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# Valorization of Moringa Oleifera Plant Waste for Green Nanoparticle Synthesis: A Review

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**ABSTRACT:**

Moringa oleifera is a medicinal and nutritionally valuable plant containing several bioactive compounds, including phenolics, flavonoids, proteins, vitamins, and minerals . During the processing and utilization of M. oleifera, different plant residues such as leaves, pods, seeds, bark, and other underutilized materials may be generated. These plant materials can serve as valuable sources of phytochemicals for green nanoparticle synthesis . Green synthesis provides an eco-friendly, cost-effective, and sustainable alternative to conventional chemical and physical methods. Phytochemicals present in M. oleifera extracts can act as reducing, stabilizing, and capping agents during nanoparticle formation . This review summarizes the phytochemical composition of Moringa plant waste, methods of extract preparation, green synthesis approaches, possible mechanisms of nanoparticle formation, characterization techniques, and potential pharmaceutical, biomedical, antimicrobial, antioxidant, and environmental applications of Moringa-mediated nanoparticles. The valorization of M. oleifera plant waste may contribute to waste reduction, resource recovery, and the development of sustainable nanotechnology .

***Keyword:*** *Moringa oleifera, plant waste, green synthesis, nanoparticles, phytochemicals, green nanotechnology, silver nanoparticles, sustainable nanotechnology.*

## Introduction:

*Moringa oleifera is a medicinal and nutritionally important plant belonging to the family Moringaceae. Different parts of the plant contain bioactive compounds such as phenolics, flavonoids, proteins, vitamins, and minerals [1]. During processing and utilization, leaves, pods, seeds, bark, and other plant residues may be generated as waste.*

*Moringa plant waste can be considered a valuable source of phytochemicals rather than simply discarded biomass. These phytochemicals possess reducing, stabilizing, and capping properties that can support the green synthesis of nanoparticles [2]. Green nanoparticle synthesis is an eco-friendly and sustainable alternative to conventional chemical methods because it can reduce the use of toxic chemicals and hazardous by-products [3].*

*Therefore, utilization of M. oleifera plant waste for nanoparticle synthesis provides a promising approach for waste valorization and sustainable nanotechnology. This review discusses the phytochemical composition of Moringa plant waste, green synthesis methods, mechanism, characterization, applications, advantages, limitations, and future perspectives.*

***Botanical Description of Moringa oleifera:***

*Moringa oleifera Lam. belongs to the family Moringaceae and is the most widely studied species of the genus Moringa. It is a fast-growing, deciduous or semi-deciduous tree that is native to the sub-Himalayan regions of northern India and is now cultivated widely throughout tropical and subtropical regions. [4,5]*

*The plant is generally a small to medium-sized tree and may reach approximately 5–12 m in height, depending on environmental and cultivation conditions. It has a relatively soft, brittle stem with pale or whitish-grey bark and a spreading, sometimes umbrella-shaped crown. [4,5]*

***Leaves***

*The leaves of M. oleifera are compound and mainly bipinnate or tripinnate. They are generally feathery in appearance and consist of numerous small, oval or elliptical leaflets. The leaves are green and are considered one of the most nutritionally and phytochemically important parts of the plant. [4,5]*

***Stem and Bark***

*The stem is generally slender, soft and branching. The bark is commonly described as smooth or slightly rough, with a whitish-grey to pale-brown colour. The stem and bark contain several secondary metabolites, including alkaloids, phenolic compounds and sterols. [5,6]*

***Flowers***

*M. oleifera produces fragrant, bisexual flowers arranged in spreading or branched inflorescences. The flowers are generally white to creamy-white or yellowish-white and possess five unequal petals. Flowering may vary according to geographical location, climate and cultivation conditions. [4,6]*

*2.4 Fruits and Pods*

*The fruit of M. oleifera is a long, slender, three-sided or three-ribbed capsule commonly known as a pod or drumstick. The immature pods are generally green and become brownish as they mature. The pods contain numerous seeds embedded within the fruit. [4,5]*

***Seeds***

*The seeds are generally brownish and approximately spherical or triangular in shape. They possess characteristic papery or wing-like structures that assist in dispersal. Moringa seeds contain considerable amounts of oil, proteins and other bioactive constituents and are therefore important for nutritional, pharmaceutical and industrial applications. [4,6]*

***Root***

*The root system of M. oleifera is relatively well developed and includes a prominent taproot with lateral roots. Roots contain characteristic phytochemicals and have been used traditionally in different medicinal preparations. However, the chemical composition of roots differs from that of leaves and seeds. [5,6]*

***Botanical and Morphological Importance***

*The different morphological parts of M. oleifera—leaves, stems, bark, flowers, pods, seeds and roots—contain different groups of nutrients and bioactive compounds. This distribution of phytochemicals makes the plant a valuable source of biomass for nutritional, pharmaceutical and industrial applications. In the context of green nanotechnology, selected plant parts and processing residues may provide phytochemicals that can participate in nanoparticle synthesis. [4,5,6]*




**Figure 1.** Morphological parts of ***Moringa oleifera.***

## Nutritiona and phytochemical Composition:

*Moringa oleifera Lam. is recognized as a nutritionally valuable and phytochemically rich plant. Different parts of the plant, particularly leaves, seeds, pods and flowers, contain proteins, carbohydrates, dietary fibre, vitamins, minerals, fatty acids and a wide variety of secondary metabolites. The concentration and distribution of these constituents vary according to the plant part, cultivar, geographical location, environmental conditions, maturity and extraction method [7,8].*

***Nutritional Composition***

*The leaves of M. oleifera are an important source of nutrients and contain proteins, amino acids, dietary fibre, vitamins and minerals. Minerals reported in Moringa include calcium, potassium,magnesium, phosphorus, iron and zinc. Vitamins and vitamin-related compounds include vitamin A precursors, vitamin C, vitamin E and several B-group vitamins [7,8]. The nutritional composition of the leaves is one of the major reasons for their use in functional foods and nutritional supplements.*

*Moringa seeds are nutritionally different from leaves. They contain considerable amounts of protein and lipid, and the seed oil is characterized by a high proportion of oleic acid. Other fatty acids, including palmitic, stearic, behenic and arachidic acids, have also been reported [1]. After oil extraction, the remaining seed cake represents an important processing by-product and may still contain proteins and bioactive compounds. Therefore, seed cake has potential for value-added applications rather than being treated only as waste [4].*

***Protein and Amino Acids***

*Proteins are important nutritional constituents of M. oleifera. Leaves contain appreciable protein and amino acids, while seeds and seed cake also represent protein-rich materials. Proteins and amino acids are important not only nutritionally but also from a nanotechnology perspective. Functional groups present in proteins can interact with nanoparticle surfaces and may contribute to stabilization or capping during green synthesis [7,8].*

***Vitamins***

*Moringa leaves contain several vitamins and provitamin compounds. Carotenoids, particularly lutein and other pigments, contribute to the nutritional and antioxidant profile of the leaves. Vitamin C and vitamin E are also reported in Moringa materials. The actual concentration can vary considerably depending on whether fresh or dried material is analyzed and which analytical method is used [7,8].*

***Minerals***

*M. oleifera contains several essential minerals. Calcium, potassium, magnesium, phosphorus and iron are among the commonly reported minerals, with zinc and copper also present in smaller amounts. The mineral composition is influenced by soil conditions, geographical origin, plant age and processing [7,8].*

***Phytochemical Composition***

*The phytochemical profile of M. oleifera is highly diverse. Major groups include flavonoids, phenolic acids, glucosinolates, isothiocyanates, carotenoids, terpenoids, alkaloids, tannins, saponins, sterols and fatty acids [7,9].*

*More than 90 compounds have been reported from M. oleifera, and some reviews describe an even broader range of identified bioactive chemicals depending on the plant material and analytical method used [1,8]. Therefore, phytochemical composition should not be considered constant for all Moringa samples.*

***Phenolic Compounds***

*Phenolic compounds are important secondary metabolites in Moringa. Reported phenolic acids include gallic acid, caffeic acid, ferulic acid, chlorogenic acid, ellagic acid, p-coumaric acid, syringic acid, sinapic acid and related compounds [7,9].*

*Phenolic compounds are relevant to green nanoparticle synthesis because their hydroxyl-containing structures can participate in redox reactions. They may contribute to the reduction of metal ions and can also interact with nanoparticle surfaces. Thus, phenolics present in Moringa residues may contribute to both nanoparticle formation and stabilization.*

***Flavonoids***

*Flavonoids are another important group of Moringa phytochemicals. Quercetin, kaempferol, rutin, isorhamnetin, myricetin, catechin and related flavonoids have been reported in different plant parts (7.9). Their antioxidant properties are associated with their ability to donate electrons or hydrogen atoms.*

*In plant-mediated nanoparticle synthesis, flavonoids may participate in metal-ion reduction and surface stabilization. The exact contribution of an individual flavonoid, however, depends on the extract composition and reaction conditions.*

***Glucosinolates and Isothiocyanates***

*Glucosinolates are characteristic compounds of the Moringa genus. Glucomoringin, chemically known as 4-O-(α-L-rhamnopyranosyloxy)-benzyl glucosinolate, is one of the major glucosinolates reported in M. oleifera [7,9]. Enzymatic hydrolysis of glucosinolates can generate isothiocyanates and other products.*

*These compounds are important because they contribute to the distinctive phytochemical profile and biological properties of Moringa. Their presence in leaves, seeds and other plant parts also makes Moringa biomass chemically valuable.*

***Carotenoids and Other Pigments***

*Moringa leaves contain carotenoids, with lutein being a prominent carotenoid reported in the foliage. Carotenoids contribute to the color and nutritional value of leaves and are associated with antioxidant functions [7,8]. Other pigments and lipid-soluble compounds may also be present depending on plant part and extraction procedure.*

***Tannins, Saponins, Alkaloids and Sterols***

*Tannins, saponins, alkaloids and sterols have been reported in different parts of M. oleifera. Alkaloids such as moringinine and related compounds have been identified in some tissues, while β-sitosterol and other sterols occur in leaves and seeds [8,9]. Tannins and saponins contribute to the broad secondary-metabolite profile of the plant.*

*These compounds are relevant to pharmaceutical and biological research, but their concentration may change substantially with extraction solvent, geographical origin and plant maturity.*

*The phytochemical richness of M. oleifera is particularly important for green nanotechnology. Phenolics, flavonoids, proteins, sugars and other biomolecules may collectively act as reducing, stabilizing and capping agents during nanoparticle synthesis [10,11].*

***Table 1. Major nutritional and phytochemical constituents of Moringa oleifera and their importance***

| ***Constituent*** | ***Examples*** | ***Importance*** |
|---|---|---|
| *Proteins* | *Amino acids* | *Nutritional & capping activity* |
| *Vitamins* | *A, C, E* | *Antioxidant activity* |
| *Minerals* | *Ca, K, Fe, Mg* | *Nutritional value* |
| *Phenolics* | *Phenolic acids* | *Antioxidant & reducing agent* |
| *Flavonoids* | *Quercetin, kaempferol* | *Antioxidant & stabilization* |
| *Tannins* | *Polyphenolic compounds* | *Biological activity* |
| *Alkaloids* | *Various alkaloids* | *Pharmacological activity* |

## Different Parts of Moringa oleifera Used:

*Different parts of Moringa oleifera, including leaves, seeds, pods, flowers, bark, and roots, contain various nutritional and bioactive compounds [12]. These compounds make the plant useful for nutritional, pharmaceutical, and green nanotechnology applications [12,13].*

***Leaves :****Moringa leaves contain proteins, vitamins, minerals, phenolic compounds, and flavonoids. These phytochemicals can act as reducing and stabilizing agents during green nanoparticle synthesis [12,13].*

***Seeds :*** *Moringa seeds contain proteins, lipids, fatty acids, phenolic compounds and other bioactive constituents. The seeds are particularly important as a source of edible and industrially useful oil. After oil extraction, the remaining defatted seed cake can be further utilized as a source of proteins and phytochemicals. [12,15]*

*Seed extracts and seed-derived materials have also attracted attention in green nanoparticle synthesis because their biomolecules can contribute to reduction and stabilization processes. [14,15]*

***Pods :****The pods contain dietary fibre, minerals, vitamins, and phenolic compounds. Pod residues generated during processing can therefore be considered a potential source of useful phytochemicals [12,13].*

***Flower :****Moringa flowers contain phenolic compounds and flavonoids and show antioxidant potential [12,13].*

***Bark and Roots :*** *Bark and roots contain several secondary metabolites, including phenolics, tannins, and alkaloids. These compounds contribute to their biological properties [12,13].*

*Thus, different parts and underutilized residues of M. oleifera can be explored as sustainable sources of phytochemicals for green nanoparticle nanotechnology*

## Plant Parts as Sources for Green Nanotechnology:

*The different parts of M. oleifera can provide biomolecules that may function as reducing, stabilizing and capping agents during nanoparticle synthesis. Phenolics, flavonoids, proteins, carbohydrates and other phytochemicals can interact with metal ions and nanoparticle surfaces. [14]*

*Therefore, not only the commonly used leaves and seeds but also underutilized plant parts and processing residues may have potential for waste valorization and sustainable nanoparticle production. In particular, Moringa seed cake obtained after oil extraction has been investigated as a promising by-product for green nanoparticle synthesis. [15]*

***Table 2. Different parts of Moringa oleifera and their potential uses***

| ***Plant part*** | ***Major constituents*** | ***Potential use*** |
|---|---|---|
| *Leaves* | *Phenolics, flavonoids, proteins, vitamins* | *Nutritionalandantioxidant applications* |
| *Seeds* | *Proteins, fatty acids, phenolics* | *Oil production and nanoparticle synthesis* |
| *Pods* | *Fibre, vitamins, phenolics* | *Nutritional and phytochemical source* |
| *Flowers* | *Flavonoids, phenolics* | *Antioxidant applications* |
| *Bark* | *Tannins, phenolics, alkaloids* | *Bioactive compound source* |
| *Roots* | *Alkaloids, phenolic compounds* | *Traditional medicinal applappl* |

*The different parts of Moringa oleifera contain diverse bioactive compounds and can serve as valuable sources of phytochemicals. Leaves are rich in phenolics, flavonoids, proteins, and vitamins, making them useful for antioxidant and green nanoparticle synthesis. Seeds contain proteins, fatty acids, and phenolic compounds and may provide useful biomolecules for nanoparticle formation and stabilization.*

*Pods and flowers contain phenolic compounds, flavonoids, vitamins, and other nutrients, while bark and roots contain secondary metabolites such as tannins, phenolics, and alkaloids. These compounds may contribute to the biological and antioxidant properties of the plant [14].*

*From the perspective of waste valorization, unused or processing residues of these plant parts can be recovered and utilized as a source of reducing, stabilizing, and capping biomolecules. Thus, instead of being discarded, Moringa plant residues can be converted into value-added materials through green nanoparticle synthesis [16].*

***Plant Waste Generation of Moringa oleifera***

*Moringa oleifera is widely cultivated for its nutritional, medicinal, agricultural, and industrial importance. During cultivation, harvesting, transportation, storage, food processing, and seed-oil extraction, a considerable quantity of plant residues can be generated. These residues are often*

*underutilized or discarded despite containing potentially valuable phytochemicals and functional biomolecules [16,17].*

*Plant waste generation can occur at different stages of the Moringa production and utilization chain. During cultivation and pruning, leaves, stems, branches, and damaged plant tissues may be generated. During harvesting and food processing, rejected leaves, mature or damaged pods, pod residues, and seeds may remain. Seed processing and oil extraction generate seed coats, broken seeds, and defatted seed cake as important by-products [16,17].*

*The chemical composition of Moringa waste varies according to the plant part and processing conditions. Leaf residues may contain phenolic compounds, flavonoids, proteins, carotenoids, vitamins, and minerals. Pod and seed residues can contain fibre, proteins, fatty acids, phenolics, and other bioactive compounds. Defatted seed cake may retain proteins and other phytochemicals after oil extraction [18].*

*Instead of disposing of these residues, they can be valorized through extraction and conversion into value-added products. In green nanotechnology, Moringa waste-derived extracts may provide biomolecules capable of participating in the reduction, stabilization, and capping of metal nanoparticles. Thus, utilization of Moringa plant waste can connect agricultural waste management with sustainable nanoparticle production [18,19].*

***Major Sources of Moringa Plant applications:***

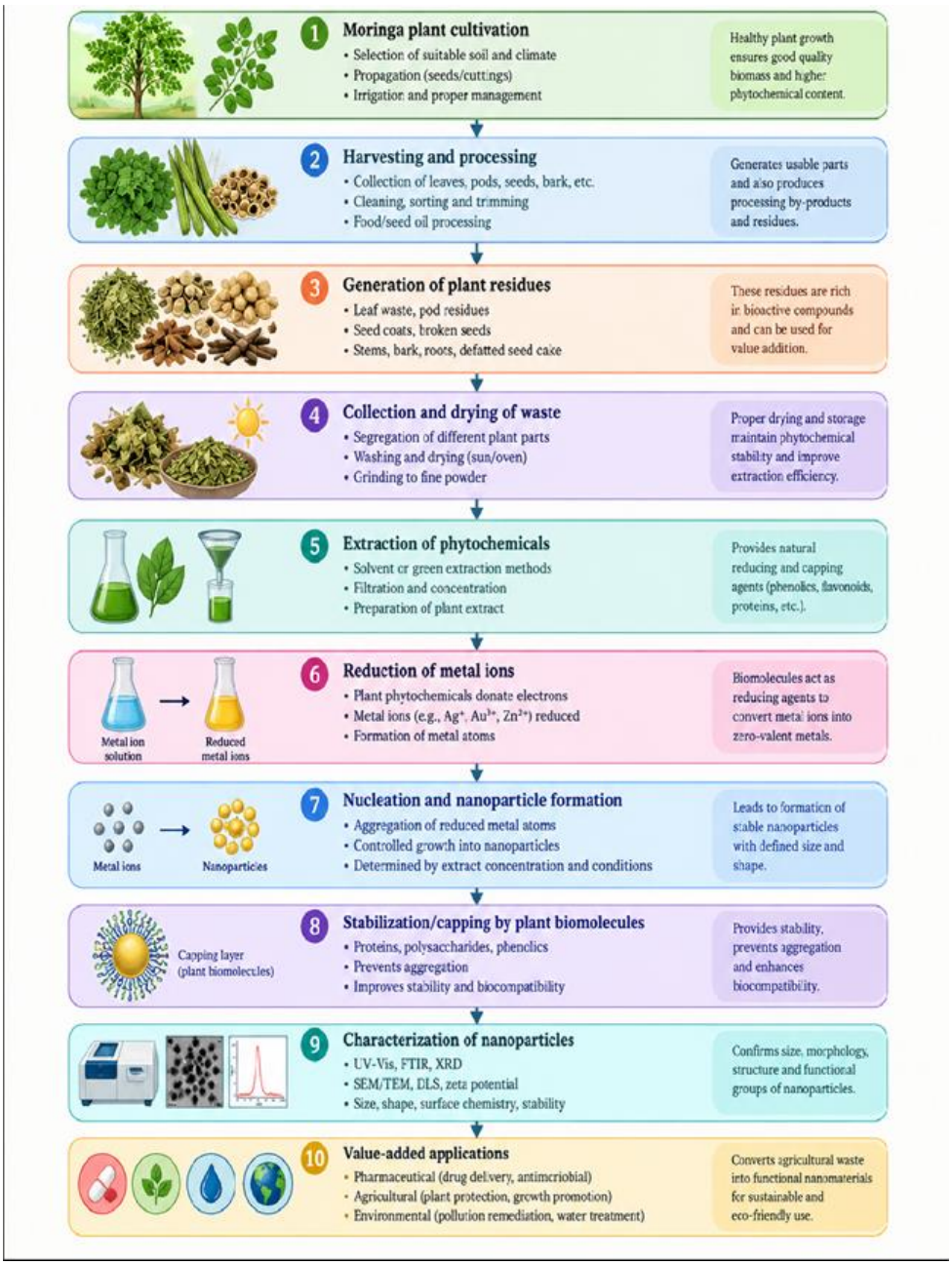
| ***Source*** | ***Waste generated*** | ***Potential valuable constituents*** |
|---|---|---|
| *Cultivation and pruning* | *Leaves, stems, branches* | *Phenolics, flavonoids, proteins* |
| *Leaf harvesting* | *Damaged/excess leaves* | *Phenolics, flavonoids, carotenoids* |
| *Pod processing* | *Pod residues, damaged pods* | *Fibre, carbohydrates, phenolics* |

| ***Source*** | ***Waste generated*** | ***Potential valuable constituents*** |
|---|---|---|
| *Seed processing* | *Seed coats, broken seeds* | *Proteins, phenolics, fatty acids* |
| *Oil extraction* | *Defatted seed cake* | *Proteins, residual phytochemicals* |
| *Bark/wood processing* | *Bark and woody residues* | *Phenolics, tannins* |
| *d processing* | *Mixed plant residues* | *Various phytochemicals* |

***Importance of Moringa Plant Waste:***

*Moringa plant waste should not be considered only as an unwanted agricultural residue. It represents a potential source of renewable biomass and phytochemicals. Recovery of these compounds can support waste reduction, resource utilization, and development of sustainable products. In particular, the use of Moringa residues for nanoparticle synthesis represents an approach to waste-to-value conversion, in which low-value biomass is transformed into functional nanomaterials [Concep*

## Waste-to-Nanoparticle Concept:



***Types of Moringa oleifera Plant Waste :***

*Different types of plant residues are generated during the cultivation, harvesting, processing and utilization of Moringa oleifera. These residues are often discarded or underutilized, although they contain valuable phytochemicals and other biomolecules. Therefore, Moringa plant waste can be considered a potential raw material for value-added applications, including green nanoparticle synthesis [20,21].*

***Leaf Waste***

*Leaf waste is generated during pruning, harvesting, cleaning and processing of Moringa leaves. Leaves contain phenolic compounds, flavonoids, carotenoids, proteins, vitamins and minerals. These bioactive constituents make leaf residues a valuable source of phytochemicals. Extracts prepared from leaf waste may be used as reducing, stabilizing and capping agents during green nanoparticle synthesis [20,21].*

***Pod Waste***

*Moringa pods, commonly known as drumsticks, generate waste during harvesting, trimming, food processing and removal of damaged or rejected pods. Pod residues contain dietary fibre, phenolic compounds, flavonoids, minerals and other bioactive constituents. Recovery of these compounds can increase the value of pod waste and reduce its disposal burden [20,22].*

***Seed Waste***

*Seed waste is produced during seed cleaning, processing and selection, particularly from damaged, immature or rejected seeds. Moringa seeds contain proteins, fatty acids, phenolic compounds and other phytochemicals. These constituents can provide functional biomolecules for biological synthesis and stabilization of nanoparticles [21,23].*

***Seed Coat Waste***

*Seed coats are generated during the dehulling and processing of Moringa seeds. Although commonly treated as a processing residue, seed coats contain organic compounds and phytochemicals that can potentially be recovered through suitable extraction methods. Their utilization may provide an additional source of plant-derived material for sustainable applications [22,23].*

***Defatted Seed Cake***

*Defatted seed cake is the solid residue obtained after extraction of oil from Moringa seeds. It contains considerable amounts of proteins, carbohydrates, minerals and residual bioactive compounds. Moringa seed cake has received particular attention as a promising waste material for green nanoparticle synthesis because it combines high availability with valuable biomolecules [23].*

***Stem and Branch Waste***

*Stem and branch residues are mainly generated during pruning, harvesting and management of Moringa trees. These residues contain structural components such as cellulose, hemicellulose and lignin along with extractable phytochemicals. Although they are less frequently investigated than leaves and seeds, they can be explored for biomass utilization, extraction of bioactive compounds and other value-added applications [20,22].*

***Bark Waste***

*Bark waste may be generated during pruning, cutting and processing of Moringa plants. Moringa bark contains phenolic compounds, tannins and other secondary metabolites. These constituents provide potential for phytochemical extraction and biological applications, thereby improving the utilization of bark residues [20,22].*

***Flower Waste***

*Flower waste is generated from fallen, damaged, dried or rejected flowers during harvesting and processing. Moringa flowers contain phenolic compounds, flavonoids, proteins and minerals. The presence of these constituents makes flower residues a potential source of bioactive extracts for value-added applications [20,22].*

***Root Waste***

*Root residues may be generated during uprooting, pruning or processing of Moringa plants. The roots contain several secondary metabolites and other bioactive constituents. However, compared with leaves and seed-derived materials, root waste has been comparatively less explored for green nanoparticle synthesis [20,22].*

***Importance of Moringa Plant Waste***

*The different residues generated from M. oleifera represent a valuable source of renewable biomass. Instead of treating these materials as waste, their phytochemicals and biomolecules can be recovered and utilized for the development of value-added products. In green nanotechnology, Moringa waste-derived extracts may act as biological reducing, capping and stabilizing systems for nanoparticle synthesis. Thus, utilization of Moringa plant waste supports waste reduction, resource recovery and sustainable nanoparticle production [21,23].*

*Overall, the conversion of Moringa plant residues into useful nanomaterials represents an important approach toward waste valorization and circular bioeconomy. Among the different residues, leaves, seeds and defatted seed cake are particularly promising because of their rich phytochemical and biomolecular composition [21,23].*

## Bioactive Compounds Present in Moringa oleifera Plant Waste :

*Moringa oleifera plant waste contains various bioactive compounds that contribute to its potential for green nanoparticle synthesis. These compounds include phenolic compounds, flavonoids, proteins, amino acids, sugars, tannins, saponins, alkaloids and glucosinolates [20,21,22,23].*

*Phenolics and flavonoids can act as reducing agents, while proteins, polysaccharides and other biomolecules can stabilize and cap the formed nanoparticles. Glucosinolates and isothiocyanates also contribute to the biological activity of Moringa-derived materials [20,21].*

*Thus, Moringa plant waste can serve as a low-cost and natural source of bioactive molecules for the eco-friendly synthesis of nanoparticles.*

## Green Synthesis of Nanoparticles Using Moringa oleifera Plant Waste :

*Green synthesis is an eco-friendly and sustainable method for the preparation of nanoparticles using biological resources. Moringa oleifera plant waste is a promising source of natural reducing, stabilizing and capping agents. s, flavonoids, proteins, amino acids, sugars and other phytochemicals that can participate in nanoparticle formation [20,21,22,23].*

*For green synthesis, the collected plant waste is generally washed, dried and powdered to remove impurities and reduce moisture. The powdered material is extracted using water or another suitable solvent. The obtained extract contains bioactive compounds responsible for the reduction and stabilization of metal ions [10,11,23].*

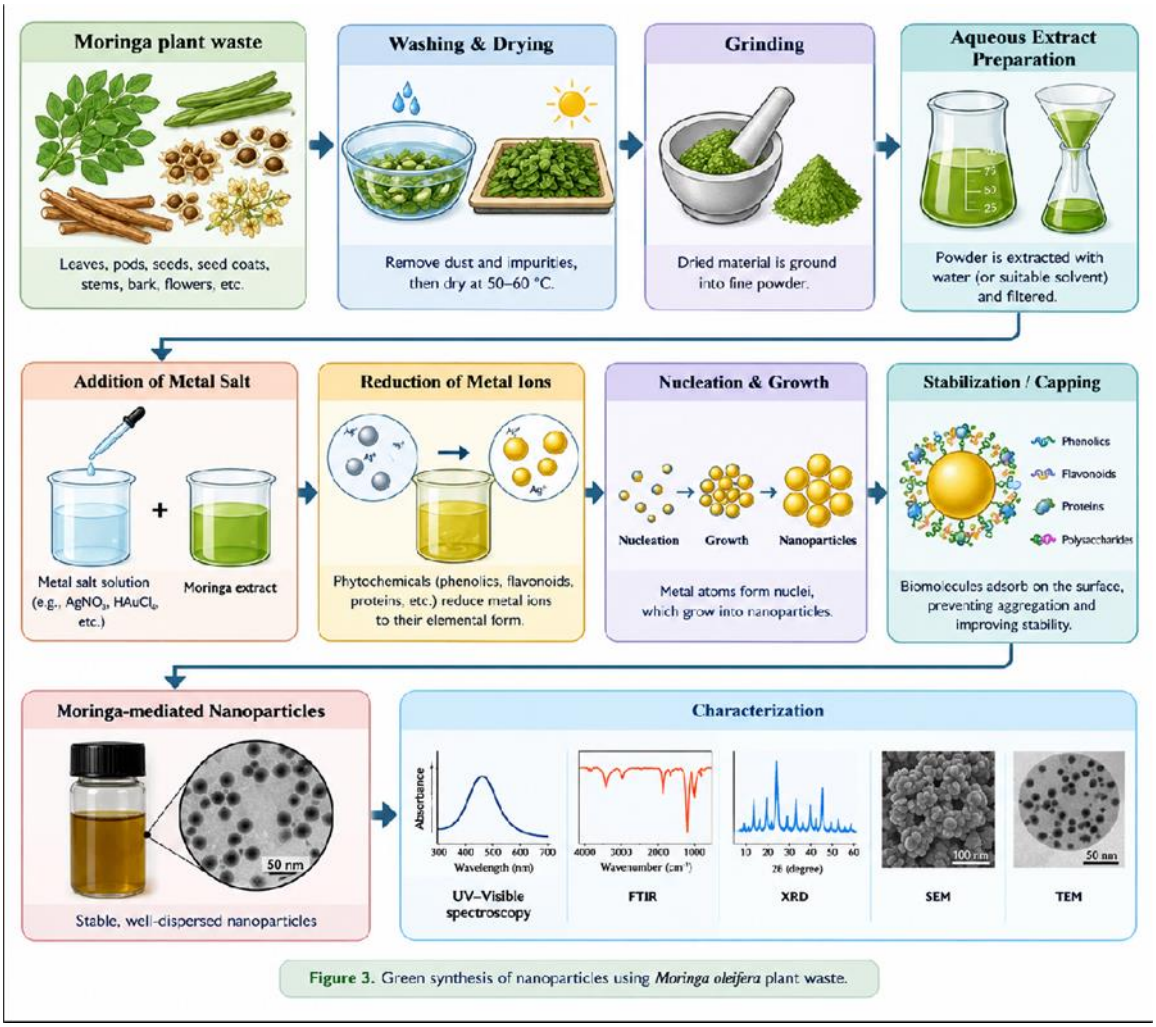



Figure 3. Green synthesis of nanoparticles using *Moringa oleifera* plant waste.

*The plant extract is then mixed with a suitable metal salt solution, such as silver nitrate ($AgNO_3$), gold chloride ($HAuCl_4$) or other metal precursors. Phytochemicals present in the extract reduce metal ions to their elemental or oxide nanoparticle forms. This process involves reduction, nucleation, particle growth and stabilization [3,23].*

*The biomolecules present in Moringa waste can also adsorb onto the nanoparticle surface and act as natural capping agents. This may help control particle aggregation and improve the stability of the synthesized nanoparticles. The final nanoparticles are collected, purified and characterized using techniques such as UV–Visible spectroscopy, FTIR, XRD, SEM and TEM. Thus, utilization of M. oleifera plant waste for nanoparticle synthesis provides a low-cost, environmentally friendly and sustainable approach while simultaneously converting agricultural waste into value-added nanomaterials [3,23].*

## Role of Moringa oleifera Plant Waste in Nanoparticle Synthesis:-

*Moringa oleifera plant waste acts as a natural source of reducing, capping and stabilizing agents during nanoparticle synthesis. Phenolics and flavonoids reduce metal ions, whereas proteins, sugars and polysaccharides stabilize the nanoparticles [10,11].*

*These compounds help in nanoparticle formation, growth control and prevention of aggregation. The use of Moringa waste also reduces chemical consumption and converts agricultural residues into useful nanomaterials [3,10,11].*

***Types of Nanoparticles:-***

*Nanoparticles are classified according to their composition and structure. The major types include:*

1. ***Metal nanoparticles*** *– Silver (Ag), Gold (Au), Copper (Cu)*
2. ***Metal oxide nanoparticles*** *– Zinc oxide (ZnO), Titanium dioxide ($TiO_2$), Iron oxide ($Fe_3O_4$)*
3. ***Polymeric nanoparticles –*** *Prepared using biodegradable polymers.*
4. ***Lipid nanoparticles*** *– Mainly used in drug delivery applications.*
5. ***Carbon-based nanoparticles*** *– Carbon nanotubes, graphene and fullerenes.*

*Among these, silver, gold and metal oxide nanoparticles are commonly synthesized using plant extracts because plant phytochemicals can act as natural reducing and stabilizing agents [17,20,22].*

***Silver Nanoparticles (AgNPs)***

*Silver nanoparticles are widely studied because of their antimicrobial, antioxidant and catalytic properties. Plant extracts can act as reducing and capping agents during their green synthesis [20,22].*

***Gold Nanoparticles (AuNPs)***

*Gold nanoparticles possess unique optical, catalytic and biomedical properties. Phytochemicals present in plant extracts can help in the reduction and stabilization of gold nanoparticles [17,20].*

***Zinc Oxide Nanoparticles (ZnO-NPs)***

*Zinc oxide nanoparticles are important because of their antimicrobial, photocatalytic and UV-blocking properties. They can be synthesized using plant-derived biomolecules [19,20].*

***Iron Oxide Nanoparticles ($Fe_3O_4$/$Fe_2O_3$-NPs)***

*Iron oxide nanoparticles show magnetic properties and are useful in drug delivery, imaging, environmental remediation and other biomedical applications. Plant extracts can assist in their green synthesis and stabilization [20,23].*

***Mechanism of Nanoparticle Formation:***

*The formation of nanoparticles using Moringa oleifera plant waste mainly occurs through reduction, nucleation, growth and stabilization.*

***Reduction:*** *Phytochemicals such as phenolics and flavonoids reduce metal ions into nanoparticles.*

***Nucleation:*** *Reduced metal atoms combine to form small nucleic* ***Growth:*** *These nuclei grow into nanoparticles.*

***Capping:*** *Proteins, sugars and other biomolecules cover the nanoparticle surface and prevent aggregation [18,20].*

***Factors Affecting Green Synthesis of Nanoparticles:***

*The synthesis of nanoparticles using Moringa oleifera plant waste is affected by several factors:* ***pH****: Changes in pH can affect nanoparticle size and shape.*

***Temperature****: Higher or lower temperature can influence the rate of nanoparticle formation.*

***Extract concentration:*** *The amount of plant extract affects reduction and capping of nanoparticles.*

***Metal salt concentration**: It influences the quantity and formation rate of nanoparticles. **Reaction time:** Longer reaction time can affect particle growth and stability [18,20].*

*Therefore, optimization of these factors is important to obtain nanoparticles with desired properties.*

***Characterization of Nanoparticles:-***

*Characterization is important to determine the size, shape, structure, surface properties and stability of nanoparticles prepared using Moringa oleifera pNanoparticle*

***UV–Visible spectroscopy**: Confirms nanoparticle formation and optical properties. **FTIR spectroscopy**: Identifies functional groups involved in reduction and capping. **XRD:** Determines crystalline structure and particle characteristics.*

***SEM:** Shows surface morphology and shape.*

***TEM:** Determines particle size and detailed morphology.*

***DLS:** Measures hydrodynamic particle size and size distribution. **Zeta potential:** Evaluates surface charge and colloidal stability [21]*

## Applications of Moringa-Derived Nanoparticles:-

*Nanoparticles synthesized using Moringa oleifera plant waste have attracted interest because of their unique physicochemical and biological properties. The phytochemicals present in Moringa waste may contribute to the biological activity of the synthesized nanoparticles.*

1. ***Antimicrobial applications:***

*Silver and zinc oxide nanoparticles can show antibacterial and antifungal activity. They may be useful in antimicrobial coatings, wound-care materials and packaging.*

2. ***Drug delivery:***

*Nanoparticles can act as carriers for therapeutic molecules and may help improve drug stability, targeted delivery and controlled release.*

3. ***Wound healing:***

*Moringa-derived nanoparticles, particularly silver-based nanoparticles, have potential in wound-care formulations because of their antimicrobial properties.*

4. ***Antioxidant applications**:*

*Phenolic and flavonoid compounds associated with Moringa extracts may contribute to antioxidant activity of the synthesized nanomaterials.*

5. ***Environmental applications:***

*Metal and metal oxide nanoparticles can be explored for pollutant removal, photocatalytic degradation and water-treatment applications.*

6. ***Food and packaging applications**:*

*Nanoparticles with antimicrobial properties may be incorporated into packaging materials to help reduce microbial contamination and improve food preservation [11,13,17,22].*

## Biological Activities of Moringa-Derived Nanoparticles:-

1. ***Antimicrobial Activity***

*Moringa-derived nanoparticles, particularly silver and zinc oxide nanoparticles, may exhibit antimicrobial activity against various bacteria and fungi. This activity makes them promising for antimicrobial coatings and wound-care applications [13,14].*

2. ***.Antioxidant Activity***

*The phytochemicals associated with Moringa oleifera, especially phenolic and flavonoid compounds, may contribute to the antioxidant activity of Moringa-derived nanomaterials. Their antioxidant potential can be evaluated using assays such as DPPH and ABTS [1,8].*

3. ***Anticancer Potential***

*Moringa-derived nanoparticles have been investigated for their potential anticancer effects. Possible mechanisms include oxidative stress, apoptosis and inhibition of cancer-cell proliferation. However, further in-vitro and in-vivo studies are required to establish their safety and therapeutic efficacy [13,17].*

## Advantages of Using Moringa oleifera Plant Waste:

*The use of Moringa oleifera plant waste for green nanoparticle synthesis offers several advantages:*

***Eco-friendly:*** *Reduces the use of toxic chemicals and hazardous solvents.*

***Low-cost:*** *Plant waste is easily available and inexpensive.* ***Renewable resource:*** *Moringa residues are naturally renewable.*

***Rich in phytochemicals****: Phenolics, flavonoids, proteins and other biomolecules support reduction and capping.*

***Waste valorization****: Converts agricultural waste into useful, value-added nanomaterials.* ***Simple synthesis:*** *Green synthesis can often be performed under relatively mild conditions.*

***Sustainable approach****: Supports waste reduction and the principles of a circular bioeconomy [16,18,20].*

### *Waste-Mediated Green Synthesis of Nanoparticles:-*

*Waste-mediated green synthesis uses plant and agricultural waste as a natural source of reducing, capping and stabilizing agents. Moringa oleifera waste contains phenolics, flavonoids, proteins and other biomolecules that help in nanoparticle formation [10,18,20].*

*The waste is generally washed, dried, powdered and extracted. The extract is then mixed with a suitable metal precursor, resulting in reduction, nucleation and stabilization of nanoparticles [18,20] This approach helps in waste valorization, reduction of chemical waste and sustainable production of value-added nanomaterials [10,18,20].*

## Limitations and Challenges:-

*Although Moringa oleifera plant waste is useful for green nanoparticle synthesis, several challenges remain:*

*Variation in plant waste composition may affect nanoparticle formation. Controlling particle size and shape can be difficult.*

*Standardization and reproducibility of the synthesis process are challenging. Large-scale production requires further optimization.*

*Nanoparticle stability and storage need proper evaluation.*

*Toxicity and safety studies are required before biomedical applications. Purification of nanoparticles may be difficult [17,21].*

## Future Perspectives

*The use of Moringa oleifera plant waste for green nanoparticle synthesis has good potential for future research. Further studies should focus on standardization of plant waste, optimization of synthesis conditions, particle-size control and large-scale production [10,11,16].*

*More research is also needed to evaluate the toxicity, stability, biological activity and long-term safety of Moringa-derived nanoparticles. Development of cost-effective and reproducible methods may support their use in pharmaceutical, biomedical and environmental applications [9,11,17].*

## Conclusion

*Moringa oleifera plant waste is a valuable and renewable resource for the green synthesis of nanoparticles. Its naturally occurring phytochemicals can facilitate the reduction, capping and stabilization of nanoparticles, making the process more eco-friendly and cost-effective*

*The conversion of Moringa waste into useful nanomaterials also supports waste valorization and sustainable development. Moringa-derived nanoparticles show promising potential in antimicrobial, biomedical, pharmaceutical and environmental applications. However, further research is required for standardization, toxicity evaluation, reproducibility and large-scale production*

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