**NEW ERA AGRICULTURE MAGAZINE**

# The Role of Noble Metallic Nanoparticles in Precision and Smart Agriculture

Dhwani Hanwat[1], Soumyakanta Swain[2], Roshni Thampi[3], Raunak Pramanik[4] and Yogita lather[5]

**Abstract: -**

In recent decades, nanotechnology has drawn significant interest from researchers in plant sciences. The physical and chemical properties of nanoparticles are closely linked to their size and shape. Among these, noble metallic nanoparticles (NMNPs) have shown great promise in enhancing agricultural productivity while reducing reliance on traditional pesticides. When used as nanofertilizers, these particles can promote plant growth and improve nutrient uptake efficiency. Additionally, NMNPs possess strong antimicrobial properties, offering protection to plants against multidrug-resistant pathogens. Nanobiosensors and nanodevices have found applications in various agricultural fields, including early disease detection and targeted delivery of agrochemicals. However, research has also highlighted concerns regarding the potential toxicity and environmental hazards associated with NMNPs. It is essential to fully understand their effects on agriculture to evaluate safety and potential threats to biodiversity and human health. This overview outlines the recent progress in the use of NMNPs for transforming agriculture and explores emerging trends in sustainable and precision farming practices.

## Introduction

Metals have played a pivotal role in advancing human civilization, marking the transition from the Stone Age and shaping progress throughout history. Evidence of metal use dates back to ancient Egyptian times. In antiquity, the term "noble metals" symbolized

***Dhwani Hanwat[1], Soumyakanta Swain[2], Roshni Thampi[3], Raunak Pramanik[4] and Yogita lather[5]***

*[1]Assistant Professor, Department of Agronomy, School of Agriculture Science, Technology and research, Sardar Patel University Balaghat (M.P.)*

*[2]M.Sc. Scholar, Department of Horticulture, Babasaheb Bhimrao Ambedkar University, Lucknow*

*[3]Assistant Professor, Department of Agricultural Extension, Kerala Agricultural University*

*[4]M.Sc. Scholar, Department of Soil Science and Agricultural Chemistry, Uttar Banga Krishi Viswavidyalaya*

*[5]Research Scholar, Department of Agronomy, CCS Haryana Agricultural University, Hisar*

wealth, power, and artistic value. Today, these elements are widely utilized across various industries such as aerospace, electronics, automotive, medicine, and biomedicine. Noble metals, though not strictly defined, typically include ruthenium, rhodium, palladium, silver (Ag), osmium, iridium, platinum (Pt), and gold (Au), listed in increasing order of atomic number. These metals are highly resistant to harsh conditions like corrosion and oxidation, even at elevated temperatures. Due to their rarity and the complexity of their extraction from Earth's crust, they are also among the most expensive elements. In recent years, metal nanoparticles (MNPs), particularly noble metallic nanoparticles (NMNPs), have gained attention for their potential in various applications, including drug delivery (notably for cancer and diabetes treatment), antimicrobial and antiviral therapies, biosensing, and agriculture. Advances in the synthesis of NMNPs have opened up numerous research opportunities, especially in biotechnology. Agriculture today faces several pressing challenges, such as climate change, soil degradation from harmful chemicals, and the urgent need to increase food production to keep pace with a rapidly growing global population. According to the United Nations, the global population is projected to reach 8.5 billion by 2030, requiring a more than 50% increase in food production to meet demand. To address these issues, a shift toward sustainable agricultural practices is essential, and NMNPs present a promising solution. This review explores the unique properties, applications, and recent progress in NMNP research, emphasizing their potential to transform agriculture. A deeper understanding of nanotechnology will be crucial for advancing global food security and meeting future agricultural demands.

**PROPERTIES AND CHARACTERIZATION OF NMNPS**

Noble metallic nanoparticles (NMNPs) are among the most extensively studied due to their ease of synthesis, high surface-to-volume ratio, distinctive optical behavior, and versatile surface chemistry that distinguishes them from bulk metals. One key feature is their localized surface plasmon resonance (LSPR)—the light-induced oscillation of free electrons-which significantly enhances their optical properties. This enhancement leads to strong light absorption and scattering. NMNPs offer tunable optical properties that can be precisely adjusted based on particle size (ranging from 1–100 nm), shape (such as nanoparticles, nanorods, or nanoshells), and composition (including noble metal alloys), making them highly valuable for imaging and photothermal therapy. The plasmonic effects also contribute to Mie scattering and heat generation. These nanoparticles are also widely used in the development of materials with electrical and catalytic functions, such as those used in surface-enhanced Raman scattering (SERS) and surface-enhanced fluorescence. The unique, size- and shape-dependent characteristics of NMNPs allow for a wide range of analytical techniques to assess their properties. Advanced tools are employed to examine synthesized NMNPs, focusing on their size, shape, distribution, aggregation behavior, surface charge, and more. Common techniques include ultraviolet-visible (UV-vis) spectroscopy, which assesses their optical behavior; transmission electron microscopy (TEM), which reveals morphology; Fourier transform infrared (FT-IR) spectroscopy, which identifies functional groups; zeta potential analysis, which measures surface charge and composition; and X-ray diffraction (XRD), which determines crystal structure, grain size, phase characteristics, and lattice parameters.

**BEHAVIOR OF NMNPS IN AGRICULTURAL SOIL**

Noble metallic nanoparticles (NMNPs) typically enter the soil ecosystem through two main pathways: direct and indirect exposure. Direct exposure involves the intentional application of nano-based agrochemicals-such as nanofertilizers, nano-pesticides, nano-herbicides, or antimicrobial agents-directly to the soil. These nanoformulations help protect crops from pests, weeds, insects, and plant pathogens, ultimately enhancing plant health and boosting productivity. For instance, silver nanoparticles (AgNPs) have been shown to function as effective nanofertilizers, improving the growth and yield of wheat and fenugreek. Similarly, colloidal gold nanoparticles (AuNPs) have been reported to enhance the production of ginsenosides and promote anti-inflammatory properties in red ginseng. In contrast, indirect exposure occurs when NMNPs reach agricultural lands through secondary sources such as sewage sludge and wastewater sediments. These particles often hitch a ride into the environment via various carriers like paints, antimicrobial products, detergents, or inkjet printing inks. Once introduced into the soil, the environmental behavior of NMNPs is largely dictated by the interaction between their physical/chemical structure and the surrounding soil properties. Due to their nanoscale size and associated quantum effects, NMNPs exhibit unique characteristics. In the soil, they often undergo physical and chemical transformations and tend to aggregate into larger clusters. This aggregation is influenced by their highly reactive surfaces and their tendency to interact with soil components. The degree of aggregation depends on various factors, including pH levels, organic matter content, the presence of dissolved ions and clays, and physical influences like Brownian motion, as well as the intrinsic properties of the nanoparticles themselves. These processes can be explained through the Derjaguin-Landau-Verwey-Overbeek (DLVO) theory. Moreover, NMNPs such as AgNPs and AuNPs can undergo chemical transformations through oxidation and reduction reactions. Sunlight-driven redox reactions and sulfidation are common transformation pathways, and the release of metal ions through dissolution is also a frequent occurrence in the soil environment.

**EXPOSURE, UPTAKE, AND TRANSLOCATION OF NMNPS IN PLANTS**

In plant physiological systems, noble metallic nanoparticles (NMNPs) can enter through two main routes: foliar exposure and root exposure. In foliar exposure, NMNPs are taken up through the plant's outer leaf surfaces, primarily via the cuticle and stomata. Different particle sizes follow specific entry routes—for example, particles ranging from 4–100 nm can pass through the cuticle, 5 nm particles can traverse cell walls, and polymer-based nanoparticles around 43 nm in diameter can be absorbed through stomatal openings. However, natural barriers like endophytic microorganisms present in leaves can impede this process. In the case of root exposure, NMNPs can be introduced into the soil either through irrigation or direct application, including spraying onto plant foliage. One study found that gold nanoparticles (AuNPs) entered tomato and rice plants through both clathrin-mediated and clathrin-independent endocytosis. Once in the soil, NMNPs are absorbed through root hairs, which secrete organic acids and mucilage-compounds that can enhance nanoparticle uptake. The distribution and movement of NMNPs within plant systems depend on factors such as their structural properties, the route of exposure, and the types of plant tissues involved. After uptake, NMNPs are translocated through the plant via two main pathways: the apoplast and symplast. The apoplastic route moves particles through extracellular spaces, while the symplastic route passes them between cells via plasmodesmata. Raliya et al. (2016) observed that when AuNPs (30–80 nm) were applied to watermelon seedlings via foliar spray, the nanoparticles entered through the stomata and were subsequently transported through the phloem from the leaves down to the roots.

**APPLICATION OF NMNPS IN AGRICULTURE**

In recent years, nanoparticles have gained significant attention due to their distinct properties and broad range of applications across fields such as agriculture, the food industry, and medicine. With the growing need for sustainable agricultural practices, nanotechnology has emerged as a vital tool in supporting environmentally friendly and efficient farming. Various noble metallic nanoparticles (such as silver and gold nanoparticles) are now being utilized in agriculture through nanoscale delivery systems that carry nanopesticides, nanofertilizers, and antimicrobial agents to enhance crop growth and yield. These nanoscale delivery systems are designed to control and prolong the release of active ingredients-such as fertilizers, pesticides, herbicides, and plant growth regulators-directly at the targeted site. Their high solubility and stability in environmental conditions make them highly effective in agricultural applications. By adhering strongly to plant surfaces, these nanocarriers minimize chemical loss to the surrounding environment, thereby increasing the efficiency of agrochemicals while reducing atmospheric contamination. In addition, NMNPs are employed in the development of nanobiosensors, which enable the precise detection of plant pathogens and facilitate real-time monitoring of plant growth and health.

## DETRIMENTAL IMPACT OF NMNPS IN *IN VIVO* AND *IN VITRO* MODELS

As the use and frequency of exposure to noble metallic nanoparticles (NMNPs) continue to rise, concerns about their potential hazards are also increasing. Numerous studies have highlighted the toxic effects and environmental risks associated with metallic nanoparticles, particularly NMNPs. These nanoparticles may enter the body through three main exposure routes: injection or contact with damaged skin, ingestion, and inhalation. Excessive or uncontrolled application of NMNPs in soil can disrupt plant development and lead to their accumulation in edible plant parts, ultimately posing a risk of human consumption. Hence, it's essential to determine the appropriate levels of NMNPs introduced into the environment, their accumulation in plants, and their impact on human health.

NMNPs, especially silver nanoparticles (AgNPs), are bioavailable and capable of crossing biological membranes, potentially causing physiological changes and toxicity in organisms. For example, AgNPs introduced into soil can alter microbial diversity, disrupt soil invertebrate communities, and affect overall plant health. Research has shown that AgNPs interfere with nitrogen-fixing microbial communities and reduce populations of beneficial soil bacteria like *Streptomyces*, *Bradyrhizobium*, *Sphingopyxis*, and *Kribbella*, which in turn suppresses plant growth-promoting functions. A risk assessment study by Schlich et al. found that AgNPs introduced through sewage sludge negatively impacted soil microorganisms, even at environmentally realistic concentrations. Additionally, exposure to AgNPs led to increased tissue apoptosis in soil organisms such as earthworms. While the potential nanotoxicity of gold nanoparticles (AuNPs) is still under investigation, some studies have reported adverse effects on soil organisms like *Caenorhabditis elegans*, potentially through the modulation of specific biological pathways. On a positive note, certain beneficial microorganisms in the rhizosphere, such as arbuscular mycorrhizal fungi, can help plants cope with nanoparticle-induced stress by enhancing nutrient uptake and promoting growth. These fungi can also mitigate the negative effects of AgNPs on soil microbial diversity. However, in aquatic ecosystems, AgNPs have shown dose-dependent toxicity, such as developmental defects in sea urchins (*Paracentrotus lividus*). When NMNPs are released beyond certain thresholds, they can act as pollutants in both land and water ecosystems. Therefore, monitoring adverse effects of NMNPs at the population or ecosystem level is crucial for evaluating their environmental risks.

**CONCLUSIONS AND FUTURE PROSPECTIVES**

The application of nanotechnology in agriculture is still in its early stages compared to its more established use in fields like the pharmaceutical industry. To promote sustainable agricultural practices, innovative techniques such as nanoparticle-based seed priming are essential. Seed nano-priming is an effective method that influences the metabolic processes and signaling mechanisms within seeds, impacting not only germination and early seedling development but also the entire growth cycle of the plant. This approach enhances plant development, boosts crop productivity, and improves nutrient uptake. Additionally, it helps regulate antioxidant activity, modulates plant growth hormones, increases resistance to stress and disease, and reduces dependence on conventional. Studies by Mahakham et al. (2016, 2017) demonstrated that seed priming with silver (AgNPs) and gold nanoparticles (AuNPs) significantly improves water absorption, plant biomass in rice, and biochemical activity in maize. Although AgNPs and AuNPs are widely explored in agricultural applications, the effects of other noble metal nanoparticles on plants remain under-researched, presenting promising opportunities for future investigation. Going forward, it is crucial to address potential environmental risks associated with NMNP use by prioritizing the development of eco-friendly and non-toxic nanoparticles, and by defining safe exposure thresholds. Any new technological implementation should be preceded by a detailed risk-benefit analysis and comprehensive cost evaluation. To ensure the safe use of nanotechnology in agriculture, future policies must emphasize the creation of standardized guidelines, safety measures, and proper training for professionals involved in the field. Furthermore, gaining consumer trust and broader public support for nanotechnology in agriculture requires active engagement with all relevant stakeholders, including consumer advocacy and non-governmental organizations.

**References**

1. Kolesnikov S, Tsepina N, Minnikova T, Kazeev K, Mandzhieva S, Sushkova S, Minkina T, Mazarji M, Singh R K, Rajput V D. 2021. Influence of silver nanoparticles on the biological indicators of haplic chernozem. *Plants*. **10**: 1022.
2. Kumar V, Arora K. 2020. Trends in nano-inspired biosensors for plants. *Mater Sci Energy Technol*. **3**: 255–273.
3. Lapied E, Moudilou E, Exbrayat J M, Oughton D H, Joner E J. 2010. Silver nanoparticle exposure causes apoptotic response in the earthworm *Lumbricus terrestris* (Oligochaeta). *Nanomedicine*. **5**: 975–984.
4. Mahakham W, Theerakulpisut P, Maensiri S, Phumying S, Sarmah A K. 2016. Environmentally benign synthesis of phytochemicals-capped gold nanoparticles as nanopriming agent for promoting maize seed germination. *Sci Total Environ*. **573**: 1089–1102.
5. Mahakham W, Sarmah A K, Maensiri S, Theerakulpisut P. 2017. Nanopriming technology for enhancing germination and starch metabolism of aged rice seeds using phytosynthesized silver nanoparticles. *Sci Rep*. **7**: 8263.
6. Raliya R, Franke C, Chavalmane S, Nair R, Reed N, Biswas P. 2016. Quantitative understanding of nanoparticle uptake in watermelon plants. *Front Plant Sci*. **7**: 1288.