



Green Synthesis of Nanoparticles from Flower Extracts: Innovative Applications in Floriculture

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This review explores about green synthesis of nanoparticles from flower extracts. Green synthesis has gathered significant attention as an environmentally friendly and sustainable approach for the synthesis of a variety of nanomaterials including, metal/metal oxide nanoparticles and bioinspired materials. Flowers are rich in secondary compounds like pigments, volatile molecules which add to fragrance and hold substantial importance predominantly in the context of disease treatment through 'Pushpa Ayurveda' or floral therapy. These phytochemicals from flowers act as efficient reducing and stabilizing agents and offer a unique medium for synthesizing a variety of metal and

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metal oxide nanoparticles, including gold, silver, copper, zinc, iron, and cadmium. This synthesis process typically occurs at ambient temperatures, making it environmentally friendly and free from the production of toxic by-products. Nanoparticles thus formed can be used to carry ethylene action inhibitors, control the growth and development of microorganisms and to introduce a new generation of packaging material that controls gases and harmful UV rays, while increasing strength, quality and packaging appearance. Furthermore, there are several examples of nanoparticles extracted from bougainvillea that are used in cosmetic industries, in the field of biomedical science, silver NP synthesized from *Hymenocallis littoralis* exhibits strong antimicrobial properties, making them useful in treating infections and enhancing the effectiveness of antibiotics. Gold nanoparticles derived from *Hibiscus rosa-sinensis* are utilized in targeted drug delivery and photothermal therapy for cancer treatment. Thus, Flower-derived nanoparticles find applications in biomedical science, offering health benefits, nanoencapsulation, prolonged vase life for cut flowers, packaging, and diverse uses in various fields.

Keywords: Pushpa ayurveda; green synthesis; nanoparticle; flower extract; ornamentals.

1. INTRODUCTION

"The growing use and applications of nanoparticles have drawn the attention of scientists of different fields. On the basis of their formation, they can be grouped into two types: natural and anthropogenic nanoparticles (NPs). Natural NPs are formed due to natural processes such as erosion and volcanic eruptions, whereas synthetic NPs are made by different processes such as mechanical ball milling techniques, mechano-chemical methods, etching techniques, sputtering, laser ablation, inert gas condensation, chemical vapor synthesis, electrochemical deposition of nanomaterials, chemical precipitation, sol-gel synthesis, Sono chemical synthesis, solvothermal decomposition of metal complexes, microwave synthesis, biological synthesis, etc" (Kandiah and Chandrasekaran, 2021; Gupta et al., 2024). "Nanotechnology is the art and science of manipulating the matter at nanoscale and it can be defined as the design, characterization, production and application of structures, devices and systems by controlling the shape and size at the nanometre scale. Nanotechnology can be a very useful technology in horticulture and particularly in the floriculture industry, with many applications at all stages of product development, handling, storage, packaging and transport of flowers" (Mousavi and Rezai, 2011). "Around 20-80% of flowers are lost due to improper handling practices from harvest to till it reach to consumer. Nanoparticles and nano-porous materials can be used to carry ethylene action inhibitors, control growth and development of microorganisms and to introduce a new generation of packaging material that controls gases and harmful UV rays, while increasing strength, quality and packaging appearance. Nanoencapsulation of biocontrol

agents enhances their effectiveness against pest and diseases, and nanogenomics to develop resistance to pest and diseases" (Sarmast and Salehi, 2016; Soriano et al., 2018; Ghidan and Antary, 2019; Zahedi et al., 2020). For green synthesis of nano-sized components both microbes and plant mediated approaches are in practice. In the synthesis involving microbes, the in-built sophisticated biochemical mechanisms are put into action for reducing of the ions into nano-sized particles, it often leads to well-defined nanoparticles varying in compositions, shapes and sizes accordingly. But when a large-scale production is in question, the synthesis involving microbial preparations is challenging. But this could easily be tackled by using plant-based extracts for synthesis where the production rate could be significantly amplified (Thakur et al., 2023; Niveditha et al., 2024).

Properties of nanoparticles: The more compact the system is, the more evident several physical phenomena become. These include quantum mechanical and statistical mechanical effects, such as the "quantum size effect," which modifies the electrical characteristics of solids at significantly smaller particle sizes. The transition from macro to micro dimensions has no bearing on this effect. However, when the so-called quantum realm—the nanoscale size range—is reached, usually at distances of 100 nanometres or fewer, quantum phenomena take centre stage. Furthermore, in comparison to macroscopic systems, a variety of physical (mechanical, electrical, optical, etc.) properties are altered. One illustration is how a material's mechanical, thermal, and catalytic properties might change when its surface area to volume ratio increases. Nanoscale diffusion and reactions, materials, and nanostructures and Nanoionics is the broad term

for nanodevices having rapid ion transport. Research in nano mechanics is interested in the mechanical properties of nano systems. When nanoparticles interact with biomaterials, there may be dangers because of their catalytic activity. Nanoscale materials can display distinct features from their macroscale counterparts, opening new application possibilities (Ahmad et al., 2003). "For example, stable materials become flammable (aluminium), opaque substances become translucent (copper), and insoluble materials become soluble (gold). At nanoscales, a substance like gold, which is chemically inert at normal scales, can act as a powerful chemical catalyst. Many of the quantum and surface phenomena that matter displays at the nanoscale are the source of great intrigue for nanotechnology systems. Most of the quantum and surface phenomena that are relevant displays at the nanoscale are the source of great intrigue for nanotechnology systems. To create nanomaterials with a particular shape, size, and function, two basic approaches—the top-down and bottom-up approaches—can be used to create nanoparticles" (Singh et al., 2018). The first approach involves the production of nanomaterials and nanoparticles using a variety of processes, including lithographic procedures, sputtering, etching, and ball milling (Cao, 2004). On the other hand, the bottom-up approach commonly employed for nanoparticle synthesis typically utilizes potent reducing agents (like hydrazine and sodium borohydride), along with a capping agent and a volatile solvent such as chloroform and toluene. These techniques prove effective in producing precise and pure metallic nanoparticles.

2. GREEN SYNTHESIS OF NPS

The green synthesis process relies on factors like plant extract, pH, and temperature, while stability is crucial for application efficacy. The green synthesis of various metal nanoparticles, including Au, Ag, Pd, and Cu, involves reducing metal ions using plant extracts or microbial agents. These nanoparticles find applications in catalysis, medicine, and antimicrobial studies, highlighting their broad potential in various fields. Several techniques have been established for the synthesis of nanoparticles. The three main categories of these methods are chemical, physical, and biological operations. In any case, because of its simplicity, safety, and affordability, the biological process is the most suitable for creating NP. Since NPs are required in areas

where humans are directly involved, it is currently imperative to develop sustainable procedures and methodologies including nanoparticles (Shams et al., 2013). We may create safe NP usage strategies by learning about green and sustainable technologies, which can be categorized under the following five approaches namely Tollens, Irradiation, polyoxometalates and polysaccharide method.

2.1 Polysaccharide Method

An example of biological applications for environmental sustainability is the green synthesis of AgNPs by the use of the polysaccharide technique (cellulose). The shoots and roots of the water hyacinth (biological uses) have a high percentage of cellulose. The plant's shoot or roots were used to extract cellulose, which was then employed as a reducing and stabilizing agent. Additionally, the pH of the solution and the reaction time were adjusted to control the size and form of the particles (Mochochoko et al., 2013).

2.2 Gold Nanoparticles (Au NPs)

"Green production of Au NPs involves reducing gold ions using reducing agents sourced from plant extracts or microorganisms. The extracts are produced by soaking ground plants in solvents (ethanol, water) in a suitable atmosphere. When the extracts are added to a gold ion solution, the mixture turns red, resulting in the formation of Au NPs" (Priya Tharishini et al., 2014; Jafarizad et al., 2015; Kumar et al., 2019). This method was used to convert chloroauric acid to Au NPs using extracts from Cassia auriculate leaves (Priya Tharishini et al., 2014). The concentration of chloroauric acid influences the green production of gold nanoparticles.

2.3 Silver Nanoparticles (Ag NPs)

The standard green synthesis method for producing silver nanoparticles (Ag NPs) involves combining silver nitrate solution with reducing agents derived from plant extracts. This procedure, akin to the one described for gold nanoparticles (Au NPs), includes obtaining extracts from plants following established protocols. These extracts, derived from plants like Tephrosia purpurea leaf powder or grass wastes (e.g., hay), are mixed with silver nitrate solution. The synthesis is confirmed when the solution changes to a brownish color, as reported

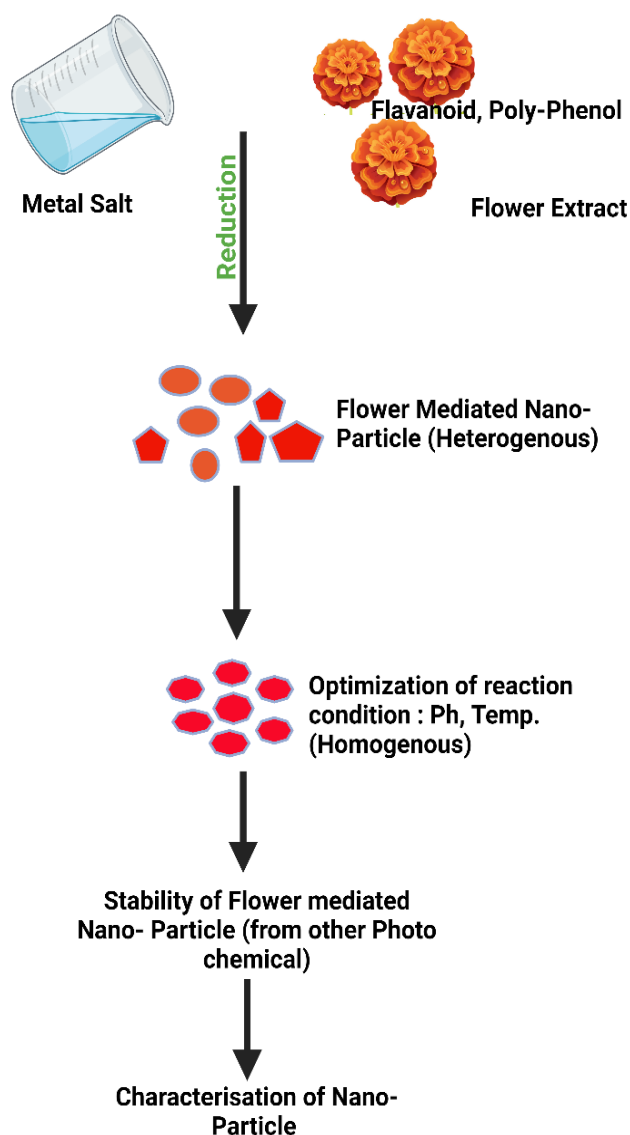


Fig. 1. Extraction process of nanoparticle

by various studies (Khatami et al., 2017; Hemmati et al., 2019; Rautela et al., 2019; Rahimullah Shaikh and Bhend, 2019; Khatami et al., 2016, Yu et al., 2019).

In one specific instance, *Tephrosia purpurea* leaf powder is mixed with Milli-Q water and heated to 60 °C for 15 minutes. The resulting solution containing Ag NPs is then obtained by filtering, adding silver nitrate, and centrifuging (Ajitha et al., 2014). Another study by Khatami et al., (2018) details the synthesis of Ag NPs using grass wastes (e.g., hay). In this case, the hay is washed, disinfected, and then subjected to boiling and filtering to obtain the extract. This

extract is subsequently mixed with various concentrations of silver nitrate to produce Ag NPs.

The shapes and sizes of the green-synthesized Ag NPs vary, with the most common forms being spherical, triangular, and hexagonal, as reported in studies by Ping et al., (2018), Kumar et al., (2017), and Arokiyaraj et al., (2017).

2.4 Palladium Nanoparticles (Pd NPs)

Palladium is a valuable and dense metal, and researchers have successfully generated palladium nanoparticles (Pd NPs) using leaf

extracts from *Filicium decipiens* (Sharmila et al., 2017). Other materials, such as black tea leaves, *Lithodor ahispidula* leaf, Rosa canina fruit, and *Sapium sebiferum* leaf, have also been employed for Pd NPs synthesis in separate studies (Lebaschi et al., 2017, Turunc et al., 2017, Veisi et al., 2016, Tahir et al., 2016). Bentonite/Cu NPs exhibit recyclability up to five times without a loss of activity. Euphorbia granulate leaf extraction has been found to offer a shorter synthesis time, with optimal parameters reported at 80 °C, 20 minutes reaction time, and a 20% dilution ratio (Nasrollahzadeh and Mohammad Sajadi, 2016). The phenolic compounds present in Euphorbia granulate leaves have been identified as potential agents preventing the oxidation of Pd NPs. Additionally, these phenols do not induce agglomeration in copper nanoparticles, as reported by researchers.

2.5 Copper Nanoparticles (Cu NPs)

Due to copper (Cu) being a member of the light transition metals group, direct generation of copper nanoparticles (Cu NPs) from simple copper salts is typically unfeasible. Capping agents, such as surfactants, are necessary to regulate particle size, as highlighted by Shende et al., (2015). Plant extracts, including those from *Thymus vulgaris* L., Eucalyptus sp., and *Ginkgo biloba* Linn., have been employed for the

synthesis of Cu NPs (Edison et al., 2016, Nasrollahzadeh and Mohammad Sajadi, 2015, Issaabadi et al., 2017). Aloe Vera flowers have also been utilized in the process, with the protein from the flower coating the particle surface to facilitate Cu NPs synthesis (Karimi and Mohsenzadeh, 2015). Additionally, *Azadirachta indica* leaf extract and *Callistemon viminalis* flower extracts were used for the synthesis of CuO NPs (Rajendaran et al., 2019).

Cu NPs, produced through environmentally friendly processes, exhibit a zeta potential of -26 mV, indicating relative stability (El-Saadony et al., 2020). Shobha et al., (2014) found that Cu NPs demonstrate superior antibacterial activity compared to silver, causing damage to vital proteins.

Green synthesis offers numerous advantages over chemical and physical methods, being non-toxic (Devi et al., 2019), pollution-free (Al-sammarraie et al., 2018), environmentally friendly, economical (Kataria and Garg, 2018), and more sustainable. However, challenges exist in terms of raw material accessibility, reaction speed, and the homogeneity of the end product. Raw materials may not be easily obtainable, the synthesis process can be time-consuming (Subramaniam et al., 2015), and achieving uniform particle size poses a challenge (Gao et al., 2016).

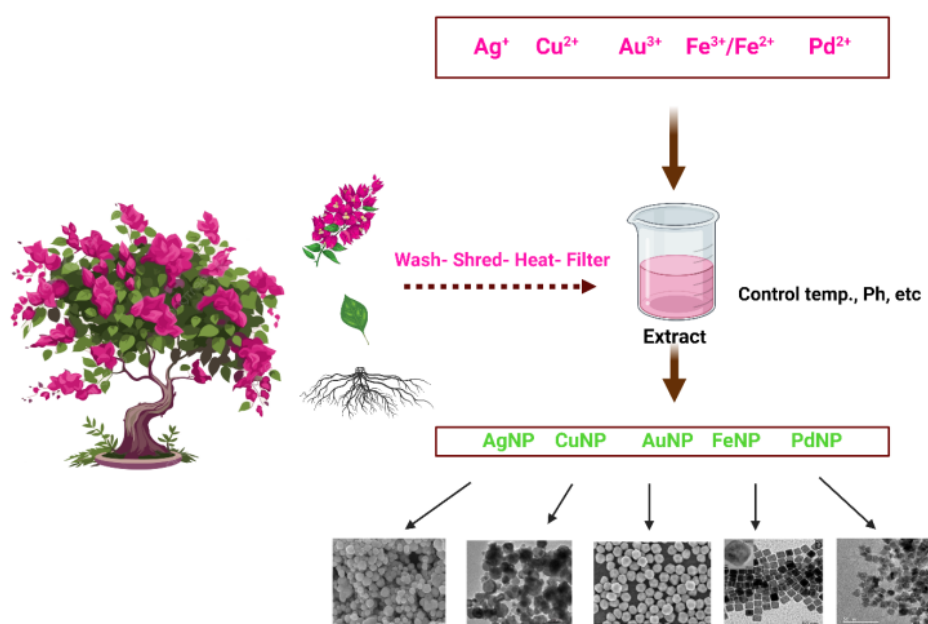


Fig. 2. Different nanoparticles that can be extracted from single ornamental plant parts

3. APPLICATIONS OF NANOPARTICLES

3.1 Medicinal Use

Nanoparticles, particularly those derived from metals like gold and silver, have garnered significant interest in the medical field. Silver nanoparticles (Ag NPs), known for their potent antimicrobial properties, find application in antibacterial coatings and wound dressings. Nanoparticles, including iron oxide and gold nanoparticles (Au NPs), play a crucial role as contrast agents in medical imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI), enhancing tissue visibility and aiding in early disease detection. Moreover, nanoparticles offer targeted drug delivery, improving treatment efficacy while minimizing side effects by delivering medicinal drugs specifically to target cells or tissues. In the realm of cancer therapy, nanoparticles, including gold and iron oxide, hold promise for targeted medication delivery, photothermal therapy, and tumor imaging. These nanomaterials exhibit antioxidant and anti-inflammatory qualities and show potential in treating neurodegenerative diseases by assisting therapeutic agents in crossing the blood-brain barrier.

Furthermore, tailored nanoparticles provide opportunities for gene delivery, contributing to advancements in gene therapy and the treatment of genetic conditions. Despite these promising applications, ongoing research in the field of nanomedicine focuses on understanding the long-term effects, safety, and biocompatibility of nanoparticles in medical contexts. Au NPs are also widely used in the medical industry. Au NPs have high surface compatibility and can adsorb a variety of biomolecules, which could provide a greater efficacies for clinical medicine (Lee et al., 2020, Naiel et al., 2022). In order to assist treat diseases, including cancer, Au NPs are utilized, for instance, as a transporter of bioactive compounds such anticancer medicines (Kumari and Meena, 2020). Green synthesis of gold nanoparticles from *Lawsonia inermis* and its catalytic activity following the Langmuir-Hinshelwood mechanism. Physicochemical and Engineering Aspects of Colloids and Surfaces A: 606, 125447. Palladium is a valuable metal with a high density. It is frequently employed as a catalyst, biosensor, and in medical diagnostics (Nasrollahzadeh and Mohammad Sajadi, 2016). It can boost yield and effectively catalyze a variety of chemical processes. The production of

Pd NPs has been thoroughly investigated because of its unique ligand-free catalysis (Siddiqi and Husen, 2016, Kaliammal et al., 2018). According to Sharmila et al., (2019) "steroids, alkaloids, phenolics, flavonoids, saponins, and tannins present in leaves extract serve as reducing and stabilizing agents" (Sharmila et al., 2017).

The biogenic production of plant-derived nanoparticles (NPs), with a spotlight on their potential as eco-friendly sustainable catalysts, is a major topic of study in the field of plant research, and their potential uses are recently being studied in nanocatalysis research. The biogenic synthesis of NPs from plants appears as a viable and effective strategy to create quick and efficient technologies and, yet, it has seldom been studied. Such NPs are well-suited for a range of biological applications because of their notable antioxidant, antibacterial, and antimicrobial activities. Some of these are also utilized as medications in healthcare, or their structural characteristics have served as a model for the synthesis of more potent synthetic pharmaceuticals. Increasing the synthesis of these secondary metabolites may be accomplished in various ways, one of which is by using nanoparticles that act as elicitors. Nevertheless, nanoparticles may offer various additional advantages for medicinal and aromatic plants, such as accelerated plant development, enhanced photosynthetic efficiency, and general performance, depending on the precise particle size, composition, concentration, and application method. Acknowledging these applications, the current review delved the updated information on exploring the medicinal plants used in NP synthesis.

The suggested mechanisms of action of NPs on the modulation of plant secondary metabolism and biomedical applications are also discussed. This highlights that a deeper study to understand the intricate complexities involved in NPs action is essential.

Silver nanoparticles (AgNPs) made by green synthesis offer a variety of biochemical properties and are an excellent alternative to traditional medications due to their low cost. In the current study, we synthesised AgNPs from the leaf extract of the medicinal plant *Uvaria narum*, commonly called narumpanal. The nanoparticles were characterised by ultraviolet-visible (UV-Vis) spectroscopy, Fourier transform

infrared spectroscopy (FTIR), scanning electron microscopy (SEM) and transmission electron microscopy (TEM). SEM analysis showed that AgNPs are highly crystalline and spherical with an average diameter of 7.13 nm. The outstanding catalytic activity of AgNPs was demonstrated by employing the reduction of 4-nitrophenol to 4-aminophenol. The AgNPs showed antiangiogenic activity in the chick chorioallantois membrane (CAM) assay. AgNPs demonstrated anticancer activity against Dalton's lymphoma ascites cells (DLA cells) in trypan blue assay and cytotoxicity against three fish cell lines: Oreochromis niloticus liver (onIL; National

Repository of Fish Cell Lines, India (NRFC) Accession number—NRFC052) cells, *Cyprinus carpio* koi fin (CCKF; NRFC Accession number—NRFC007) cells and *Cyprinus carpio* gill (CyCKG; NRFC Accession number—NRFC064). Furthermore, the AgNPs demonstrated their ability to inhibit pathogenic microorganisms, *Staphylococcus aureus*, and *Escherichia coli*. The results from the study displayed green synthesised AgNPs exhibit antiangiogenic activity, cytotoxicity, and antimicrobial and catalytic properties, which are crucial characteristics of a molecule with excellent clinical applications.

Table 1. Summarized list of ornamental plants used for extraction of nanoparticles

Plants used	Nano particle	Plant part used	Properties	Reference
<i>Pedilanthus tithymaloides</i>	AgNP	Latex	Antibacterial	Patil et al., (2012)
<i>Cycas</i>	AgNP	Leaf	Antioxidant	Jha and Prasad (2010)
<i>Melia azedarach</i>	AgNP	Leaf	Antitumor activity	Sukirtha et al., (2011)
<i>Nelumbo nucifera</i>	AgNP	Leaf	Larvicidal activity against malaria and filariasis vectors	Santhoshkumar et al. (2011)
<i>Azadirachta indica</i>	AgNP	Leaf	Antimicrobial	Gavhane et al. (2012)
<i>Hibiscus rosa sinensis</i>	AgNP	Leaf	Fish pathogen <i>A. hydrophila</i>	Philip (2010)
<i>Hibiscus subdariffa</i>	ZnONPs	Leaf	Antibacterial and Antidiabetic	Bala et al. (2015)
<i>Aloe barbadensis</i>	ZnONPs	Leaf	Cosmetics	Sangeetha et al., (2011)
<i>Nyctanthes arbor-tristis</i>	ZnONPs	Flower	Antifungal	Jamdagni et al., (2018)
<i>Azadirachta indica</i>	ZnONPs	Leaf	Antimicrobial	Elumalai and Velmurugan (2015)
<i>Uvaria narum</i>	Ag NP	Leaf	Antibacterial, Antiangiogenic, Anticancer	Ajaykumar et al., (2023)
<i>Zephyranthes candida</i>	Ag NP	Flower	anti-inflammatory, anti-diabetic, anti-oxidant, anticancer	Kaliammal et al., (2021)
<i>Passiflora caerulea</i>	ZnONPs	Leaf	Antibacterial	Santhoshkumar et al. (2017)
<i>Withania coagulans</i>	Ag NP	Leaf	Antioxidant, anticancerous	Tripathi et al., (2019)
<i>Ocimum Tenuiflorum</i> and <i>Calotropis Gigantea</i>	TiO ₂	leaf	-	Reddy et al., (2019)
<i>Cassia angustifolia</i>	Ag NP	flower	Antioxidant	Bharati et al., (2018)
<i>Tagetes erecta</i>	Ag NP	flower	Antibacterial	Padalia et al., (2014)

“Silver nanoparticles (AgNPs) have great potential for their mechanistic role in biomedical researches. Recently, green biosynthetic approaches have received much attention in plant science for nanoparticles production. Therefore, in the present study AgNPs have been synthesized utilizing in-vitro grown leaf extract of anti-diabetic medicinal plant *Withania coagulans* Dunal by the reduction of silver nitrate solution. *W. coagulans* synthesized silver nanoparticles (WcAgNPs) were characterized by UV–visible spectroscopy, scanning electron microscopy, energy dispersive X-ray analysis, transmission electron microscopy, X-ray powder diffraction and Fourier transform Infrared spectroscopy. All cumulative results showed that WcAgNPs were ~14 nm in size having spherical shape with face centred cubic structure. High-performance liquid chromatography confirmed the involvement of withanolides in AgNPs synthesis as a reducing/capping agent. Synthesized WcAgNPs showed greater antioxidative potential when compared with *W. coagulans* leaf extract. WcAgNPs have efficient antimicrobial potential and suppress the growth of both gram positive and gram-negative bacteria. In our finding, we also observed cytotoxicity of WcAgNPs against SiHa (cervical cancerous, hyper-triploid) cell lines and apoptosis in SiHa cells after 48 hour incubation with 13.74 $\mu\text{g ml}^{-1}$ (IC₅₀) concentration of WcAgNPs. As results suggested, this is the first report which explains that *W. coagulans* leaf extract have potential as bio-reducing agent for the synthesis of silver nanoparticles, which can be exploited as an anti-oxidant, antimicrobial and anti-cancerous agent and depicts an effective way for utilizing bioactive resources in the restoration of medicinal properties of this plant with high efficacy” (Tripathi et al., 2019).

“The flower like TiO₂ nanoparticles have been identified as potential electrode material for efficient next-generation electrochemical energy storage devices. The present work reports, a novel green approach to synthesize high surface area TiO₂ nanoparticles using medicinal plant leaf extracts namely *Ocimum Tenuiflorum* Plant and *Calotropis Gigantea* Plant. The TiO₂ nanoparticles synthesized using *Calotropis Gigantea* plant confirmed rutile phase from X-ray powder diffraction and Raman spectra. The fourier transform infrared spectroscopy spectra of the sample indicate the presence of TiO₂ vibrational bonds. The field emission scanning electron microscopy images revealed the flower-like shape of nano-granules with an average

granule size of 200 nm. The presence of Ti and O elements was qualitatively confirmed using energy dispersive spectroscopy spectra, which shows the good stoichiometry in the sample. The flower-like shapes with nano petals were further disclosed with the help of high resolution transmission electron microscopy. The corresponding optical band gap was observed to be 3.0 eV. The electrochemical investigations of the sample exhibited a high specific capacitance of 224 F g⁻¹ at 0.5 A g⁻¹ with 71% of capacitive retention after 5000 cycles” (Reddy et al., 2019).

3.2 Therapeutic Use

Nanoparticles, both natural and artificial, have been proposed as carriers for drugs in cancer treatment due to the fact they may boost the therapeutic effect by increasing drug accumulation in target tissues (Zocchi et al., 2020).

3.3 Extending Post-harvest Life

To meet the demands of consumers, countries worldwide are fiercely competing for cut flowers, and the quality of post-harvest flowers is a crucial factor in the competitive dynamics of the global flower market. The industry has faced significant challenges due to the limited vase life of flowers, leading to substantial waste in fresh-cut and loose flowers. Flowers such as tulips, carnations, gerberas, orchids, liliun, and anthurium, among others, are particularly vulnerable to ethylene, a primary factor contributing to the reduction in their vase life (Naing and Kim, 2020). The decrease in the vase life of cut flowers is primarily attributed to microbial infection, specifically bacteria causing stem blockage at the cut end, vascular occlusion, and physiological injuries. Other factors influencing the reduction in postharvest life include water imbalance, depletion of carbohydrate reserves, and ethylene synthesis (Carrillo-López et al., 2016). The use of nanoparticles has emerged as an innovative solution to extend the vase life of cut flowers by combating key adversaries in the floriculture sector, including bacteria, fungi, and ethylene. Nanoparticles, with sizes less than 100 nanometres, are effectively employed in nanocomposites to address various challenges in the flower industry, such as reducing product waste, enhancing packaging materials, managing plant diseases, and protecting stored products from harmful gases and sunlight (Manzoor et al., 2020).

This application of nanoparticles has proven to improve the durability of packaging materials, leading to a 20–30% reduction in waste in the supply chain (Manzoor et al., 2020; Yadollahi et al., 2010; Ruffo et al., 2019). For instance, silver nanoparticles (SNPs) synthesized from Mexican tea (*Chenopodium ambrosioides* L.) have been shown to promote flower opening and extend the vase life of chrysanthemums (*Dendranthema grandiflora*) by combating bacteria and ethylene (Carrillo-Lopez et al., 2016). “Similarly, SNPs synthesized from betel leaves (*Piper betle*) have retained the vase life of gladiolus (*Gladiolus grandiflorus*) by acting as a bactericide and a signalling molecule that scavenges reactive oxygen species (ROS) to reduce lipid peroxidation and maintain membrane stability” (Maity et al., 2019). “The synthesis of SNPs from lasia (*Lasia spinosa*) extract has maintained membrane stability index and total soluble solids (TSS) while suppressing bacterial proliferation in cut rose stems” (Aier et al., 2017). “The biological synthesis of SNPs offers numerous advantages, including stable production with controlled shape and size, along with rapid synthesis, making it a cost-effective technique conducted at ambient temperature and pressure, which is faster than other methods” (Richard, R. & Hugo, 1994, Singh et al., 2016; Tran and Le, 2013).

Nanomaterial-based sensors play a significant role in the postharvest management of climacteric fruits like apples and peaches, as well as in the food industry, particularly in the packaging of vegetables (Cristescu et al., 2012).

In the context of cut flowers, the application of nano-sensors has the potential to enhance vase life by enabling the continuous monitoring of ethylene concentrations in storage areas of major growers and wholesale markets. However, a comprehensive cost-benefit analysis is imperative to assess whether the additional expenses associated with nano-sensor implementation would be justified by the prolonged vase life observed across diverse flower species and within specific market conditions.

Nano-sized silver (Ag⁺) particles (NS) find extensive use as antimicrobials in various applications (Furno et al., 2004). “Leveraging their high surface area-to-volume ratio, NS are deemed more effective in preventing the growth of bacteria and microorganisms compared to other oxidation states of silver. NS release Ag⁺” (Lok et al., 2007), “which has been reported to interact with cytoplasmic components and nucleic acids, inhibit respiratory chain enzymes, and disrupt membrane permeability” (Russell and Hugo, 1994). “While relatively new in the context of pulse and vase solution treatment for cut flowers, studies have explored the efficacy of NS in extending the vase life of various flowers, such as carnations, gerberas, acacias, and roses” (Moradi et al., 2012; Nazemi Rafi and Ramezani, 2013). The observed positive impact of NS pulse treatment is attributed to the inhibition of bacterial growth in the vase solution and at the cut stem ends.

Table 2. Different type of nano particles used in enhancing the vase life of flowers

S.No.	Name	Used for	Mechanism
1	Silica Nanoparticles (SiNPs)	water use efficiency, water translocation, and relative water content, contributing to prolonged flower life	ability to penetrate plant tissues have a high surface-to-volume ratio, which allows them to efficiently interact with plant structures
2	Silver Nanoparticles (AgNPs)	antimicrobial properties	Their application in floriculture aims to reduce microbial contamination in vase water
3	Zinc Oxide Nanoparticles (ZnO NPs)	enhancing plant growth and stress tolerance.	contribute to improved water uptake and nutrient absorption, promoting overall flower health and longevity
4	Carbon Nanotubes (CNTs)	maintaining proper water balance in cut flowers	unique structural and mechanical properties, have been investigated for their role in improving water transport within plant tissues.
5	Copper Nanoparticles (CuNPs)	antimicrobial properties	contribute to maintaining water quality by reducing microbial contamination

Table 3. List of nanoparticles extracted from different spp. of flowering/foilage plants and their impact

Species	Treatments with optimal concentration	Impact	Reference
Alstomeria	NS (10 mg L ⁻¹)	Reducing bacterial growth and improving water uptake	Langroudi et al., (2020)
<i>Anthurium andreanum</i>	NS (10 mg L ⁻¹)	Reducing bacterial growth and improving water uptake	Amin (2017)
Alstroemeria (<i>Alstroemeria aurea</i>)	Vase solution 15 mg L ⁻¹	Improved floret diameter and flower fresh weight	Alimoradi et al., (2013)
	Vase solution 4 mg L ⁻¹	improved anthocyanin content in flower petal	Moradi et al., (2012)
Chrysanthemum (<i>Chrysanthemum morifolium</i> L.	NS 5mg	decreases water stress and increased vase life, reduce stem bacteria	Kazemipour et al.,
gerbera (<i>Gerbera jamesonii</i> cv. 'Dune')	NS 5 mg L ⁻¹	Improved Relative Fresh Weight	Solgi et al., (2009)
<i>Gerbera jamesonii</i> cv. 'Balance'	NS 5 mg L ⁻¹	antimicrobial property and delayed senescence in cut gerbera	Safa et al., (2015)
Gladiolus	NS 4 mg L ⁻¹	maintain spikes fresh and dry weight, reduce the vascular blockage, improve the antioxidative defense, and stabilize the membrane integrity that leads to delay senescence	Maity et al., (2019)
<i>Rosa Hybrida</i> L.	SiNP 2 mg	maximized the longevity by reducing lipid peroxidation	R.S. El-Serafy (2019)
<i>Gerbera jamesonii</i>	ZnO-NP	increase the shelf life of cut flowers, antimicrobial	Zeng et al., (2024)
Roses var. Taj Mahal	NS 50 ppm	Improved water uptake, reduced transpirational loss, reduced bacterial growth	Amingad et al., (2017)
Carnation	NS (5 or 10 mg L ⁻¹) + GA3 (5 or 10 mg L ⁻¹) + BA (80 mg L ⁻¹)	Increased water intake	Hamidimoghadam et al., (2014)
Carnation	NS (40 mg L ⁻¹)	Reduced bacterial growth and ethylene production	Xia et al., (2017)
Carnation	NS (15 mg L ⁻¹)	Inhibited microbial growth	Hashemabadi (2014)
Carnation	NS (2.3 mM)	Reduced bacterial growth	Liu et al., (2018)
Carnation	NS (25 mg L ⁻¹)	Reduced ethylene content and bacterial growth	Naing et al., (2017)
Carnation	NS (0.23 mM) + Sucrose (58 mM)	Reduced ethylene content and bacterial growth	Park et al., (2017)
Carnation	NS (15 mg L ⁻¹) pulsing2 , NS (7.5 mg L ⁻¹)	Reduced bacterial growth	Liu et al., (2008)
Rose cv. 'Movie Star'	NS (50 mg L ⁻¹)	Reduced bacterial growth	Li et al., (2012)
Rose cvs. 'Avalanche'	NS (200 mg L ⁻¹)	Reduced bacterial growth	Nazemi Rafi and

Species	Treatments with optimal concentration	Impact	Reference
and 'Fiesta'			Ramezani (2013)
Rose cv. 'Movie Star'	NS (50 or 100 mg L ⁻¹)	Reduced bacterial growth	Lü et al., (2010)
Rose cv. 'First Red'	Biologically synthesized NS (50 ppm) + Sucrose (4%)	Reduced bacterial growth	Aier et al., (2017)
Tulip cv. 'White Parrot'	NS (10 mg L ⁻¹)	Increased RFW	Byczyńska (2017)
Peony	NS (10 mg L ⁻¹)	Reducing bacterial growth and improving water uptake	Zhao et al. (2018)
Orchid	NS (5 mg L ⁻¹)	Reduced bacterial growth	Rahman et al., (2019)
Gardenias 'fortuniana'	NS (15 mg L ⁻¹)	Reducing bacterial growth and improving water uptake	Lin et al., (2019a)
Gladiolus 'Eerde'	NS (15 mg L ⁻¹)	Reducing bacterial growth and improving water uptake	Li et al., (2017)
Rosa hybrida cv. Black magic	CTS-NP 10 mg L ⁻¹	enhance light usage efficiency, promote production of additional carbohydrate products for plant growth	Seyed Hajizadeh et al., (2023)
Lisianthus (<i>Eustoma grandiflora</i> cv. Echo)	silicon nanoparticle 40 mg L ⁻¹	inhibited microbial growth, ethylene	Kamiab et al., (2017)
Carnation and chrysanthemum	CuNPs 20 mg L ⁻¹	inhibiting the growth of bacterial population	Rashidiani et al., (2020)
Chrysanthemum cv. Snowball	Green CuNPs 75 ppm	Antimicrobial, enhanced relative water uptake	Saikia et al., (2022)

4. PACKAGING

"Utilizing nanocomposite technology and materials presents an opportunity to enhance the physical properties of packaging materials, including mechanical strength, thermal stability, gas barrier, physicochemical characteristics, and recyclability" (Arora and Padua, 2010). To maintain the quality and freshness of plant products during commercialization and consumption, thoughtful material selection and the adoption of packaging technologies capable of preserving the desired atmosphere are crucial. Nanotechnology provides effective scavengers with selective capabilities to eliminate various gases such as oxygen and ethylene. Specifically, the incorporation of nanoscale fillers like Pd into the matrix can improve the impermeability of plastic films to ethylene (Neethirajan et al. 2011). Nanoparticles serve as small physical barriers, hindering the movement of gas molecules by obstructing their path through the material.

"Achieving nano-catalytic degradation of ethylene and other pollutants represents a challenging yet highly desirable objective in the development of environmentally friendly catalysts" (Rickerby et al., 2007). This process involves the actual breakdown of organic contaminants rather than their mere transfer from one phase to another. Pd and TiO₂ fixed on activated carbon have demonstrated effectiveness as catalysts for practical ethylene removal. "Titanium dioxide (TiO₂) has garnered attention for its light-activated photocatalytic degradation under ultraviolet (UV) irradiation, whether from natural (sun) or artificial (lamp) sources, owing to its physical and chemical stability, low cost, availability, and non-toxicity" (Hussain et al., 2016). While the application of nanocomposites and nanocatalysts in floriculture is presently limited, ongoing advancements in packaging materials and formats indicate promising prospects for future developments.

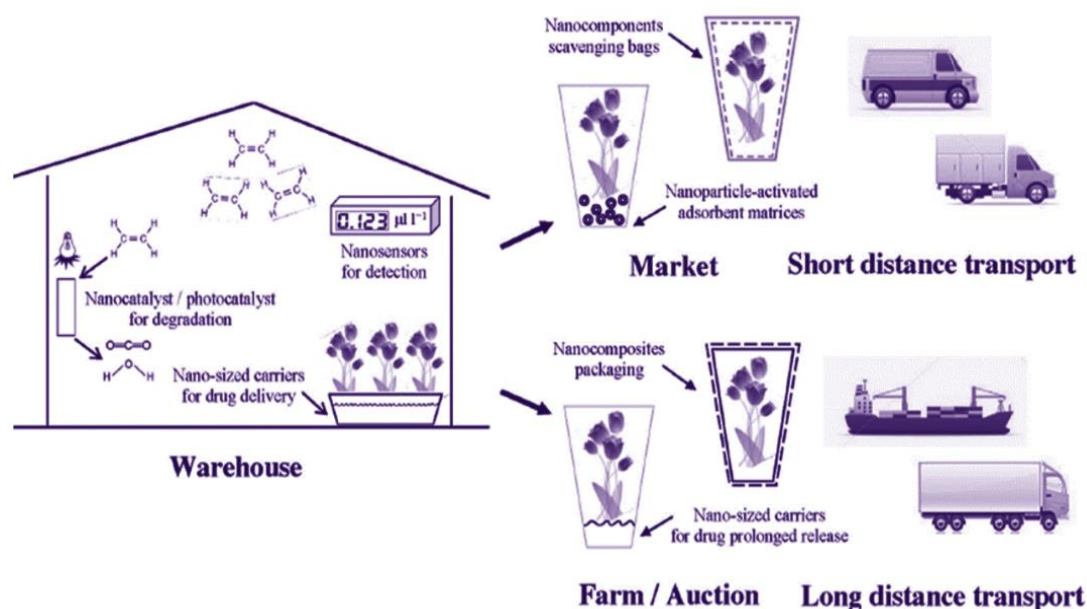


Fig. 3. Diagram representing the use of nanoparticle-based packaging/products while transportation and post-harvest management of flowers

5. CONTROL OF PEST AND DISEASES

Ag NPs have several uses, including being a potent catalyst and microbial growth inhibitor. Researchers discovered that Ag NPs had a strong inhibitory effect on both Gram-positive and Gram-negative bacteria using the disk diffusion experiment, something that Au NPs were unable to accomplish (Nayem et al., 2020). Terminalia arjuna plant extracts were used to generate Cu NPs, which showed strong anti-bacterial activity against *S. aureus* and *E. coli*, but reduced efficaciousness against *S. typhi* and *P. aeruginosa* (Lebaschi et al., 2017). The Cu NPs utilized in antibacterial research were produced by *Nerium oleander* leaf extract (Karimi and Mohsenzadeh, 2015). *Staphylococcus aureus* was significantly inhibited by the Fe NPs that were generated using *Gardenia jasminoides* (Naseem and Farrukh, 2015).

The effectiveness of green generated copper nanoparticles in treating chrysanthemum (*Dendranthema grandiflora*) cv. Snowball leaf spot disease. Additionally, the CuNPs were examined in a vase solution including chopped chrysanthemums. The findings demonstrated that, in comparison to the standard fungicide's (48.57%) mycelial growth inhibition, the green produced CuNPs demonstrated mycelial growth inhibition at 60.52%, 57.13%, and 52.44% for night jasmine, allamanda, and yellow oleander,

respectively. Allamanda mediated CuNPs at 75 ppm and night jasmine-mediated CuNPs at 75 ppm were shown to be the most effective among all other treatments that extend the vase life of cut chrysanthemum beyond custom. It is possible to deduce from the study that green synthesis of nanoparticles from decorative plants Chrysanthemum leaf spot disease can be effectively managed and the vase life of cut chrysanthemums can be extended with the use of yellow oleander and allamanda. But it was discovered that CuNPs mediated by night jasmine were more successful (Saikia et al., 2022).

Nano-scale systems could be applied to cut flowers for ethylene detection, removal and photocatalytic degradation in the store environment. Nanocomposites are used in active packaging and they are able to enhance vase life by scrubbing ethylene. The use of new natural formulations (e.g nanosponges) is able to increase the bio-availability of the active ingredients.

They help to minimize the impact of agriculture on the environment and to reduce production costs. In contrast, green synthesis of NPs using plant extracts is an economical, clean, time saving, easy and eco-friendly technique because of the minimum use of toxic chemicals that pollute the environment.

Table 4. Nanoparticle expressing anti-bacterial properties against various phytopathogens

Plant (Scientific name)	Plant part	Ionic element	Size and shape	Phytopathogen tested
Lemongrass (<i>Cymbopogon citratus</i>)	Leaves	Al ₂ O ₃	34.5 nm Spherical	<i>Pseudomonas aeruginosa</i>
Neem (<i>Azadirachta indica</i> A. Juss),	Flowers, leaves, Peels	Au	20–30 nm Spherical	<i>Pseudomonas aeruginosa</i>
Climbing lily (<i>Gloriosa superba</i> L.)	Leaves	CeO ₂	5 nmSpherical	<i>Pseudomonas aeruginosa</i>
White leadtree (<i>Leucaena leucocephala</i> L.)	Leaves	CdO	36–57 nmSpherical	<i>Pseudomonas aeruginosa</i> , <i>Aspergillus niger</i>
Tulsi (<i>Ocimum sanctum</i> L.)	Leaves	Cu	25 nmRod, cylindrical and elliptical	<i>Alternaria carthami</i> , <i>Aspergillus niger</i> , <i>Colletotrichum gloeosporioides</i> , <i>Colletotrichum lindemuthianum</i> , <i>Drechslera sorghicola</i> , <i>Fusarium oxysporum</i> f.sp. <i>carthami</i> , <i>Fusarium oxysporum</i> f.sp. <i>cicero</i> , <i>Fusarium oxysporum</i> f.sp. <i>udum</i> , <i>Macrophomina phaseolina</i> , <i>Rhizoctonia bataticola</i> , <i>Rhizoctonia solani</i> , <i>Xanthomonas axonopodis</i> pv. <i>citri</i> , <i>Xanthomonas axonopodix</i> pv. <i>punicae</i>
Lamb's ears (<i>Stachys lavandulifolia</i> Vahl.)	Flowers	CuO	80 nm	<i>Pseudomonas aeruginosa</i>
Water hyacinth (<i>Eichhornia crassipes</i> (Mart.) Solms)	Leaves	CuO	28 nm	<i>Aspergillus flavus</i> , <i>Aspergillus niger</i> , <i>Aspergillus fumigatus</i> , <i>Fusarium oxysporum</i> , <i>Fusarium culmorum</i>
Savila (<i>Aloe vera</i> L.)	Leaves	Se	50 nmSpherical	<i>Colletotrichum coccodes</i> , <i>Penicillium digitatum</i>
Ashwagandha, bufera(<i>Withania somnifera</i> L.)	Leaves	Se	45–90 nmSpherical	<i>Bacillus subtilis</i>
Bermuda grass (<i>Cynodon dactylon</i>)	Leaves	Si	62.1 nmSpherical	<i>Pseudomonas aeruginosa</i>
Coral jasmine (<i>Nyctanthes arbor-tristis</i> L.)	Flower	ZnO	12–63 nm	<i>Alternaria alternata</i> , <i>Aspergillus niger</i> , <i>Botrytis cinerea</i> , <i>Fusarium oxysporum</i> , <i>Penicillium expansum</i>
Bala (<i>Sida cordifolia</i> L.)	Leaves	Fe ₂ O ₃	10–22 nm	<i>Staphylococcus aureus</i>
Neem (<i>Azadirachta indica</i> A. Juss.)	Leaves	Fe ₂ O ₃	20–80 nm	<i>Alternaria mali</i> , <i>Botryosphaeria dothidea</i> , <i>Diplodia seriata</i>
Yuquilla (<i>Ruellia tuberosa</i> L.)	Leaves	FeO	52.78 nm	<i>Staphylococcus aureus</i>
Eucalyptus (<i>Eucalyptus robusta</i> Sm.)	Leaves	Fe ₂ O ₃	8 nmSpherical	<i>Pseudomonas aeruginosa</i> , <i>Bacillus subtilis</i>
Cadillo (<i>Tridax procumbens</i> L.)	Leaves	Fe ₂ O ₃	26 nmSpherical	<i>Sclerotium rolfsii</i> , <i>Fusarium oxysporum</i>

Plant(Scientific name)	Plant part	Ionic element	Size and shape	Phytopathogen tested
Muicle (<i>Justicia spicigera</i> Schltdl.)	Leaves	Ag	86–100 nm Spherical	<i>Colletotrichum</i> sp., <i>Fusarium solani</i> , <i>Alternaria alternata</i> , <i>Macrophomina phaseolina</i>
Persian clover (<i>Trifolium resupinatum</i> L.)	Seed	Ag	17 nm	<i>Neofusicoccum parvum</i> , <i>Rhizoctonia solani</i>
Grass	Leaves	Ag	15 nm Spherical- oblate	<i>Fusarium solani</i> , <i>Rhizoctonia solani</i>
Pine cone(<i>Pinus coulteri</i> D. Don)	Leaves	Ag	20–100 nm triangular and hexagonal	<i>Bacillus megaterium</i> , <i>Pseudomonas syringae</i> , <i>Burkholderia glumae</i> , <i>Xanthomonas oryzae</i> pv. <i>oryzae</i>
Myriostachya (<i>Myriostachya wightiana</i> Nees ex Steud.)	Leaves	Ag	15–65 nm Irregular shape	<i>Xanthomonas campestris</i> , <i>Ralstonia solanacearum</i>
<i>Drosera binata</i> , <i>Drosera indica</i> L., <i>Drosera spatulata</i> , <i>Dionaea muscipula</i> Sol. ex J. Ellis	Leaves	Ag	5–10 nm Spherical	<i>Pectobacterium atrosepticum</i> , <i>Pectobacterium parmentieri</i> , <i>Pectobacterium wasabie</i> , <i>Dickeya dadantii</i>
Indian acalypha(<i>Acalypha indica</i> L.)	Leaves	Ag	10–50 nm	<i>Alternaria alternata</i> , <i>Sclerotinia sclerotiorum</i> , <i>Macrophomina phaseolina</i> , <i>Rhizoctonia solani</i> , <i>Botrytis cinerea</i> , <i>Curvularia lunata</i>

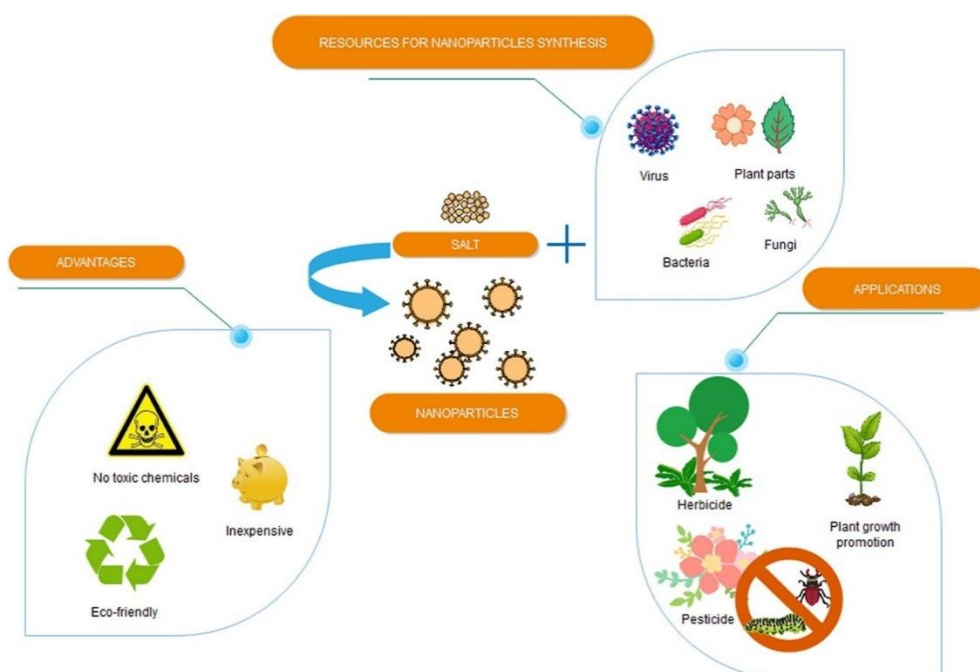


Fig. 4. Advantages of plant extracted nanoparticle

6. FUTURE PROSPECTS

The efficiency and the economic benefit of applying each strategy to the flower industry need to be evaluated in the different crop/market contexts. Focused research is required in the use of nanoparticles in preservative solutions and Nano packing to improve the Quality and the postharvest life of flowers.

7. CONCLUSION

Modern agriculture makes considerable use of chemicals to increase quality and productivity. However, there are health and environmental risks associated with their use. Due to their negative effects on the environment, several compounds that presently extend the shelf life of flowers by affecting the synthesis or action of ethylene may soon be outlawed. Conscientious resource use and production methods that are safe for the environment and human health have become essential in recent decades to achieve the objective of more sustainable plant production. Therefore, using a systems biology approach to integrate existing bio-, info-, and nanotechnologies will be necessary for continued advancement.

There has been discussion about the green synthesis of Au, Ag, Fe, Cu, and Pd NPs. The green synthesis of nanoscale metals is possible, according to studies conducted on a variety of

plant materials. Numerous studies on the green synthesis of nanoscale metal have been published in recent years. The practical production and use of green synthesized nanomaterials, however, requires overcoming a number of obstacles, including low yield, irregular particle sizes, intricate extraction processes, seasonal and regional raw material availability, and other issues. Therefore, improving the yield of nanoscale metal particles, using low-cost raw materials, and employing simple energy-saving technology are the research directions needed in the future. At present, there have been successful cases of using grass to synthesize Ag NPs. Therefore, it is possible that green synthesis of nanoscale metals has a broad prospect and a great potential for development.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declares that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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