Biological Forum – An International Journal **15(12): 457-469(2023)**

ISSN No. (Print): 0975-1130
ISSN No. (Online): 2249-3239

Biosynthesis, Characterization and Application of Silver Nanoparticle (Ag NPs) to Enhance Seed Quality: A Review

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(Received: 18 September 2023; Revised: 19 October 2023; Accepted: 28 November 2023; Published: 15 December 2023)
(Published by Research Trend)

ABSTRACT: Nanoparticles are microscopic fragments with a nanoscale dimension ranging from 1-100 nm, with excellent thermal conductivity, catalytic reactivity, nonlinear optical performance, and chemical stability due to their enormous surface area-to-volume ratio. Nanoparticles can be synthesized utilizing several processes, including chemical, physical, and biological. However, the chemical and physical methods used are costly, complex, and possibly harmful to the environment because of the toxic chemical compounds utilized as reducing agents. The synthesis of nanoparticles using green approaches may be easily scaled up, and they are also cost-effective. Because of their superior qualities, greenly coordinated nanoparticles are currently preferred over traditionally delivered NPs. Green synthesis approaches are particularly appealing due to their ability to reduce toxicity of nanoparticles. As a consequence, the usage of vitamins, amino acids, and plant extracts has become more common. Capping and reducing agents play a key role in nanoparticle synthesis while harmful and highly poisonous compounds are utilized in the chemical and physical methods which may cause environmental problems. The reducing or capping agents are costly which employed in chemical and physical procedures. The nanoparticles as a seed treatment can improve germination, increases seedling length, vigour, viability and improve seed quality. The present review is an attempt to summarize and assess the prospects of silver nanoparticles (Ag NPs) as an alternative approach to improving seed quality through biosynthesized nanoparticles.

Keywords: Nanoparticles, green synthesis, germination, vigour, viability and seed quality.

INTRODUCTION

Nanotechnology is an emerging cutting-edge technology in several sectors of study, including biology, chemistry, and material science (Pirtarighat *et al.*, 2019). Nanotechnology is increasingly being used in research and development to create nanoscale products (Albrecht *et al.*, 2006; Castillo *et al.*, 2020). Nanoparticles are microscopic fragments with a nanoscale dimension ranging from 1-100 nm, with excellent thermal conductivity, catalytic reactivity, nonlinear optical performance, and chemical stability due to their enormous surface area to volume ratio (Agarwal *et al.*, 2017). They are often divided into categories based on their sizes, forms, and features. Carbon-based nanoparticles, metal nanoparticles, ceramic nanoparticles, polymeric nanoparticles, and many more are among the several categories (Khan *et al.*, 2019). Nanoparticles can be synthesised utilizing a number of processes, including chemical, physical, and biological. However, the chemical and physical methods used are costly, complex, and possibly harmful to the environment because of the toxic chemical compounds utilized as reducing agents (Ahmad and Sharma 2012). The biological technique, also known as the green synthesis method, is now increasing popularity due to the growing need to develop a sustainable method for nanoparticle synthesis (Sesuvium *et al.*, 2010). Because of its easy methods and low cost, both the scientific and industrial sectors are interested in green silver nanoparticle production for use in a variety of applications in biomedicine, the environment, and industry (McNamara and Tofail 2017).

Traditional methods have been utilized for many years, however research has shown that green methods are more effective for generating nanoparticles due to lower failure rates, lower costs, and simplicity of characterization (Abdelghany *et al.*, 2018). Because of their hazardous by products, physical and chemical approaches to the synthesis of NP have placed significant strain on the environment. Plant-based NP synthesis is a simple technique; a metal salt is produced using plant extract, and the reaction takes minutes to a few hours at ambient temperature. This technique has received a lot of attention in the last decade, especially for silver (Ag) and gold (Au) nanoparticles, which are more secure than other metallic nanoparticles. The synthesis of nanoparticles using green approaches may be easily scaled up, and they are also cost-effective. Because of their superior qualities, greenly coordinated nanoparticles are currently preferred over traditionally delivered NPs.

The use of more chemicals that are dangerous and poisonous to human health and the environment may increase particle reactivity and toxicity, as well as have unwanted adverse effects on health due to a lack of assurance and uncertainty about composition (Hussain *et al.*, 2016). Green synthesis approaches are particularly appealing due to their ability to reduce nanoparticle toxicity. As a consequence, the usage of vitamins, amino acids, and plant extracts has become more common (Baruwati *et al.*, 2009). Capping and reducing agents play a key role in nanoparticle synthesis while harmful and highly poisonous compounds are utilized in the chemical and physical methods which may cause environmental problems. The reducing or capping agent employed in chemical and physical procedures is costly. Biologically generated compounds are employed in biological techniques that are safe for the environment. Thus, the biological technique is the preferred way for nanoparticle synthesis (Irfan *et al.*, 2020).

Silver nanoparticles are among the most frequently studied nanomaterials due to their great stability and low chemical reactivity when compared to other metals. They are often synthesized with toxic reducing agents that convert metal ions into uncharged nanoparticles. However, in recent decades, various efforts have been made to develop green synthesis processes that prevent the use of harmful substances. Silver nanoparticles are generated by natural biomolecules found in plants, including proteins/enzymes, amino acids, polysaccharides, alkaloids, alcoholic substances, and vitamins. The green synthesis of silver nanoparticles is an environmentally benign strategy that should be examined further for the ability of various plants to produce nanoparticles (Tijjani *et al.*, 2022). Although there have been publications on the green synthesis of silver nanoparticles utilizing various plants as biological materials, their effect on seed quality enhancement has yet to be thoroughly studied.

1. Concentrations of plant extract and $AgNO_3$. Increasing the content of plant extract in the reaction mixture can increase the absorbance intensity (Ahmed *et al.*, 2016; Anandalakshmi *et al.*, 2016). When higher extract concentrations are used, biomolecules function as reducing agents, covering the nanoparticle surfaces, reducing aggregation and boosting stability (Khalil *et al.*, 2014). The silver nitrate ($AgNO_3$) concentration has a significant impact on the green synthesis of $AgNO_3$. An increase in $AgNO_3$ concentration increases absorption, with a concentration of 1 mM considered ideal for nanoparticles synthesis (Vanaja and Annadurai 2013). Furthermore, increasing the concentration of $AgNO_3$ may result to larger nanoparticles (Bar *et al.*, 2009).

2. Characterization of nanoparticles: The nanoparticles can be classified as quantitative or qualitative. These are characterized by, Dynamic light scattering (DLS), scanning electron microscope (SEM), energy dispersive spectroscopy (EDS), UV-Vis spectroscopy, X-ray diffraction (XRD), fourier transform infrared spectroscopy (FT-IR), surface-enhanced remain spectroscopy (SERS), atomic force microscopy (AFM), high angle annular dark field (HAADF), atomic absorption spectroscopy (AAS), and X-ray photoelectron spectroscopy (XPS) are some of these methods (Chanda, 2014; Mohammadlou *et al.*, 2016)

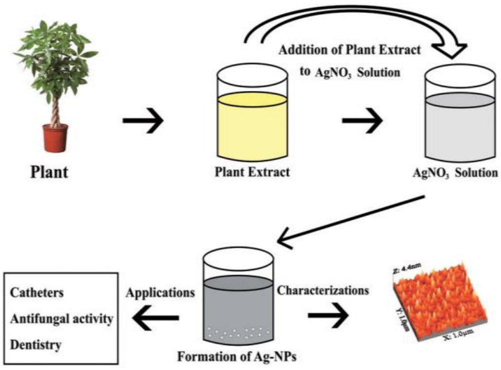

Fig. 1. Schematic diagram for synthesis of Ag-NPs by using plant extracts. (Muhammad *et al.*, 2017.)

3. Green synthesis of silver nanoparticles (AgNPs) from plant extract. Singhal *et al.* (2010) reported the synthesis of silver nanoparticles with *Ocimum sanctum* leaf extract. These biosynthesized nanoparticles were characterized using a UV-vis spectrophotometer, Atomic Absorption Spectroscopy (AAS), Dynamic light scattering (DLS), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), and Transmission Electron Microscopy (TEM) with sizes ranging from 4 to 30 nm. It was discovered that *O. sanctum* leaf extract may convert silver ions to silver nanoparticles in 8 minutes of reaction time. This technology can be employed for a rapid and sustainable biosynthesis of stable silver nanoparticles.

Zhang *et al.* (2010) revealed synergistic antibacterial properties of silver nanoparticles derived from A. vera using a green technique. The TEM picture revealed that these NPs were primarily spherical, with an average size of 25 nm. The crystalline structure of AgNPs was determined using an X-ray diffractometer (XRD).

Thirunavukkarasu *et al.* (2011) reported a green synthesis of silver nanoparticles from lotus (*Nelumbo lucifera*) leaf extract. 10 g of *N. lucifera* leaves were boiled in 100 ml of distilled water in a conical flask. The filtrate (12 ml) was then mixed with 88 ml of aqueous 1mM $AgNO_3$ solution and incubated in the dark at room temperature. The appearance of a brownish yellow solution indicated the synthesis of AgNPs.

Mason *et al.* (2012) described a green procedure mediated by *Panicum virgatum* extract for synthesis of silver nanoparticles from silver nitrate solution at room temperature. UV-visible spectroscopy investigation showed a rapid reduction of silver (Ag^+) ions, with a peak at 435 nm verifying the synthesis of silver nanoparticles. The silver nanoparticles started to develop after 15 minutes, and the reduction reaction completed within 2 hours. Silver nanoparticles were structurally characterized using an X-ray diffractometer (XRD), confirming their face-cantered cubic (FCC) symmetry and lattice parameter of 4.0962 Å. The particle size of biosynthesized silver nanoparticles was measured by transmission electron microscopy (TEM) and found to be in the range of 20-40 nm.

Ramteke *et al*. (2013) synthesized antibacterial silver nanoparticles (AgNPs) from *Ocimum sanctum* (tulsi) leaf extract. UV-visible spectroscopy, TEM, and X-ray diffractometry were used to examine the produced AgNPs. The mean particle size of synthesized nanoparticles was determined to be 18 nm, as validated by TEM. Fourier transform infrared spectroscopy (FTIR) research revealed that the extract contained eugenols, terpenes, and other aromatic chemicals that stabilized the AgNPs.

Agarwal *et al.* (2014) reported the production of silver nanoparticles utilizing a callus extract of *Capsicum annuum* via bioreduction of silver nitrate ($AgNO_3$). These were characterized using a UV-Vis absorption spectrophotometer, photoluminescence, FTIR, XRD, SEM, and EDS. The SEM image showed that the mixed phase contained cubic and hexagonal particles with an average size of 15 nm.

Sangeetha *et al.* (2014) reported a green synthesis technique for producing bio-entity encapsulated silver nanoparticles from *Ferula asafetida.* The average crystallite size of nano particles shows surface Plasmon resonance peaks in the wave length range of 400-453 nm. Transmission electron microscopy images stated spherical particle morphology due to their stability and the presence of important ferulic acid as a capping agent, along with particle size 10.4 nm.

Das *et al*. (2016) synthesized silver nanoparticles in an environmentally friendly manner by reducing and stabilizing them with *Amaranthus* spp. leaf extract. The colour changes in the reaction solution were observed for the characterization of silver nanoparticles and confirmed by various analytical techniques such as UV-Vis spectrum analysis, Field emitter Scanning Electron Microscope (FE-SEM) equipped with EDAX (energy dispersive X-ray) and X-ray diffraction (XRD). SEM micrographs indicated that the NPs were monodisperse and spherical in nature with 16–23 nm.

Usha *et al.* (2017) reported that tulsi includes alkaloids, glycosides, tannins, saponins, and aromatic compounds, as well as minerals such as Ca, Mn, Cu, Zn, P, K, Na, and Mg, with tulsi leaves having a higher concentration of Cu than other leaves. It contains 12.31 mg/kg of copper. Recently, *Ocimum sanctum* L. leaf extracts have been employed to synthesize silver and gold nanoparticles. Tulsi contains bio-reduction compounds and stabilizers. Several instrumental techniques were used to characterize the produced Cu NPs, including the Dynamic light scattering analyzer (Zetasizer), UV-Vis spectroscopy, FTIR, SEM, TEM, and XRD.

Yadav *et al.* (2018) synthesized silver nanoparticles from leaf extracts of *Ocimum sanctum* L. and *Ocimum americanum* L. Various techniques were used to characterize these biosynthesized nanoparticles, including a UV-Vis spectrophotometer, Fourier transform infrared spectroscopy (FTIR), and scanning electron microscopy. The surface plasmon resonance (SPR) absorption band observed at 408 nm in *Ocimum americanum* L. and 427 nm in *Ocimum sanctum* L. indicates the reduction of silver metal ions into silver nanoparticles. FT-IR analysis was performed to investigate the probable functional group involved in the production of AgNPs. The SEM results showed that AgNPs were primarily spherical in shape, with particle sizes ranging from 40 to 95 nm.

Sahana (2019) synthesized green silver nanoparticles from Citrus limon leaf, fruit rind, and seed extract, which act as reducing and capping agents. The size of the produced silver nanoparticles ranged from 60 to 80 nm.

Jebril *et al.* (2020) produced silver nanoparticles from *Melia azedarach* leaf extract. The colour changed to brown as silver ions were reduced to AgNPs. UV-Visible spectroscopy was used to characterize the biosynthesized AgNPs, which were complemented with dynamic light scattering (DLS), zeta potential, scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD), and fourier transform infrared spectroscopy (FTIR). The maximum absorbance of the UV-vis spectra was 400 nm, confirming the synthesis of silver nanoparticles. SEM investigation shows the presence of spherical nanoparticles ranging in size from 18 to 30 nm (average: 23 nm).

Tailor *et al.* (2020) tried to synthesize silver nanoparticles by a green technique utilizing leaves of *Ocimum canum* Sims (American basil). SEM and XRD were used to characterize the synthesized silver nanoparticles. The spherical and rod-like shapes were confirmed using SEM methods. The crystallographic structure was confirmed by XRD, and the average particle size of the produced silver nanoparticles was found to be 15.72 nm.

Suke (2022) reported green synthesis of AgNPs using *Annona squamosa* peel and seed aqueous extract. The synthesized AgNPs characterised by various biophysical techniques *viz.,* XRD, SEM, TEM, UV and the average size was measured 40 to 150 nm.

Lan *et al.* (2023) give a simple, environmentally friendly, and green method for synthesizing silver nanoparticles (AgNPs) from an $AgNO_3$ solution using an aqueous extract of *Callisia fragrans* leaf. UV-Vis spectroscopy, X-ray diffraction pattern, energy-dispersive X-ray spectroscopy, field emission scanning electron microscopy, transmission electron microscopy (TEM), dynamic light scattering (DLS), and FTIR were used to examine the AgNPs. TEM and DLS investigations revealed that the produced AgNPs were predominantly spherical in shape, with an average size of 48 nm. The colloidal solution of AgNPs has a zeta potential of -27 mV, suggesting their capacity to disperse. The results of GC-MS and FTIR investigations demonstrate the presence of biomolecules in the aqueous extract of *C. fragrans*, which works as reducing and capping agents for the biosynthesis of AgNPs.

Anthyalam *et al.* (2023) synthesized AgNPs from a leaf extract of *Uvaria narum*. The nanoparticles were examined using ultraviolet-visible (UV-Vis) spectroscopy, Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), and transmission electron microscopy (TEM). SEM research revealed that AgNPs are extremely crystalline and spherical, with an average diameter of 7.13 nm.

Table 1: Green synthesis of Ag-NPs using plant (Leaves extract).

Sr. No.	**Name of plant**	**Size (nm)**	**Structure/shape**	**References**
1	*Aloe vera*	15.2±4	Spherical	Chandran *et al.* (2006)
	Cinnamomum camphora	3.2–20	Cubic	Huang *et al.* (2007)
	Capsicum annuum	10±2	Spherical	Li *et al.* (2007)
	Mentha piperita	5–30	Spherical	Parashar and Saxena (2009)
	Brassica juncea	2–35	Spherical	Haverkamp and Marshall (2009)
	Carica papaya	60–80	Spherical	Mude *et al.* (2009)
	Cycas sp.	2–6	Spherical	Jha and Prasad (2010)
	Argemone mexicana	30	Spherical& hexagonal	Singh *et al.* (2010)
	Lippia citriodora	15–30	Crystalline	Cruz *et al.* (2010)
0	*Acalypha indica*	20–30	Spherical	Krishnaraj *et al.* (2010)
1	*Eucalyptus citriodora*	20	Spherical	Ravindra *et al.* (2010)
2	*Garcinia mangostana*	35	Spherical	Veerasamy *et al.* (2010)
3	*Coriandrum sativum*	8-75	Spherical	Sathyavathi *et al.* (2010)
4	*Hibiscus rosa sinensis*	14	Spherical/prism	Philip (2010)
5	*Sesuviumportulacastrum*	5-20	Spherical	Nabikhan *et al.* (2010)
6	*Nelumbo nucifera*	25–80	Spherical & triangular,	Santhoshkumar *et al.* (2011)
7	*Syzygiumcumini*	29–92	Spherical	Banerjee and Narendhirakannan (2011)
8	*Ocimum sanctum*	9.5	Spherical	Mallikarjuna *et al.* (2011)
9	*Citrullus colocynthis*	31	Spherical	Satyavani *et al.* (2011)
0	*Ocimum sanctum*	10–20	Spherical	Philip and Unni (2011)
1	*Memecylonedule*	50-90	Square	Elavazhagan and Arunachalam (2011)
2	*Rhizophora mucronata*	60-95	Spherical	Gnanadesigan *et al.* (2011)
3	*Citrus limon*	50	Spherical & spheroidal	Prathna *et al.* (2011)
4	*Ocimum tenuiflorum*	25–40	Spherical	Patil *et al.* (2012)
5	*Annona squamosa*	20-100	Spherical	Vivek *et al.* (2012)
6	*Camellia sinensis*	2-10	Spherical	Loo *et al.* (2012)
7	*Suaedamonoica*	31	Spherical	Satyavani *et al.* (2012)
8	*Catharanthtus roseus*	35–55	Cubical	Ponarulselvam *et al.* (2012)
9	*Melia azedarach*	78	Spherical	Sukirtha *et al.* (2012)
0	*Coccinia grandis*	20-30	Spherical	Arunachalam *et al.* (2012)
1	*Coleus aromaticus*	40-50	Spherical	Vanaja and Annadurai (2013)
2	*Ceratonia siliqua*	5–40	Spherical	Awwad *et al.* (2013)
3	*Origanum vulgare*	63-85	Spherical	Sankar *et al.* (2013)
4	*Vitex negundo*	5-74	Spherical	Prabhu *et al.* (2013)
5	*Alternanthera dentate*	5-100	Spherical	Kumar *et al.* (2014)

6	*Piper longum*	46	Spherical	Reddy *et al.* (2014)
7	*Dalbergia spinosa*	18±4	Spherical	Muniyappan *et al.* (2014)
8	*Moringa oleifera*	40	Spherical & pentagonal	Vasanth *et al.* (2014)
9	*Justicaadhatoda*	11–20	Smooth and spherical	Kudle *et al.* (2014)
0	*Melia dubia*	7.3	Irregular, but mostly spherical	Kathiravan *et al.* (2014)
1	*Ficus benghalensis*	10–50	Spherical	Saware *et al.* (2014)
2	*Eucalyptus globulus*	1.9–4.3 and 5–25	Spherical	Ali *et al.* (2015)
3	*Phyllanthus niruri*	30–60	Crystalline FCC & spherical	Suresh *et al.* (2015)
4	*Mukiamaderaspatana*	13-34	Spherical	Chitra *et al.* (2015)
5	*Lantana camara*	14-27	Spherical	Ajitha *et al.* (2015)
6	*Camellia japonica*	12–25	--	Karthik *et al.* (2017)
7	*Azadirachta indica*	11–35	--	Shaikh and Sukalyan (2018)
8	*Mentha piperita*	35	Spherical	Khatoon *et al.* (2018)
9	*Sesbania grandiflora*	10-50	Spherical	Mallikarjuna *et al.* (2018)
0	*Premna integrifolia*	9–35	--	Singh (2019)
1	*Cynara scolymus*	98.47 ± 2.04	--	Erdogan *et al.* (2019)
2	*Capparis zeylanica*	23	Spherical	Nilavukkarasi *et al.* (2020)
3	*Caesalpinia pulcherrima*	9	Spherical	Moteriya and Chanda (2020)
4	*Carya illinoinensis*	12–30	Spherical	Dalir *et al.* (2020)
5	*Shorearobusta*	12–37	--	Shaikh *et al.* (2020)
6	*Prosopis julifora*	30	--	Malini *et al*. (2020)
7	*Gymnemasylvestre*	20–30	--	Rajkumar (2020)
8	*Uncariagambir*	6–39	--	Labanni (2020)
9	*Melia azedarach*	18–30	--	Jebril *et al.* (2020)
0	*Teucrium polium*	70–100	--	Hashemi *et al.* (2020)
1	*Annona glabra*	10–100	Spherical	Amarasinghe *et al.* (2020)
2	*Nymphae odorata*	15 ± 5	Spherical	Gudimalla *et al.* (2021)
3	*Coccinia indica*	8–48	Spherical	Chinni *et al.* (2021)
4	*Kalanchoe pinnata*	40.8	spherical	Aryan *et al.* (2021)
5	*Cymbopogon citratus*	47	--	Rakib *et al.* (2022)
6	*Cuphea carthagenensis*	10.65 ± 0.1	Cubic and spherical	Rather *et al.* (2022)
7	*Moringa oleifera*	15.22–29.45	Spherical	Mohammed *et al.* (2022)
8	*Callisia fragrans*	48 nm	Spherical	Lan *et al.* (2023)
9	*Uvaria narum*	7.13 nm	Crystalline & spherical	Anthyalam *et al.* (2023)

4. Effect of silver nanoparticles on seed quality parameter. Nanoscience is a new scientific innovation platform that comprises developing ways for a number of low-cost nanotech applications for improved seed germination, plant growth, development, disease management, and environmental adaptation.

Effect of biosynthesized silver nanoparticle on seed germination and vigour. Hojjat and Hojjat (2015) studied the impact of silver nanoparticles on plant growth metrics such as root length, fresh weight, dry weight, speed of germination, and percent germination in fenugreek. Seed germination data demonstrated that AgNPs at lower concentrations improved seed germination and early seedling growth in Fenugreek, but higher concentrations had mild negative impacts. the seeds showed a significant increase in root length, root fresh weight, root dry weight, and root elongation as compared to the control.

The impact of silver nanoparticles on the germination of corn (*Zea mays* L.), watermelon (*Citrullus lanatus*), and zucchini (*Cucurbit apepo* L.) seeds was investigated by Zainab *et al.* (2015). At the seed germination stage, seven AgNP concentrations (0.05, 0.1, 0.5, 1, 1.5, 2, and 2.5 mg/ml) were investigated. Regarding the studied growth characteristics and germination parameters, the three species exhibited distinct dosage responses to AgNPs. It increases the rates at which all three plants germinated. When comparing the watermelon and zucchini plants treated with AgNPs to untreated seeds, a significant increase in the germination percentage values was observed.

Elbeshehy *et al.* (2015) investigated that foliar spraying with AgNPs (5 g/mL) reduced the number of fungal spores, implying that biosynthesized AgNPs are efficient against fungal spore formation. The number of lesions decreased from 2.9/leaf in pathogen-infected plants to 0.9/leaf in silver nanoparticle-treated plants, indicating that green synthesis of silver nanoparticles could boost plant productivity and reverse 10-30% damage. Similarly, using phytogenic AgNPs improves seed germination, plant development, chlorophyll, carotenoids, and protein content, as well as antifungal efficacy against *Aspergillus niger* in important agricultural crops such as *Oryza sativa*, *Zea mays*, and *Arachis hypogaea.*

Hojjat (2016) conducted the study to assess the efficacy of silver nanoparticles in reducing the adverse impacts of drought stress on lentil seed germination and growth. the experiment was conducted using polyethylene glycol (PEG) at varying levels (control, -0.4, -0.6, -0.9, and -1.1 Mpa) and five levels of silver nanoparticles (0, 10, 20, 30, and 40 µg mL-1). The results showed that different PEG and silver nanoparticle concentrations had significant impacts on germination rate and percentage, root length, root fresh and dry weight. Silver nanoparticles enhanced germination percentage and growth compared to control.

Saloni *et al*. (2016) investigated the effect of silver nanoparticles on many parameters, including seed germination and seedling biology in *Vigna radiata* (mung bean). The seeds were cultivated in vitro on Murashige and Skoog's medium, strength 1/20, which was enriched with filter sterilized silver nanoparticles at concentrations of 10, 20, 50, and 100 ppm. The addition of silver nanoparticles at a concentration of 10 ppm increased seed germination percentage, shoot and root length. These preliminary findings indicate that nanoparticles at low concentrations may improve seedling growth.

Mahakham *et al.* (2017) made silver nanoparticles (AgNPs) using kafir lime leaf extract as a nanopriming agent to improve seed germination in aged seeds of rice. These seeds primed with photosynthesized AgNPs at 5 and 10 ppm revealed significantly improved germination performance and seedling vigour than unprimed control, $AgNO_3$ priming, and traditional hydropriming. Nanopriming can boost α-amylase activity, resulting in more soluble sugar content to assist seedling growth. Furthermore, nanopriming induced the upregulation of aquaporin genes in germinating seeds. Meanwhile, nanopriming therapy resulted in higher ROS production in developing seeds compared to unprimed control.

Das *et al.* (2018) experimented to investigate the effect of silver nanoparticles (AgNPs) on onion yield, quality, and shelf life. AgNPs less than 100 nm at five different concentrations (0, 25, 50, 75, and 100 ppm) were utilized as a treatment. The results show that the effect of AgNPs on several metrics was concentration dependant. A higher concentration of AgNPs gives better results than a lower concentration. The maximum yield was reported at 100 ppm compared to the control. T1 (100ppm) had the largest equatorial diameter, polar diameter, ten bulb weight, and number of rings, but there was no significant difference in TSS or bulb dry weight between treatments. A significant increase in shelf life was also observed. Rotting percentage (%) and black mould incidence were significantly reduced in T_4 (100 ppm), although there was no significant variation in PLW and TSS during storage.

Gupta *et al.* (2018) found that bio-synthesized silver nanoparticles (AgNPs) promoted seed germination and seedling growth in rice (*Oryza sativa* L) under in vitro conditions. All of the measured AgNP concentrations prompted both shoot and root growth, shown by the seedlings' increased length and biomass. Exposure to AgNPs also significantly boosted chlorophyll and carotenoid levels. Growth stimulation of rice seedlings by AgNPs was further supported by a low level of reactive oxygen species (ROS), which was associated with a decrease in lipid peroxidation and H_2O_2 content when compared to the control.

Noshad *et al.* (2019) studied the influence of biogenic AgNPs on seed germination and seedling growth in *Solanum lycopersicum*. Treatment with silver nanoparticles (AgNPs) resulted in a significantly higher germination rate and seedling growth than untreated seeds. In addition, its bactericidal activity on the bacterial pathogen *Clavibacter michiganensis* subsp. *michiganensis* (cmm) infection in *Solanum lycopersicum* was investigated. In this study, fungal extracts of *T. harzianum* and *A. fumigatus* were utilized individually as reducing agents to synthesis AgNPs at different doses (0.088 mg/L, 0.176 mg/L, and 0.44 mg/L). Plants treated with AgNPs had dramatically improved growth characteristics.

Smitha *et al.* (2019) biosynthesised silver nanoparticles (AgNPs) from *Achyranthes aspera* roots, and standard AgNPs were tested using a zetasizer, UV-Visible spectrophotometer, and scanning electron microscope. The efficacy of biosynthesised and conventional AgNPs was evaluated using groundnut seed quality parameters. The average size of AgNPs was 50.37 nm (standard) and 23.21 nm (biosynthesis). The characteristic absorbance peak was found at 407.40 and 420.80 nm for standard and biosynthesized AgNPs, respectively. SEM scans showed that both standard and biosynthesized AgNPs were spherical in shape. AgNPs at 150 ppm were found to be the most effective at enhancing seed quality indicators such as germination percentage, germination speed, root length, shoot length, and so on. The experiments also showed that biosynthesized AgNPs performed similarly to standard AgNPs with respect of enhancing groundnut seed quality. Singla *et al.* (2019) found that low concentrations (10 µg mL^{-1}) of AgNPs increased seed germination in lentils, but greater quantities had detrimental impacts.

Chandrashekhara *et al.* (2020) describe synthesized AgNPs and Cu NPs from an aqueous extract of *K. alvarezii* using SEM analysis. The size ranged from 60 to 90 nm and 60 to 90 nm, respectively. They studied the impact of biosynthesized silver nanoparticles (AgNPs) and copper nanoparticles (CuNPs) on different seed quality parameters of chilli. They discovered that 400ppm of silver and 50ppm Cu NPs had a significantly higher percentage of seed germination, seedling vigour index, seedling dry weight, shoot and root length compared to other treatments, but there was no significant difference between silver nitrate, bavistin, plant sample, and raw silver solutions. 50 ppm Cu NPs greatly increases seed germination, seedling vigour index, seedling dry weight, shoot and root length over other treatments.

Prazak *et al.* (2020) studied the effects of silver nanoparticles (AgNPs) on seed germination, field emergence, and physiological characteristics of seedlings from two bean cultivars, 'Bali' and 'Delfina'. The AgNPs solutions (0.25, 1.25, and 2.5 mg dm^{-3}) were applied to seeds as a short-term pre-sowing treatment. The low concentrations of AgNPs (0.25, 1.25 mg dm^{-3}) had an immediate beneficial effect, resulting in fast and uniform germination in laboratory and field conditions, as well as a positive effect in the later stages of seedling development, showing as an increase in the average seedling height, fresh and dry weight, and net photosynthesis.

Soliman *et al.* (2020) evaluated the influence of biosynthesized AgNPs on the seedlings of *Zea mays* L., *Trigonella foenumgraecum* L., and *Allium cepa* L. AgNPs were biosynthesized in blue gum (*Eucalyptus globules*) leaves and studied using UV-Visible spectra, Fourier Transform Infrared (FTIR), and Scanning Electron Microscopy. Biogenic AgNPs were applied at various doses (25, 50, 75, and 100 mg L^{-1}) to study their effects on seed germination, seedling growth, oxidative stress, and antioxidant enzyme activity. The use of AgNPs considerably increased seed germination and growth of *Z. mays* L., *T. foenum graecum* L., and *A. cepa* L. Notably, increased concentrations of AgNPs prompted growth. Applications of AgNPs also increased the activity of antioxidant enzymes such as catalase, peroxidase, and ascorbate peroxidase, as well as glutathione and ascorbate levels. Antioxidant enzyme expression levels were increased in AgNP-treated seedlings compared to the control. They observed that applying silver nanoparticles significantly improved seed germination, antioxidant machinery, and early growth characteristics in both monocot and dicot crops.

Chakraborty and Bordolui (2021) noted that seed priming with Ag-nanoparticles and GA_3 in green gram (*Vigna radiata* L.) improved seed yield and quality. The doses of Ag nanoparticles were 10 ppm, 20 ppm, and 50 ppm, whereas GA_3 doses were 50 ppm, 100 ppm, and 150 ppm, respectively. The germination percentage and vigour were measured to evaluate the changes in seed quality following priming with 50 ppm GA_3 and 20 ppm Ag Nanoparticle.

Effect of biosynthesized silver nanoparticle on antimicrobial activity on seeds. Lamsal *et al.* (2011) investigated the effect of silver nanoparticles on pepper anthracnose at various doses, and silver nanoparticles were applied at various concentrations to assess in vitro antifungal effects as well as in field conditions. Under in vitro conditions, the application of 100 ppm concentrations of silver nanoparticles resulted in the greatest inhibition of conidial germination and fungal hyphae growth in comparison to the control, and in field conditions, it resulted in inhibition of fungal attack before disease outbreak on the plants.

Anitha *et al.* (2012) biosynthesized silver nanoparticles from *Amaranthus* spp. leaf extract and investigated their antibacterial efficacy against *Pseudomonas fluorescens* and *Klebsiella pneumonia*, which indicated zones of inhibition at 6 mm and 11 mm, respectively. The biosynthesized silver nanoparticles' antimicrobial activity was examined, and they were found to be effective against pathogenic gram-negative bacteria such as *Klebsiella pneumonia*, *Pseudomonas putida*, and *Pseudomonas flourescens*. They concluded that silver nanoparticles, in general, show stronger antimicrobial activity.

San and Mashitah (2013) investigated the antibacterial properties of silver nanoparticles synthesized using mycelia reduction, Schizophylum culture, and silver nitrate. The antibacterial properties of silver nanoparticles are investigated against *Aspergillus niger*, *Staphylococcus epidermidis, Staphylococcus aureus*, *Escherichia coli*, and Candida albicans. The results showed that silver nanoparticles synthesised by the interaction of silver nitrate with mycelia fungus, when treated with Staphylococcus aureus, and silver nanoparticles synthesised by the interaction of silver nitrate and culture supernatant, when treated with Staphylococcus epidermidis, provided the greatest inhibition area.

Khadri *et al.* (2013) use green synthesis to produce potential anti-microbial silver nanoparticles, which is an environmentally friendly alternative to traditional chemical synthesis. The enzymatic process of olive seeds was used to synthesize silver nanoparticles and test their efficacy as antifungal agents before evaluating their physical characteristics with FTIR, UV-Vis, and TEM analysis. Silver nanoparticles have been found to inhibit the growth and development of mycelia of *Aspergillus niger*.

Othman *et al.* (2014) investigated the effect of silver nanoparticles (AgNPs) produced by the *Aspergillus terreus* (KC462061) on the growth and aflatoxin production of five A. flavus isolates. The results showed that all five A. flavus isolates were inhibited by different concentrations of silver nanoparticles, with 150 ppm producing the most significant inhibition. AgNPs reduced *A. flavus* growth by affecting cellular activities, resulting in distortion of fungal hyphae. AgNPs produce a decrease in spore quantity, abnormalities, and hypertrophy, all of which result in spore destruction and damage.

Eduardo *et al.* (2015) investigated the antifungal activity of silver nanoparticles produced using green synthesis. The AgNPs showed excellent antibacterial activity, which can be highly valuable, particularly against microbes that are resistant to traditional antimicrobials. *C. albicans* and *C. tropicalis* demonstrated considerable sensitivity to AgNPs. They had strong action against *C. albicans* and *C. tropicalis*, similar to that noted with the antifungal amphotericin, and may constitute an alternative for treating fungal infections.

Kolya *et al.* (2015) reported the green manufacture of silver nanoparticles with antibacterial characteristics from *Amaranthus* sp. leaf extract. Silver nanoparticles produced shown inhibitory action against Gram-positive, Gram-negative, and fungal microorganisms. The antibacterial activity of produced AgNPs was tested using the conventional agar-well diffusion method, and pathogens from the actively growing fungal plant *Sclerotia* sp. were aseptically converted onto the midpoint of sterile standard potato dextrose agar (PDA) plates and incubated at 25 °C for 2 days. AgNPs at concentrations of 0.4 μg/ml, 0.2 μg/ml, and 0.1 μg/ml were put into separate wells and grown for 3 days. The growth of *Sclerotinia* sp. was found to be inhibited by 0.2 μg/ml concentration of three distinct AgNPs. As a result, the silver nanoparticles created showed promise in terms of action against both Gram-negative and Gram-positive bacteria and fungus.

Praveen and Rao (2015) studied at the phytotoxicity of silver nanoparticles (AgNPs) on *Pennisetum glaucum.* Silver nanoparticles (AgNPs) are synthesized from aqueous leaf extracts of *Cassia auriculata*. Seeds treated with synthetic AgNPs germinated better, although higher levels of AgNPs had an effect on seedling growth in the examined species. Silver nanoparticles may have considerable agricultural benefits, and by selectively preventing damaging fungus and bacteria on seeds, they could serve as an alternate supply of fertilizer, thereby improving sustainable agriculture.

Teimoori *et al.* (2017) investigated the characterization and antifungal activity of silver nanoparticles using *Amaranthus retroflexus* leaf extract. The antifungal potential of biosynthesized AgNPs was studied using a modified approach. Before the autoclaved media solidified, five millilitres of AgNPs were added at varied concentrations (50, 100, 200, and 400 mg/ml in sterile distilled water). The suppression of mycelia growth by AgNPs at varied doses was measured daily for all tested fungus in comparison to the negative control. AgNPs inhibited the growth of *M. phaseoliona*, *A. alternata*, and *F. oxysporum* in a dose-dependent manner as compared to the negative control.

CONCLUSIONS

The present review focused on biosynthesis utilizing leaf extract, characterisation of silver nanoparticles, and the effect of silver nanoparticles on seed quality parameters. It is believed that many natural chemicals found in plant extracts work as reducing and stabilizing agents during the synthesis of silver nanoparticles. AgNPs increase the activity of antioxidant enzymes such as catalase, peroxidase, and ascorbate peroxidase, as well as glutathione and ascorbate levels in seeds and crop plants. As a result, green-mediated silver nanoparticles have various advantages, including improved germination percentage, root-shoot length, dry matter content, net photosynthesis, growth, yield, lower electrical conductivity, and reduced microbial infection, etc. Another advantage is that silver nanoparticles are environmentally friendly and cost-effective, resulting in an assumption that they will play an important role in seed science technology for quality enhancement in the future.

Acknowledgement. I extend my sincere thanks to Dr. V.R. Shelar (Research guide & Chairman of advisory committee), to my all advisory committee members and the head, department of agricultural botany, PGI, MPKV, Rahuri for giving me proper guidance throughout study.

Conflict of Interest. None.

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How to cite this article: Wankhade N.J., Shelar V.R., Bhalerao B.M., Karjule A.P. and Jadhav V.B. (2023). Biosynthesis, Characterization and Application of Silver Nanoparticle (Ag NPs) to Enhance Seed Quality: A Review. *Biological Forum – An International Journal, 15*(12): 457-469.