to terrestrial plants. Faraji and Sepehri (2018) studied the joint effects of TiO_2 NPs and sodium nitroprusside (SNP) donor of NO (nitric oxide) on seed germination and seedling growth of wheat under cadmium (Cd) stress and concluded that it would be an approach in preventing the negative effects of Cd stress. Both nano titanium dioxide (n-TiO_2) and sodium nitroprusside (SNP)increases tolerance under salinity stressin barley by increasing the some antioxidant enzyme activities (Karami and Sepehri, 2018). Under water deficient stress, foliar application of titanium dioxide nanoparticles increases plant growth characteristics of thyme in *Thymus vulgaris* (Nasab *et al.,* 2018). TiO_2NPs enhances the nitrate reductase, carbonic anhydrase activities, Chlorophyll fluorescence, net photosynthetic rate, essential oil productivity and yield of *Mentha piperita* L. (Ahmad *et al*. 2018).

(v) Gold Nanoparticles

Betwixt metal-based nanoparticles, impact of AuNPs on germination, water balance, nutrition, genotoxicology or seed production is still unexplored (Hendel *et al*., 2017).Gold nanoparticles are biocompatible and have the potential to be used as nanocarriers in agriculture (Ndeh *et al*., 2017). Smaller sized gold nanoparticles were more effective in inducing the percentage of seed germination and shoot length of tomato seedlings, and have higher content of chlorophyll in contrast to control plant (Thakur *et al*. 2018).Barrena *et al*. (2009) in lettuce and cucumber, Savithramma *et al*. (2012) in *Boswellia ovalifoliolata*, Arora *et al*. (2012) in *Brassica juncea* and Gopinath *et al*. (2014) in *Gloriosa superba* observed that AuNPs enhance seed germination. AuNPs enhance the number of leaves, leaf area, plant height, chlorophyll content, and sugar content that lead to the better crop yield.

(vi) Carbon Nanotubes

Betwixt NPs, carbon nanotube (CNTs) possess a significant place due to their exceptional mechanical, electrical, optical and thermal properties (Hurt *et al*., 2006; Bennett *et al*., 2013; Srivastava *et al*., 2015). The majority of current CNTs research has focused on people and animals (Ke *et al*., 2011 and Tiwari *et al*., 2014). There has been a scarcity of information on carbon nanotubes and their interactions with plant cells and metabolism (Siddiqui *et al*., 2015). Two different types of CNTs, single-walled (SWCNT) and multi-walled (MWCNT) (Vithanage *et al*., 2017). Delivery of chemicals to cells, penetration in the cell wall and cell membrane by carbon nanotube (Siddiqui *et al*., 2015). CNTs added to soil mix through watering and two times more yield of flower and fruit in comparison to control plant in tomato with regular soil thus act as a plant growth regulator (Khodakovskaya *et al*., 2013). CNTs greatly influence the cell walls of tomato seed coats and stimulate the seedling growth and germination (Khodakovskaya *et al*., 2009). Oloumi *et al*. (2018) observed that the response of MWCNTs on heavy metal and growth parameters accumulation in plant seedlings is mainly depends on heavy metal type, MWCNTs concentration and plant species. Water soluble carbon nanotubes at 6.0 mg mL^{-1}increased growth rate of every part of *Cicer arietinum*, indicating better water absorption and retention related to enhanced growth (Tripathi *et al*., 2011). The effectiveness of NPs is determined by their concentration, which varies from plant to plant (Table 2).

Table 2 : Effective role and concentration(s) of Nanoparticles on plant growth and development

Nanoparticles	Effective concentration(s)	Plant	Effect on plant part	References
ZnO NPs	400mg/kg	*Cucumis sativus* fruit	Micronutrients (Cu, Mn, and Zn)	Zhao *et al*. (2014)
	1.5 ppm (foliar spray)	*Cicer arietinum*	Improved shoot dry weight	Burman *et al*. (2013)
	20 ppm (suspension,foliar spray)	*Vigna radiata*	Enhanced biomass	Dhoke *et al*. (2013)
	500, 1,000, 2,000 and 4,000 ppm	*Vigna radiate*	Increased dry weight	Patra *et al*. (2013)
	1,000 ppm	*Arachis hypogaea*	Enhanced stem, root growth and yield	Prasad *et al*. (2012)
AgNPs	60 ppm	*Phaseolus vulgaris*, *Zea mays*	Increased root length	Salama (2012)
	10–30 µg/mL	*Boswellia ovalifoliolata*	Improved germination and seedling growth	Savithramma *et al*. (2012)
	60 ppm	*Phaseolus vulgaris*, *Zea mays*	Increased Shoot length	Salama (2012)
	60 ppm	*Phaseolus vulgaris*, *Zea mays*	Increased Dry weight of root and shoot	Salama (2012)
	100 µM	*Vigna radiata*	Antagonize inhibition by 2,4 dichlorophenoxyacetic acid (2,4-D) at 500 µM of plant growth	Karuppanapandian *et al*. (2011)
TiO_2 NPs	60 ppm	*Foenicutum vulgare*	Increased germination	Feizi *et al*. (2013)
	1,000 mg/L	*Triticum aestivum*	Improved chlorophyll content	Mahmoodzadeh *et al*. (2013)

	0.05–0.2 g/L	*Lycopersicon esculentum*	Net photosynthetic rate, conductance to H_2O, and transpiration rate, Regulation of photosystem II (PSII)	Qi *et al*. (2013)
	lower than 200 mg/L	*Lemna minor*	Enhanced plant growth	Song *et al*. (2012)
	400 mg/L	*Arabidopsis thaliana*	Improved root length	Lee *et al*. (2010)
	0.25 %	*Spinacia oleracea*	Hill reaction, non-cyclic photophosphorylation, protect chloroplasts from aging	Hong *et al*. (2005a, b)
SiO_2NPs	20ppm	*Sorghum bicolor*	Seedling biology	Bhatia *et al*. (2014)
	15 kg/ha	*Zea mays*	Improved growth parameters	Yuvakkumar *et al*. (2011)
Iron oxide NPs	50 ppm (foliar spray)	*Vigna radiata*	Increased Biomass	Dhoke *et al*. (2013)
	0.5–0.75 g/L	*Glycine max*	Enhanced yield and quality	Sheykhbaglou *et al*. (2010)
MWCNTs	50-200µg/ml	*Lycopersicum esculentum*	Improvement in germination and seedling growth	Khodakovskaya *et al*. (2013)

Conclusion and future perspective

Due to unique properties, nanoparticles have become an important topic of research in recent years such as agriculture, health care, environment, etc. This review displays the effect of various nanoparticles on different plants of many concentrations, sizes, and shapes. It is evident from compiled knowledge that the effect of NPs is distinct from plant to plant. Future research should focus on molecular/genetic response in the presence of NPs, mode of action of NPs and the interaction with biomolecules. In Green synthesis, numerous kinds of natural resources have been used viz. yeast, bacteria, fungi and plant extract, plant extract among all has proven the best as stabilizing and reducing agent.

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