**Nanotechnology based applications in floriculture: A comprehensive review**

**Abstract**

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 adds to fragrance and holds 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 offer a unique medium for synthesizing a variety of metal and 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 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 are used in cosmetic industries, in the field of biomedical science, silver NP synthesized from *Hymenocallis littoralis* exhibit 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

**Introduction**

Nanotechnology is an 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 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 reaches 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 enhance their effectiveness against pest and diseases, nanogenomices to develop the resistance to pest and diseases (Sarmast and Salehi, 2016; Soriano *et al*., 2018; Ghidan and Antary, 2019; Zahedi *et al*., 2020).

**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 nanometers or fewer, quantum phenomena take center 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 (aluminum), 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.

**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 best 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, polyoxonetalates and poly saccharide method.

**Figure 1: Extraction process of Nanoparticle**

**Polysaccharide method**

A example of biological applications for environmental sustainability is the green synthesis of AgNPs by the use of the polysaccharide technique (cellulose). The shoot 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).

**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 (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 (Tharishini *et al*., 2014). The concentration of chloroauric acid influences the green production of gold nanoparticles.

**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 by various studies (Khatami *et al*., 2018; Hemmati *et al*., 2019; Rautela *et al*., 2019; Rahimullah Shaikh and Bhend, 2019; 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*., (2017b), and Arokiyaraj *et al*., (2017).

**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.

**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*., 2015). 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 a 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 (Alsammarraie *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 (Subramaniyam *et al*., 2015), and achieving uniform particle size poses a challenge (Gao *et al*., 2016).



**Figure 2: Different nanoparticles that can be extracted from single ornamental plant parts**

**Applications of nanoparticles**

**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

**Table 1: Summarized list of ornamentals plants used for extraction of nanoparticles**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Plants used** | **Nano particle** | **Plant part used** | **Properties** | **Reference** |
| Pedilanthus tithymaloides | AgNP | Latex | Antibacterial | [Patil](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib101) *[et al](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib101)*[., (2012)](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib101) |
| Cycas | AgNP | Leaf | Antioxidant | [Jha and Prasad (2010)](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib59) |
| Melia azedarach | AgNP | Leaf | Antitumor activity | Sukirtha  *et al*., 2011 |
| Nelumbo nucifera | AgNP | Leaf | Larvicidal activity against malaria and filariasis vectors | [Santhoshkumar](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib123)  *[et al](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib123)*[., (2011)](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib123) |
| Azadirachta indica | AgNP | Leaf | Antimicrobial | [Gavhane](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib42)  *[et al](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib42)*[., (2012)](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib42) |
| *Hibiscus rosa sinensis* | AgNP | Leaf | Fish pathogen A. hydrophila | [Philip (2010)](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib104) |
| Hibiscus subdariffa | ZnONPs | Leaf | Antibacterial and Antidiabetic | [Bala](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib10)  *[et al](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib10)*[., (2015)](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib10) |
| *Aloe barbadensis* | ZnONPs | Leaf | Cosmetics | Sangeetha  *et al*., (2011) |
| *Nyctanthes arbor-tristis* | ZnONPs | Flower | Antifungal | [Jamdagni](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib55)  *[et al](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib55)*[., (2018)](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib55) |
| *Azadirachta indica* | ZnONPs | Leaf | Antimicrobial | [Elumalai and Velmurugan (2015)](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib35) |
| *Uvaria narum* | Ag NP | Leaf | Antibacterial, Antiangiogenic, Anticancer | Anthyalam  *et al*., (2023) |
| *Zephyranthes candida* | Ag NP | Flower | anti-inflammatory, anti-diabetic, anti-oxidant, anticancer | Kaliammal  *et al*., 2021 |
| *Passiflora  caerulea* | ZnONPs | Leaf | Antibacterial | [Santhoshkumar](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib122)  *[et al](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib122)*[., (2017)](https://www.sciencedirect.com/science/article/pii/S187881811931299X%22%20%5Cl%20%22bib122) |
| *Withania coagulans* | Ag NP | Leaf | Antioxidant, anticancerous | Tripathi  *et al*., (2019) |
| *Ocimum Tenuiflorum and Calotropis Gigantea* | TiO2 | leaf | - | Reddy  *et al*., (2019) |
| *Cassia angustifolia* | Ag NP | flower | Antioxidant | Bharati  *et al*., 2018 |
| *Tagetes erecta* | Ag NP | flower | Antibacterial | Padalia  *et al*., 2014 |

can adsorb a variety of biomolecules, which could provide a greater efficacies for clinical medicine ([Lee *et al*., 2020](https://www.sciencedirect.com/science/article/pii/S2352186422000359#b76)). 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). According to Sharmila et al., steroids, alkaloids, phenolics, flavonoids, saponins, and [tannins](https://www.sciencedirect.com/topics/earth-and-planetary-sciences/tannin) present in leaves extract served as reducing and stabilizing agents ([Sharmila *et al*., 2017](https://www.sciencedirect.com/science/article/pii/S2352186422000359#b131)).

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 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 chorioallantoic 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 (onlL; 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, antimicrobial and catalytic properties, which are crucial characteristics of a molecule with excellent clinical applications.

Silver nanoparticles (AgNPs) have great potential for their mechanistic role in biomedical researches. Recently, green biosynthetic approaches have been 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 Infra-Red 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 suppresses 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 μg ml−1 (IC50) concentration of WcAgNPs. As results suggested, this is the first report which explain that *W. coagulans* leaf extract have potential as bio-reducing agent for synthesis of silver nanoparticles, which can be exploited as anti-oxidant, antimicrobial and anti-cancerous agent and depicting an effective way for utilizing bioactive resources in 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 that the flower like shape of nano-granules with an average granule size of 200 nm. The presence of Ti and O elements 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)

**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).

**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, lilium, 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 signaling 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). 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 (Singh *et al*., 2016; Tran and Le, 2013).

**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 tissueshave 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 contaimination |

Nanomaterial-based sensors play a significant role in 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; Park *et al*., 2005). 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 Ramezanian, 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 3: List of nanoparticle extracted from different spp. of flowering/foliage plants and their impact**

|  |  |  |  |
| --- | --- | --- | --- |
| **Species** | **Treatments with optimal concentration** | **Impact** | **Reference** |
| Alstomeria | NS (10 mg L−1 ) | Reducing bacterial growth and improving water uptake | Ershad Langroudi *et al*., (2020) |
| *Anthurium andreanum* | NS (10 mg L−1 ) | Reducing bacterial growth and improving water uptake | Amin (2017) |
| Alstroemeria (*Alstroemeria aurea*) | 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 (*Chrysanthemum morifolium* L | NS 5mg | decreases water stress and increased vase life, reduce stem bacteria | Sedigheh Kazemipour *et al*., |
| gerbera (*Gerbera jamesonii* cv. ‘Dune’) | NS 5 mg L−1 | Improved Relative Fresh Weight | Solgi *et al*., 2009 |
| *Gerbera jamesonii* 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 |
| *Rosa Hybrida* L. | SiNP 2 mg | maximized the longevity by reducing lipid peroxidation | R.S. El-Serafy 2019 |
| *Gerbera jamesonii* | ZnO-NP | increase the shelf life of cut flowers, antimicrobial | Gupta *et al*., 2018 |
| 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*., (2017b) |
| 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’ and ‘Fiesta’ | NS (200 mg L−1 ) | Reduced bacterial growth | Nazemi Rafi and Ramezanian (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 efciency, promote production of additional carbohydrate products for plant growth | Seyed Hajizadeh *et al*., 2023 |
| Lisianthus ( *Eustoma grandiflora* cv. Echo) | silicon nanoparticle 40 mg L−1 | inhibited microbial growth, ethylene | Fereshteh Kamiab 2017 |
| Carnation and chrysanthemum | CuNPs 20 mg L-1 | inhibiting the growth of bacterial population | **Nahid Rashidiani** *et al*., **2020** |
| Chrysanthemum cv. Snowball | Green CuNPs 75 ppm | Antimicrobial, enhanced relative water uptake | Sewali Saikia *et al*., 2022 |

**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*., 2000). 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*., 2011). 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.**Figure 3: Diagram representing the use of nanoparticle based packaging/products while transportation and post-harvest management of flowers**

**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 shown 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

**Table 4: Nanoparticle expressing anti-bacterial properties against various phytopathogens**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Plant(Scientific name)** | **Plant part** | **Ionic element** | **Size and shape** | **Phytopathogen tested** |
| Lemongrass (*Cymbopogan citratus*) | Leaves | Al2O3 | 34.5 nmSpherical | *Pseudomonas aeruginosa* |
| Neem (*Azadirachta indica* A. Juss), | Flowers, leaves, Peels | Au | 20–30 nmSpherical | *Pseudomonas aeruginosa* |
| Climbing lily (*Gloriosa superba* L.) | Leaves | CeO2 | 5 nmSpherical | *Pseudomonas aeruginosa* |
| White leadtree (*Leucaena leucocephala* L.) | Leaves | CdO | 36–57 nmSpherical | *Pseudomonas aeruginosa*,*Aspergillus niger* |
| Tulsi (*Ocimum sanctum* L.) | Leaves | Cu | 25 nmRod, cylindrical and elliptical | *Alternaria carthami*,*Aspergillus niger*,*Colletotrichum gloeosporioides*,*Colletotrichum lindemuthianum*,*Drechslera sorghicola*,*Fusarium oxysporum* f.sp. *carthami*,*Fusarium oxysporum* f.sp. *cicero*,*Fusarium oxysporum* f.sp. *udum*,*Macrophomina phaseolina*,*Rhizoctonia bataticola*,*Rhizoctonia solani*,*Xanthomonas axonopodis* pv. *citri*,*Xanthomonas axonopodix* pv. *punicae* |
| Lambʼs ears (*Stachys lavandulifolia* Vahl.) | Flowers | CuO | 80 nm | *Pseudomonas aeruginosa* |
| Water hyacinth (*Eichhornia crassipes* (Mart.) Solms) | Leaves | CuO | 28 nm | *Aspergillus flavus*,*Aspergillus niger*,*Aspergillus fumigatus*,*Fusarium oxysporium*,*Fusarium culmorum* |
| Savila (*Aloe vera* L.) | Leaves | Se | 50 nmSpherical | *Colletotrichum coccodes*,*Penicillium digitatum* |
| Ashwagandha, bufera(*Withania somnifera* L.) | Leaves | Se | 45–90 nmSpherical | *Bacillus subtilis* |
| Bermuda grass (*Cynodon dactylon*) | Leaves | Si | 62.1 nmSpherical | *Pseudomonas aeruginosa* |
| Coral jasmine (*Nyctanthes arbor-tristis* L.) | Flower | ZnO | 12–63 nm | *Alternaria alternata*,*Aspergillus niger*,*Botrytis cinerea*,*Fusarium oxysporum*,*Penicillium expansum* |
| Bala (*Sida cordifolia* L.) | Leaves | Fe2O3 | 10–22 nm | *Staphylococcus aureus* |
| Neem (*Azadirachta indica* A. Juss.) | Leaves | Fe2O3 | 20–80 nm | *Alternaria mali*,*Botryosphaeria dothidea*,*Diplodia seriata* |
| Yuquilla (*Ruellia tuberosa* L.) | Leaves | FeO | 52.78 nm | *Staphylococcus aureus* |
| Eucalyptus (*Eucalyptus robusta* Sm.) | Leaves | Fe2O3 | 8 nmSpherical | *Pseudomonas aeruginosa*,*Bacillus subtilis* |
| Cadillo (*Tridax procumbens* L.) | Leaves | Fe2O3 | 26 nmSpherical | *Sclerotium rolfsii*,*Fusarium oxysporum* |

were generated using *Gardenia jasminoides* (Naseem and Farrukh, 2015).

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



**Figure 4: Advantages of plant extracted nanoparticle**

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) 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 minimum use of toxic chemicals that pollute the environment

**Future prospects**

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

**Conclusion**

Chemicals are used extensively in modern agriculture in order to improve yield and quality. However, their use poses environmental and public health concerns. Many chemicals that affect ethylene synthesis or its action, which are currently in use to extend the shelf-life of flowers, may be soon banned due to their environmental impact. Over the last decades, environmentally and health-friendly production methods and conscientious use of resources have become crucial for reaching the goal of more sustainable plant production. Thus further progress will require an integration of available bio-, info- and nanotechnologies through a systems biology approach.

Green synthesis of Au, Ag, Fe, Cu, and Pd NPs have been discussed. Studies on various plant materials show that the green synthesis of nanoscale metals is feasible. In recent years, a large number of research has been reported regarding green synthesis of nanoscale metal. However, green synthesis has many challenges and shortcomings such as low yield, non-uniform particle sizes, complex extraction procedures, seasonal and regional availability of raw materials, and other difficulties that need to be overcome for practical production and application of green synthesized nanomaterials. Therefore, improving 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.

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