PLANT SCIENCE TODAY
12(4): 1-8
https://doi.org/10.14719/pst.8893

eISSN 2348-1900

REVIEW ARTICLE

Antimicrobial potential of *Moringa oleifera*: Phytochemicals, mechanisms and nanotechnology applications

Varinder Kaur[1,2], Ajar Nath Yadav[3,4,5] & Puja Gupta[2*]

[1]Genesis Institute of Dental Sciences and Research, Ferozepur 152 004, Punjab, India
[2]School of Biosciences, RIMT University, Mandi Gobindgarh, Sirhind 147 301, Punjab, India
[3]Department of Biotechnology, Dr. KSG Akal College of Agriculture, Eternal University, Baru Sahib 173 101, Himachal Pradesh, India
[4]Department of Biotechnology, Graphic Era Deemed to be University, Dehradun 248 002, Uttarakhand, India
[5]Centre for Research Impact and Outcome, Chitkara University, Rajpura 140 401, Punjab, India

*Correspondence email - pujagupta.metagenomics@gmail.com

Received: 15 April 2025; Accepted: 10 October 2025; Available online: Version 1.0: 26 November 2025; Version 2.0: 11 December 2025

Cite this article: Varinder K, Ajar NY, Puja G. Antimicrobial potential of *Moringa oleifera*: Phytochemicals, mechanisms and nanotechnology applications. Plant Science Today. 2025; 12(4): 1-8. https://doi.org/10.14719/pst.8893

Abstract

Antibiotic resistance is increasing rapidly and is a major health problem worldwide. As a result, researchers are actively investigating safe and superior alternative therapeutic agents. Medicinal plants contain a wide array of bioactive compounds have found certain viability for such a purpose. *Moringa oleifera* is among such medicinal plants that exhibit several pharmacological features and are receiving attention for their antibiotic potential, represented by broad-spectrum antimicrobial action. The present review article emphasizes the antimicrobial potential of *M. oleifera*, highlighting the phytochemical profile, antibacterial mechanisms and its usage in the green synthesis of nanomaterials. The mentioned plant has a varied range of bioactive compounds e.g., flavonoids, glucosinolates, phenolic acids, alkaloids, sterols and terpenes that provide broad-spectrum antimicrobial activity by interfering with cell wall physiology, inhibiting protein synthesis and interfering with DNA replication. It has strong anti-quorum sensing and antibiofilm properties in addition to its direct antibacterial effects. The green synthesis of nanoparticles using *M. oleifera* has also been explored as a non-toxic and sustainable method of producing new antimicrobial materials. Overall, *M. oleifera* is a natural antibacterial agent that shows great promise and has a variety of therapeutic uses. Besides, antivirulence and nanotechnology approaches provide creative answers to address the rising issues of antibiotic resistance in current medicine.

Keywords: antibacterial; antibiotic resistance; antifilm; *Moringa oleifera*; nanoparticles; medicinal plants; phytochemicals; quorum sensing

Introduction

The rapid increase in antibiotic resistance is a pressing global health crisis, intensified by the misuse and overuse of antibiotics in human use (1). Consequently, there is an urgent need to develop effective, safe and environmentally friendly new therapies to address this challenge. One of the promising therapies is the use of plant-based antimicrobials, which offer a wide range of bioactive compounds with antibacterial properties such as alkaloids, flavonoids, tannins, terpenoids and others. These compounds have antimicrobial properties and, therefore, can be used in place of conventional antibiotics (2). Researchers are prompted to explore plant families, particularly those with traditional uses and rich phytochemical profiles. The Moringaceae family has gained interest due to their potential therapeutic or medicinal uses, specifically their antibacterial uses. The four most closely studied species in this genus are *Moringa stenopetala*, *Moringa peregrine*, *Moringa drouhardii* and *Moringa oleifera*.

M. stenopetala (African Moringa tree) is recognised for its medicinal, nutritional properties, drought resistance and ability to purify water, particularly in Ethiopia and Kenya (3, 4). *M. peregrine* (Ben oil tree) is traditionally acknowledged for its stable edible oil and medicinal uses (5). *M. drouhardii* (Bottle Tree or Malagasy) has been utilized in treating digestive problems, providing nutritional supplements, therapeutic qualities and is suitable for arid climates (6). The most commonly occurring species in the Moringaceae is *M. oleifera*, often termed the “drumstick tree” or “miracle tree”, with origins from the Indian subcontinent. It is a rapidly growing drought-resistant tree, native to the Indian subcontinent (7). *M. oleifera* contains high levels of bioactive compounds such as flavonoids, glucosinolates, isothiocyanates and phenolic acids, contributing to its vast range of medicinal and therapeutic properties (Fig. 1) (8). The leaves, seeds, pods and roots of *M. oleifera* are utilized in traditional medicine to treat various ailments like inflammation, infections, malnutrition and diabetes (9). The primary aim of this review is to explore the antimicrobial potential of plants from the Moringaceae family, with a particular focus on *M. oleifera*. Besides, it explores the phytochemical profile, mechanisms of action, anti-quorum-sensing and anti-biofilm activities. Green synthesis of nanoparticles from *M. oleifera* is also included will also be discussed as a promising agent in the development of future antimicrobial therapies.

Key bioactive compounds found in Moringaceae

M. oleifera is well known for its medicinal effects, which are mediated by its bioactive compounds. Flavonoids, alkaloids, phenolic acids, glucosinolates, terpenoids, peptides and many other

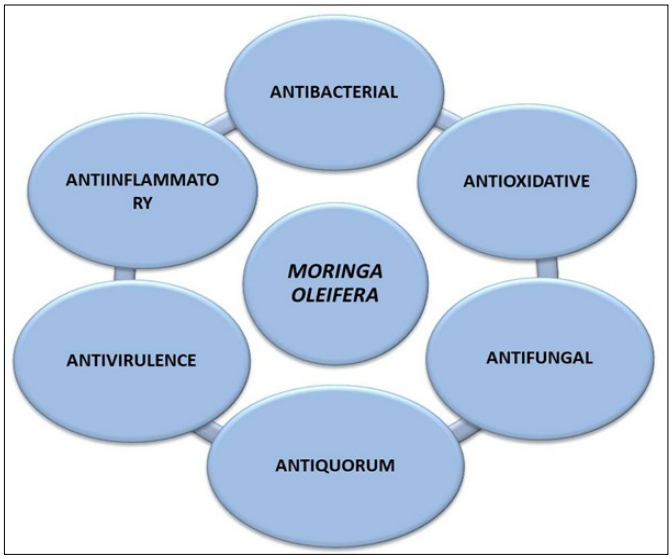

Fig. 1. Overview of therapeutic compounds found in different parts of *Moringa oleifera* (leaves, seeds, roots and pods).

phytochemicals with powerful antimicrobial, antioxidant and anti-inflammatory effects are present in the plant. Such bioactive components are not only useful for their traditional functions in infection treatment but also offer great potential for the manufacture of novel therapeutics. The antioxidant activity in the genus *Moringa* is largely due to the flavonoid content attributed to the genus. Flavanols and flavonoid glycosides are the primary flavonoids in the genus. The elimination of free radicals and the health benefits that flavonoids provide to plants are well known (7). The *Moringa* species also contains glucosinolates, a group of biologically important sulfur-containing compounds. When plant tissues are damaged due to chewing or cutting, myrosinase is released. This myrosinase enzyme promotes the conversion of glucosinolates to isothiocyanates, a much biologically active class of compounds (10). The *Moringa* genus also contains triterpenoid glycosides and sterol glycosides. The genus does not possess α-carotene, which is usually present in leafy green plants. It is assumed that all of the α-carotene had been converted into lutein (11). The major bioactive constituents and their biological activities are detailed in Table 1.

Antimicrobial activity

M. oleifera leaf extract displays considerable antibacterial activity against various pathogenic bacteria e.g., *Bacillus subtilis*, *Enterococcus faecalis*, *Escherichia coli*, *Klebsiella pneumoniae*, *Pseudomonas aeruginosa*, *Salmonella typhimurium*, *Streptococcus pyogenes*, *Staphylococcus aureus* and *Vibrio cholerae* (12). Literature reports inhibition zones ranging from 12.5 ± 0.5 mm to 23.5 ± 0.45 mm, with minimum inhibitory concentrations (MIC) ranging from 0.652 to 5.265 mg/mL. The extract was most effective against *Bacillus cereus* (MIC 0.652 mg/mL) and least effective against *Pseudomonas aeruginosa* (MIC 5.265 mg/mL) (13). Likewise, a previous study conducted *in vitro* trials against pathogenic bacteria mentioned earlier and reported inhibition zones of 14–24 mm and MIC in the range of 6.25-12.5 mg/mL. Together, these observations evidence broad-spectrum antibacterial activity of *M. oleifera* extracts; however, the activity varies based on strain (14). The leaf and root extracts of *M. oleifera* also show antifungal effect against *Aspergillus flavus*, *Aspergillus terreus*, *Aspergillus nidulans*, *Aspergillus niger*, *Aspergillus oryzae*, *Cladosporium cladosporioides*, *Fusarium solani*, *Penicillium sclerotigenum*, *Penicillium* species, *Pullarium* species, *Rhizoctonia solani* and *Trichophyton mentagrophytes* (15). Earlier research examined aqueous leaf extracts of *Moringa* against various pathogenic fungi and yeast (13). The extracts exhibited variable antifungal activity, with inhibition zones ranging from 6.6 ± 0.47 mm (*Alternaria* sp.) to 18 ± 0.54 mm (*C. parapsilosis*) and corresponding mean growth inhibition percentages of 20.3 ± 0.75 % to 80.0 ± 0.70 %, indicating the highest potency against *C. parapsilosis* and the lowest against *Alternaria* sp., *F. oxysporum* and *C. albicans*. MIC values ranged from 3.20 mg/mL (*Rhizopus stolonifer*) to 18.75 mg/mL (*Fusarium oxysporum*), with *Alternaria* sp. and *C. albicans* showing no detectable inhibition (13). Similarly, previous findings examined the methanolic and ethanolic extracts of the leaves of *M. oleifera* for antifungal activity against *A. flavus* and *R. stolonifer*. They reported inhibition zones of 12.80 ± 0.20 mm (methanolic) and 11.40 ± 0.10 mm (ethanolic) for *A. flavus* and 9.66 ± 0.33 mm (methanolic) and 8.67 ± 0.10 mm (ethanolic) against *R. stolonifer*. The minimum inhibitory concentrations (MICs) for *A. flavus* and *R. stolonifer* were determined to be 75 mg/mL and 100 mg/mL, respectively (16).

The antibacterial and antifungal effects of *M. oleifera* can be attributed to the phenolic constituents in its leaves (7), pterygospermin in its seed extracts (17), N-benzylethyl thioformate (a deoxyniazimin aglycone) in its root extract (18) and 4-(alpha-L-rhamnosyloxy) benzyl isothiocyanates in its seed extracts (19). Certain studies have pointed out that the leaf extracts of *Moringa* can be more effective than the conventional antibiotics (20, 21). An earlier study describes a safe profile of the extracts of *M. oleifera* with negligible adverse effects, even at slightly high doses (22). The extracts prepared from the leaves, root and seed of *M. oleifera* still

Table 1. Key bioactive compounds found in Moringaceae

Phytochemical class	Representative compounds	Reported activities	References
Alkaloid glycosides (leaves)	Marumoside A, marumoside B, pyrrolemarumine-4″-O-α-L-rhamnopyranoside	Therapeutic	(60)
Flavonoids	Apigenin, kaempferol, quercetin, isorhamnetin, astragali, daidzein, epicatechin, genistein, rutin, kaempferol-3-O-glucoside, kaempferol-3-rutinoside, kaempherol-3-O-α-rhamnoside, kaempferide 3-O-(2″,3″-diacetylglucoside), luteolin, myricetin, procyanidins, vicenin-2, quercetin-3-O-glucoside, quercetin-3-O-(6″-malonyl) glucoside	Antioxidant, anti-inflammatory, cardioprotective	(7, 10, 29, 61–66)
Glucosinolates/Isothiocyanates (leaves and seeds)	GMG, 4-(α-L-rhamnosyloxy) benzyl isothiocyanate (GMG-ITC), glucotropaeolin	Anticancer, antimicrobial, antidiabetic	(25, 75, 76)
Phenolics	Gallic acid, Chlorogenic acid, Ferulic acid, Ellagic acid	Antioxidant, antimicrobial, anti-inflammatory	(7, 69, 77)
Sterols (leaves and seeds)	β-sitosterol	Anti-inflammatory, cholesterol-lowering	(10)
Carotenoids (leaves)	Lutein, E-luteoxanthin, 13-Z-lutein, 15-Z-β-carotene, Zeaxanthin, β-carotene derivatives	Eye health, antioxidant	(11, 78)

need more in-depth investigations, particularly vis-à-vis long-term toxicity, to fully understand the safe and adverse effects of the extracts.

Mechanism of action

The genus *Moringa* contains a variety of bioactive components that inhibit bacterial growth in different ways, such as inhibition of enzymatic activities, destruction of the cellular wall and nucleic acid replication (23). The action of quercetin, in particular, has been extensively studied in the case of *M. oleifera*, where it inhibits bacterial DNA gyrase, crucial for replication (24). Kaempferol causes damage to the bacterial cell wall and membranes, which results in increased permeability and leakage of cell contents (25). Glucosinolates and isothiocyanates, on the other hand, inhibit bacterial growth by interfering with enzymatic activities and protein synthesis (26). These mechanisms highlight the multi-targeted approach of antibacterial activity in *M. oleifera*, making it effective against a wide range of pathogens (Fig. 2).

Biofilm inhibition and quorum sensing interference

Bacterial communication relies on a small signaling molecule that regulates gene expression through a process known as quorum sensing (QS). Quorum sensing has a profound impact on the regulation of virulence factors and biofilm formation, both of which play an important role in chronic infections. Inhibiting QS signaling represents a novel approach to controlling bacterial infections without bactericidal activity (27). This approach is attractive from a pharmaceutical perspective because it does not promote antibiotic resistance. A previous study assessed the QSI activity of phytochemicals derived from varied plant parts of *M. oleifera* (28). The aqueous seed extract was identified as the strongest violacein pigment inhibitor with high QSI activity based on *Chromobacterium violaceum* 12472 as a bioindicator strain. The biofilm dispersion was highest against *Pseudomonas* spp. (35 %) followed by *Klebsiella* spp. (25 %). Phytochemical analysis confirmed the presence of cardiac glycosides, phytosterols, saponins, triterpenes and volatile oils. Saponins and cardiac glycosides showed high QSI activity. Surprisingly, the crude seed extract outperformed the pure compounds, suggesting that its constituents worked in concert. These findings support the use of the seed extract of *M. oleifera* as a natural QSI agent to treat biofilm-induced infections (28). Furthermore, the superior performance of crude extracts over isolated compounds points to a synergistic effect, which is a useful characteristic in drug formulation. Earlier research examines the antibacterial and anti-quorum sensing activities of the ethanolic leaf extract of *M. oleifera* against *P. aeruginosa* PAO1 and *C. violaceum* (29). Phytochemical screening of the extract showed the presence of alkaloids, flavonoids, phenolics, steroids, terpenoids and tannins. The extract showed MIC and MBC values of 10 mg/mL and 20 mg/mL, respectively, against both test strains. It dramatically repressed QS by inhibiting the biosynthesis of violacein and pyocyanin, the major pigments associated with virulence. Moreover, the extract interrupted biofilm development and swarming motility, further supporting its value as a natural antivirulence candidate (29). The most bioactive antioxidant fraction was isolated and characterized from *M. oleifera* leaf extract and named MOEF (30). MOEF suppressed violacein production by more than 70 % in *C. violaceum* 12472. It also strongly inhibited several virulence factors of *P. aeruginosa* PAO1 at sub-MIC concentrations. Additionally, MOEF suppressed prodigiosin production, protease activity and swarming motility in *Serratia marcescens* and exhibited broad-spectrum antibiofilm activity, suppressing biofilm formation by more than 70 % against tested pathogens. Microscopy analyses (SEM and CLSM) also validated a significant suppression of biofilm growth. GC-MS revealed major constituents like 2-oleo-palmitostearin and 4-O-methylphorbol-12,13-didecanoate, whereas LC-qTOF-MS elucidated rich bioactive constituents further. Collectively, these studies suggest that *M. oleifera* extracts can serve as lead candidates for antivirulence drug development by targeting virulence mechanisms rather than bacterial survival. Such natural compounds offer a promising, resistance-evasive strategy to complement or replace conventional antibiotics (30).

Green synthesis of metallic nanoparticles from *Moringa* spp.

Green synthesis is a clean, non-toxic and eco-friendly alternative to conventional physical and chemical methods of synthesising nanoparticles (31). The bioactive compounds act as reducing agents and

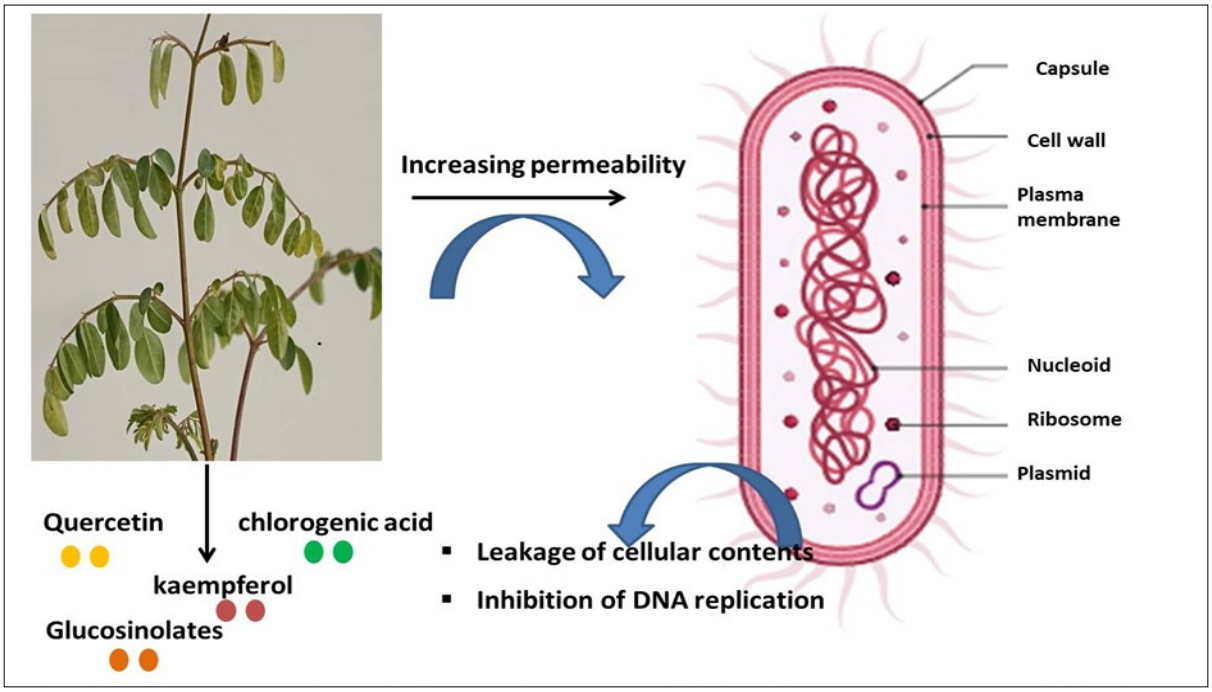

Fig. 2. Proposed antibacterial mechanisms of bioactive compounds of *Moringa oleifera*.

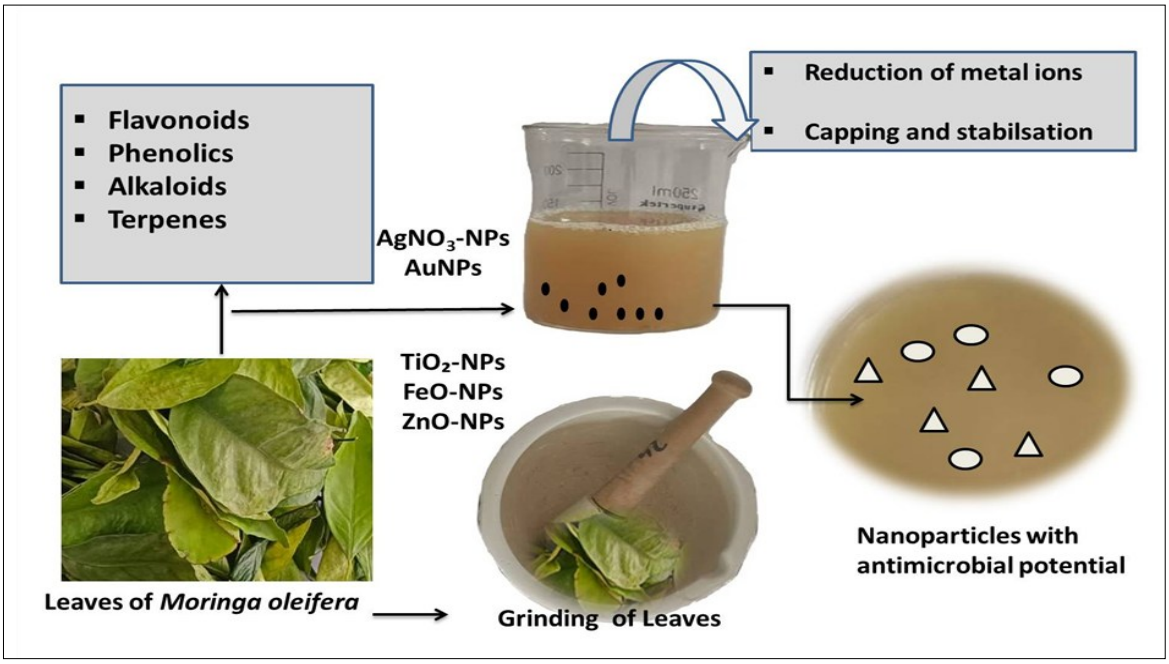

Fig. 3. General steps in green synthesis of metal nanoparticles using leaf extracts of *Moringa oleifera*.

stabilizers in the synthesis process, which results in nanoparticles with enhanced antimicrobial properties (Fig. 3). The biosynthesizing of metal nanoparticles with the plant extracts of *Moringa* comprises three primary stages (1) the initiation phase in which the reduction of metal ions and the nucleation of reduced metal atoms occurs (2) the growth phase in which nanoparticles aggregate and form larger particles (3) the termination phase in which the ultimate morphology of the nanoparticles is decided (32). Nanoparticles assume the most energetically favourable configuration in the termination phase (33). Heat has a crucial role in commencing and sustaining the reaction system during the green synthesis of nanoparticles (NPs). It remains persistent until the capping agents derived from *Moringa* extracts become active and inhibit the growth of high-energy atomic planes, leading to the formation of specific nanoparticles (NPs). Phytochemicals present in the extracts act as organic reducing agents by donating electrons to metal ions and changing them into their zerovalent state, which causes the metal ions to aggregate into stable nanoparticles. Functional moieties, such as amine groups from proteins, hydroxyl and carboxyl groups from polyphenols and groups derived from amino acids and polysaccharides, support metal ion chelation, thereby improving the reduction process and stabilizing nanoparticles. These biomolecules also act as capping agents, preventing uncontrolled aggregation and imparting long-term stability to the synthesized NPs. A diverse range of nanoparticles, including silver (Ag), gold (Au), titanium dioxide (TiO_2), iron oxide (FeO) and zinc oxide (ZnO), have been successfully synthesized from different parts of *M. oleifera* through this eco-friendly biogenic approach. Thus, highlighting its potential as a sustainable resource for nanomaterial fabrication.

Metallic nanoparticles from *Moringa* spp.

Phytochemicals such as flavonoids, reducing sugars and phenolic compounds in *M. oleifera* act as natural reducing and capping agents, facilitating green synthesis (34). A wide range of metal and metal oxide nanoparticles, including silver, gold, iron, ZnO and TiO_2, have been synthesized using *M. oleifera*, exhibiting notable biological activities (35, 36).

Silver nanoparticle (Ag-NP)

Several parts of the *M. oleifera* i.e., flowers, leaves, seeds and stem bark, have been successfully used for the synthesis of silver nanoparticles (AgNP). Flower-extracted AgNPs (~8 nm) inhibited antimicrobial activity against *K. pneumoniae* and *S. aureus*, while leaf -derived AgNPs displayed substantial antimicrobial activity against *E. coli* and *S. aureus*, with enhanced efficacy under sunlight as an energy source (37). The morphology of biosynthesized AgNPs varied e.g., colloidal, nanorods and triangular shapes, depending on the method of extraction (38). Polyethylene glycol (PEG)-mediated AgNP synthesis using *M. oleifera* extracts has been recognized as biocompatible, cost-effective and sustainable (39). Khor reported a simple and efficient method using aqueous leaf extract, yielding spherical nanostructures (40). Similarly, multivariate optimization of AgNP synthesis from flower extracts, leaf and stem bark resulted in sphere-shaped nanoparticles measuring 273.98 nm, 96.72 nm and 95.12 nm, respectively (41). A rapid and eco-friendly method was developed to produce stable, crystalline AgNPs with centered-cubic shapes (~32 nm) from leaf extract (42). Another study used leaf and seed extracts to reduce $AgNO_3$ in the presence of tannic acid, forming a dark grey colloidal solution stabilized with sodium citrate. Additionally, stem bark extracts were used to generate stable AgNPs with potential anticancer applications, while a cold synthesis approach using aqueous extracts was reported as non-toxic and efficient (43).

Gold nanoparticles (AuNPs)

Gold nanoparticles (AuNPs) have been created using leaves, pods, flowers, seeds and gum extracts of *M. oleifera.* A one-pot synthesis, from the leaf extract of *M. oleifera*, caused a quick color change from pale yellow to red-brown, which is due to the surface plasmon resonance (SPR) of the nanoparticles. Additionally, gum extracts serve as stabilizing and reducing agents, giving SPR its ruby red hue (44). AuNPs are reduced and stabilized with the help of leaf proteins and metabolites. AuNPs were synthesized using aqueous extracts prepared from whole flowers of *M. oleifera* (45). The presence of colloidal AuNPs was confirmed through UV-Vis spectroscopy (200-800 nm). TEM analysis showed different shapes, including triangular, hexagonal and irregular spherical particles, with an average size of about 100 nm (45). Flower extracts mediate AuNP synthesis by the formation of pink-hued, stable nanoparticles (46). Yet another study demonstrated the green synthesis of AuNPs using methanolic extracts

of *M. oleifera* seeds at room temperature. UV-Vis spectroscopy confirmed nanoparticle formation with a characteristic Surface Plasmon Resonance (SPR) peak at 546 nm, while TEM analysis revealed spherical particles. FTIR spectra indicated the involvement of bioactive compounds in the reduction of gold ions. AuNPs are reported to exhibit strong antioxidant activity (via DPPH radical scavenging) and antimicrobial effects against *E. coli* and *Staphylococcus aureus*, with minimum inhibitory concentrations (MICs) of 400 µg/mL and 200 µg/mL, respectively (47).

Titanium dioxide nanoparticles (TiO_2-NPs)

TiO_2-NPs has gathered substantial attention for their effective antimicrobial properties, chiefly when synthesized or modified using biocompatible agents. One approach is the green synthesis of TiO_2-NPs using leaf extract from *M. oleifera*, which serves as both a reducing and stabilizing agent. This method not only improves the physical and chemical properties of TiO_2 but also introduces biological activity due to the bioactive compounds in Moringa. The resulting TiO_2-*Moringa* nanocomposites demonstrate strong antimicrobial, antibacterial and anti-inflammatory effects. This makes them suitable for biomedical applications. Titanium tetra isopropoxide (TTIP) and titanium dioxide solutions are often used as starting materials. Different synthesis methods have led to TiO_2-NPs with various shapes and sizes e.g., using ethanolic leaf extracts with TTIP stirred at 50 °C for 4 hr created tetragonal TiO_2-NPs (~12 nm). Other research with aqueous leaf extracts generated spherical TiO_2-NPs (~100 nm), while ball-milling with Moringa seed extract resulted in similar properties (39, 48). These nanoparticles showed photocatalytic activity by breaking down methylene blue dye under sunlight, demonstrating their potential for environmental cleanup (49). TiO_2-NPs were synthesized using aqueous leaf extract of M. *oleifera* and tested their wound healing ability in albino rats, showing significant improvements in wound closure rates. The antibacterial action of the TiNPs was also assessed, showing strong effectiveness against both Gram-positive and Gram-negative bacteria (50). In a similar study, the effect of TiO_2-NPs incorporated in a gelatin matrix on methicillin-resistant *S. aureus* (MRSA) infected skin wound healing was evaluated in a rat model (51). The TiO_2/gelatin composite significantly increased wound contraction, reduced bacterial load and stimulated fibroblast growth, collagen buildup and reepithelialization compared to controls. These findings highlight the broad potential of TiO_2-NPs, especially when combined with natural biopolymers for antimicrobial treatment and wound healing (51).

Iron oxide nanoparticles (FeO-NPs)

FeO-NPs, particularly in the forms of magnetite (Fe_3O_4), hematite (α-Fe_2O_3) and maghemite (γ-Fe_2O_3), are important for biomedical applications. They possess magnetic properties, making them suitable for MRI and hyperthermia therapy in cancer treatment. Green synthesis of FeO-NPs uses different plant parts such as leaves, fruit, seeds and oils (52, 53). In one method, researchers prepared iron nanoparticles by gradually adding a 0.5 M iron salt solution to an *M. oleifera* extract in a sonicated reactor. The formation of FeO-NPs was indicated by a color change to black, which was further confirmed by UV-Vis spectroscopy that showed a peak around 400 nm. The structures were irregularly shaped, with an average diameter of 45 nm, as observed through transmission and scanning electron microscopy. These FeO-NPs are of interest because they can be used in antimicrobial food coatings, catalysis, cosmetics and especially in biomedical fields. They can be modified with ligands or antibodies for targeted drug delivery, offering a more effective and precise therapeutic option. The green synthesis process using *M. oleifera* is not only eco-friendly and free of toxic substances but also cost-effective (54). This is especially advantageous for low- and middle-income countries where *M. oleifera* is easily accessible. Green synthesis of FeO-NPs with *M. oleifera* extracts has been confirmed through UV-Vis spectroscopy, TEM, SEM and XRD. The nanoparticles exhibit spherical, cubic, or rod-like shapes depending on the synthesis conditions (53, 55). Functionalization with *Moringa*-derived biomolecules improved their stability and compatibility with biological systems.

Zinc oxide nanoparticles (ZnO-NPs)

ZnO-NPs can be prepared from the leaves, flowers, seeds, roots and crude gum of M. oleifera using eco-friendly green synthesis methods like precipitation. The ZnO-NPs exhibit a hexagonal wurtzite structure, with particle sizes ranging from 10.8 to 60 nm depending on the plant part used for preparation (56). The leaf extracts produced the smallest nanoparticles, with average crystallite sizes as low as 10.81 nm, along with improved properties such as surface area, reactivity and optical behavior. Air annealing at 500 °C was essential for obtaining the pure wurtzite phase. Doping copper into the ZnO lattice with Moringa leaf extract improved its ability to adsorb Congo red dye, showing potential for environmental cleanup (57). ZnO-NPs were produced from M. oleifera gum using a simple green synthesis method that is both eco-friendly and cost-effective. These ZnO-NPs displayed strong antibacterial activity against *E. coli* and *S. aureus*, with effectiveness against methicillin-resistant *S. aureus* (MRSA) (58). UV-Vis spectroscopy confirmed the formation of ZnO-NPs, showing a surface plasmon band at 223.5 nm. FTIR analysis identified the functional groups involved in the synthesis. SEM-EDS analysis revealed well-defined nanostructures with good stability and XRD confirmed their crystalline nature. The average particle size was about 15.3 nm, which verifies their nanoscale dimensions. The biosynthesized ZnO-NPs showed strong antimicrobial activity against various bacterial and fungal strains, emphasizing their potential in biomedical applications (59).

Challenges and future directions

Moringa spp. holds great importance due to its antimicrobial activity, but several challenges exist in the development of these findings into clinical uses. The absence of standard extraction formulation processes, poor knowledge of pharmacokinetics and bioavailability of the active metabolites are limitations. Furthermore, advances in nanotechnology and drug delivery systems could help to improve the stability, absorption and targeted delivery of *Moringa*-derived compounds to make the most of their therapeutic benefits. Future studies need to focus on developing targeted nanoformulations of *Moringa* bioactives to improve stability and controlled release; co-delivery strategies that combine *Moringa* compounds with conventional antibiotics to tackle multidrug resistance; detailed toxicity and safety studies at the cellular, animal and clinical levels and standardizing extraction, purification and formulation methods to ensure consistent results.

Conclusion

The Moringaceae family, particularly *M. oleifera*, offers a rich source of antibacterial agents with potential applications in medicine and industry. *M. oleifera* exhibits broad-spectrum antimicrobial activity due to its diverse bioactive compounds such as flavonoids,

glucosinolates, phenolic acids, alkaloids, sterols and terpenes. These compounds contribute significantly to their antioxidant, antimicrobial, anti-inflammatory and therapeutic potential, which are distributed across various plant parts (leaves, seeds, bark, etc.). The potent antibacterial activity occurs through multiple mechanisms, including disruption of cell walls, inhibition of protein synthesis and interference with DNA replication. These multifaceted actions make *Moringa* a strong natural candidate for developing novel antimicrobial therapies. *M. oleifera* exhibits strong quorum-sensing inhibitory and antibiofilm activities against multiple pathogenic bacteria. Its extracts, particularly from seeds and leaves, interfere with key virulence factors, swarming motility and pigment production. These findings highlight *M. oleifera* as a promising natural antivirulence agent for combating resistant biofilm-associated infections. Green synthesis using *M. oleifera* offers a sustainable, non-toxic approach to nanoparticle production, harnessing the plant's rich phytochemical profile. The resulting nanoparticles exhibit diverse morphologies and potent antimicrobial properties, with applications in medicine. Continued exploration of *Moringa*-based nanomaterials could lead to innovative solutions in combating microbial resistance and enhancing human health. Future studies should focus on clinical validation and formulation development to establish *M. oleifera*-derived compounds and nanomaterials as next-generation therapeutic candidates.

Acknowledgements

PG and VK are thankful to RIMT University for their support. Besides, PG is thankful to the Department of Science and Technology (DST) for the award of Women Scientist-A (SR/WOS-A/LS-136/2017).

Authors' contributions

PG conceptualized the manuscript, provided critical revisions and supervised the overall work. AN provided critical revisions and VG drafted the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

References

1. Owusu E, Ahorlu MM, Afutu E, Akumwena A, Asare GA. Antimicrobial activity of selected medicinal plants from a Sub-Saharan African country against bacterial pathogens from post-operative wound infections. Med Sci. 2021;9(2):23. https://doi.org/10.3390/medsci9020023
2. Kebede T, Gadisa E, Tufa A. Antimicrobial activities evaluation and phytochemical screening of some selected medicinal plants: a possible alternative in the treatment of multidrug-resistant microbes. PLoS One. 2021;16(3):e0249253. https://doi.org/10.1371/journal.pone.0249253
3. Tissot F, Cuadrado M, Santander J, Torres J, Machado I. Nutritional and antioxidant properties of South American *Moringa stenopetala*. Brazilian J Anal Chem. 2023;10(41):443–50. https://doi.org/10.30744/brjac.2179-3425.AR-125-2022
4. Eilert U, Wolters B, Nahrstedt A. The antibiotic principle of seeds of *Moringa oleifera* and *Moringa stenopetala*. Planta Med. 1981;42(5):55–61. https://doi.org/10.1055/s-2007-971546
5. Al-Dabbas MM. Antioxidant activity of different extracts from the aerial part of *Moringa peregrina* (Forssk.) Fiori, from Jordan. Pak J Pharm Sci. 2017;30(6).
6. Boopathi NM, Abubakar BY. Botanical descriptions of *Moringa* spp. 2021. p. 11–20. https://doi.org/10.1007/978-3-030-80956-0_2
7. Leone A, Spada A, Battezzati A, Schiraldi A, Aristil J, Bertoli S. Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: an overview. Int J Mol Sci. 2015;16(6):12791–835. https://doi.org/10.3390/ijms160612791
8. Chiş A, Noubissi PA, Pop OL, Mureşan CI, Fokam Tagne MA, Kamgang R, et al. Bioactive compounds in *Moringa oleifera*: mechanisms of action, focus on their anti-inflammatory properties. Plants. 2023;13(1):20. https://doi.org/10.3390/plants13010020
9. Zarina, Wani AW, Rawat M, Kaur H, Das S, Kaur T, et al. Medicinal utilization and nutritional properties of drumstick (*Moringa oleifera*) -a comprehensive review. Food Sci Nutr. 2024;12(7):4546–68. https://doi.org/10.1002/fsn3.4139
10. Maiyo FC, Moodley R, Singh M. Cytotoxicity, antioxidant and apoptosis studies of quercetin-3-O-glucoside and 4-(β-D-glucopyranosyl-1→4-α-L-rhamnopyranosyloxy)-benzyl isothiocyanate from *Moringa oleifera*. Anticancer Agents Med Chem. 2016;16(5):648–56. https://doi.org/10.2174/1871520615666151002110424
11. Saini RK, Shetty NP, Giridhar P. Carotenoid content in vegetative and reproductive parts of commercially grown *Moringa oleifera* Lam. cultivars from India by LC–APCI–MS. Eur Food Res Technol. 2014;238(6):971–8. https://doi.org/10.1007/s00217-014-2174-3
12. Pareek A, Pant M, Gupta MM, Kashania P, Ratan Y, Jain V, et al. *Moringa oleifera*: an updated comprehensive review of its pharmacological activities, ethnomedicinal, phytopharmaceutical formulation, clinical, phytochemical, and toxicological aspects. Int J Mol Sci. 2023;24(3):2098. https://doi.org/10.3390/ijms24032098
13. Al-husnan LA, Alkahtani MDF. Impact of *Moringa* aqueous extract on pathogenic bacteria and fungi in vitro. Ann Agric Sci. 2016;61(2):247–50. https://doi.org/10.1016/j.aoas.2016.06.003
14. El-Sherbiny GM, Alluqmani AJ, Elsehemy IA, Kalaba MH. Antibacterial, antioxidant, cytotoxicity, and phytochemical screening of *Moringa oleifera* leaves. Sci Rep. 2024;14(1):30485. https://doi.org/10.1038/s41598-024-80700-y
15. Upadhyay P, Mk Y, S M, Sharma P, Purohit S. *Moringa oleifera*: a review of the medical evidence for its nutritional and pharmacological properties. Int J Res Pharm Sci. 2015;5(2):12–6.
16. Suraka B, Ibrahim D, Suleman K, Usman U, Usman SI. Antifungal activity of *Moringa oleifera* leaves crude extract against *Aspergillus flavus* and *Rhizopus stolonifer*. Dutse J Pure Appl Sci. 2022;7(4b). https://doi.org/10.4314/dujopas.v7i4b.2
17. Mangundayao K, Yasurin P. Bioactivity of *Moringa oleifera* and its applications: a review. J Pure Appl Microbiol. 2017;11(1):43–50. https://doi.org/10.22207/JPAM.11.1.07
18. Mishra G, Singh P, Verma R, Kumar S, Srivastav S, Jha KK, et al. Traditional uses, phytochemistry and pharmacological properties of *Moringa oleifera* plant: an overview. Der Pharmacia Lettre. 2011;3:141–64.
19. Padla EP, Solis LT, Levida RM, Shen CC, Ragasa CY. Antimicrobial isothiocyanates from the seeds of *Moringa oleifera* Lam. Zeitschrift für Naturforsch C. 2012;67:557. https://doi.org/10.1515/znc-2012-11-1205
20. Al-Khalasi SS, Al-Ghafri AS, Al-Saqri SN, Al-Jahdhami HA, Al-Badi AM. Comparative study between *Moringa peregrina* plant extracts and a standard antibiotic against *Candida albicans*. Open Access Res J Sci Technol. 2023;9(2):22–38. https://doi.org/10.53022/oarjst.2023.9.2.0065

21. Vankwani S, Ansari A, Azhar A, Galani S. Synergistic evaluation of *Moringa oleifera* extract and β-lactam antibiotic to restore the susceptibility of methicillin-resistant *Staphylococcus aureus*. Mol Biol Rep. 2022;49(1):421–32. https://doi.org/10.1007/s11033-021-06889-7

22. Stohs SJ, Hartman MJ. Review of the safety and efficacy of *Moringa oleifera*. Phyther Res. 2015;29(6):796–804. https://doi.org/10.1002/ptr.5325

23. Saini RK, Sivanesan I, Keum YS. Phytochemicals of *Moringa oleifera*: a review of their nutritional, therapeutic and industrial significance. 3 Biotech. 2016;6(2):203. https://doi.org/10.1007/s13205-016-0526-3

24. Huang W, Wang Y, Tian W, Cui X, Tu P, Li J, et al. Biosynthesis investigations of terpenoid, alkaloid, and flavonoid antimicrobial agents derived from medicinal plants. Antibiotics. 2022;11(10):1380. https://doi.org/10.3390/antibiotics11101380

25. Zhou H, Xu M, Guo W, Yao Z, Du X, Chen L, et al. The antibacterial activity of kaempferol combined with colistin against colistin-resistant Gram-negative bacteria. Microbiol Spectr. 2022;10(6). https://doi.org/10.1128/spectrum.02265-22

26. Romeo L, Iori R, Rollin P, Bramanti P, Mazzon E. Isothiocyanates: an overview of their antimicrobial activity against human infections. Molecules. 2018;23(3):624. https://doi.org/10.3390/molecules23030624

27. Juszczuk-Kubiak E. Molecular aspects of the functioning of pathogenic bacteria biofilm based on quorum sensing signal-response system and innovative non-antibiotic strategies for their elimination. Int J Mol Sci. 2024;25(5):2655. https://doi.org/10.3390/ijms25052655

28. Jonnalagadda S, Deshabathini UK. Anti quorum sensing potential of *Moringa oleifera* seed extract. Int J Pharm Pharm Sci. 2016;8(1):76–82.

29. Suhartono S, Ismail YS, Muhayya SR. The interference of *Moringa oleifera* leaf extracts to modulate quorum sensing-facilitated virulence factors. Biodiversitas J Biol Divers. 2019;20(10). https://doi.org/10.13057/biodiv/d201031

30. Haris Z, Ahmad I. Evaluation of antioxidant-rich bioactive plant extracts with special reference to *Moringa oleifera* Lam. for their interference to bacterial quorum sensing and biofilm. Phytomedicine Plus. 2024;4(2):100511. https://doi.org/10.1016/j.phyplu.2023.100511

31. Kandeil MA, Mohammed ET, Hashem KS, Aleya L, Abdel-Daim MM. *Moringa* seed extract alleviates titanium oxide nanoparticles-induced cerebral oxidative damage and increases cerebral mitochondrial viability. Environ Sci Pollut Res. 2020;27(16):19169–84. https://doi.org/10.1007/s11356-019-05514-2

32. Virk P, Awad MA, Saleh Abdu-llah Alsaif S, Hendi AA, Elobeid M, Ortashi K, et al. Green synthesis of *Moringa oleifera* leaf nanoparticles and an assessment of their therapeutic potential. J King Saud Univ Sci. 2023;35(3):102576. https://doi.org/10.1016/j.jksus.2023.102576

33. Husen A, editor. Secondary metabolites based green synthesis of nanomaterials and their applications. Singapore: Springer Nature Singapore; 2023. https://doi.org/10.1007/978-981-99-0927-8

34. Eric CA, Benjamín V, Monica C, Mario AC, Francisco DM, Rogelio AR, et al. Silver nanoparticles biosynthesized by secondary metabolites from *Moringa oleifera* stem and their antimicrobial properties. African J Biotechnol. 2017;16(9):400–7. https://doi.org/10.5897/AJB2016.15840

35. Katata-Seru L, Moremedi T, Aremu OS, Bahadur I. Green synthesis of iron nanoparticles using *Moringa oleifera* extracts and their applications: removal of nitrate from water and antibacterial activity against *Escherichia coli*. J Mol Liq. 2018;256:296–304. https://doi.org/10.1016/j.molliq.2017.11.093

36. Mehwish HM, Rajoka MSR, Xiong Y, Cai H, Aadil RM, Mahmood Q, et al. Green synthesis of silver nanoparticles using *Moringa oleifera* seed and its applications for antimicrobial and sunlight-mediated photocatalytic water detoxification. J Environ Chem Eng. 2021;9(4):105290. https://doi.org/10.1016/j.jece.2021.105290

37. Moodley JS, Krishna SBN, Pillay K, Sershen, Govender P. Green synthesis of silver nanoparticles from *Moringa oleifera* leaf extracts and its antimicrobial potential. Adv Nat Sci Nanosci Nanotechnol. 2018;9(1):015011. https://doi.org/10.1088/2043-6254/aaabb2

38. Sathyavathi R, Krishna MBM, Rao DN. Biosynthesis of silver nanoparticles using *Moringa oleifera* leaf extract and its application to optical limiting. J Nanosci Nanotechnol. 2011;11(3):2031–5. https://doi.org/10.1166/jnn.2011.3581

39. Perumalsamy H, Balusamy SR, Sukweenadhi J, Nag S, MubarakAli D, El-Agamy Farh M, et al. A comprehensive review on *Moringa oleifera* nanoparticles: importance of polyphenols in nanoparticle synthesis, nanoparticle efficacy and applications. J Nanobiotechnology. 2024;22(1):71. https://doi.org/10.1186/s12951-024-02332-8

40. Khor KZ, Joseph J, Shamsuddin F, Lim V, Moses EJ, Abdul Samad N. The cytotoxic effects of *Moringa oleifera* leaf extract and silver nanoparticles on human Kasumi-1 cells. Int J Nanomedicine. 2020;15:5661–70. https://doi.org/10.2147/IJN.S244834

41. Mokgweetsi P. Green synthesis of silver nanoparticles using *Moringa oleifera*, employing multivariate optimization methodologies. Int J Adv Res. 2018;6(7):953–62. https://doi.org/10.21474/IJAR01/7445

42. Pratiwi DE, Side S, Nisa NAT. Synthesis of silver nanoparticles using *Moringa oleifera* L. leaf extract as bioreductor. Mater Sci Forum. 2019;967:145–9. https://doi.org/10.4028/www.scientific.net/MSF.967.145

43. Ghosh N, Paul S, Basak P. Silver nanoparticles of *Moringa oleifera* – green synthesis, characterisation and its antimicrobial efficacy. J Drug Deliv Ther. 2014;4(3-s):42–6. https://doi.org/10.22270/jddt.v0i0.906

44. Tiloke C, Phulukdaree A, Anand K, Gengan RM, Chuturgoon AA. *Moringa oleifera* gold nanoparticles modulate oncogenes, tumour suppressor genes, and caspase-9 splice variants in A549 cells. J Cell Biochem. 2016;117(10):2302–14. https://doi.org/10.1002/jcb.25528

45. Anand K, Gengan RM, Phulukdaree A, Chuturgoon A. Agroforestry waste *Moringa oleifera* petals mediated green synthesis of gold nanoparticles and their anticancer and catalytic activity. J Ind Eng Chem. 2015;21:1105–11. https://doi.org/10.1016/j.jiec.2014.05.021

46. Mohammed GM, Hawar SN. Green biosynthesis of silver nanoparticles from *Moringa oleifera* leaves and its antimicrobial and cytotoxicity activities. Int J Biomater. 2022;2022:4136641. https://doi.org/10.1155/2022/4136641

47. Bouttier-Figueroa DC, Loreto-Romero MA, Roldan MA, González-Gutiérrez FH, Cortez-Valadez M, Flores-Acosta M, et al. Green synthesis of gold nanoparticles via *Moringa oleifera* seed extract: antioxidant, antibacterial and anticarcinogenic activity on lung cancer. J Environ Sci Health Part A. 2024;59(5):231–40. https://doi.org/10.1080/10934529.2024.2366736

48. Ao B, Jiang H, Cai X, Liu D, Tu J, Shi X, et al. Synthesis of tellurium nanoparticles using *Moringa oleifera* extract and antibacterial and antibiofilm effects against bacterial pathogens. Microorganisms. 2024;12(9):1847. https://doi.org/10.3390/microorganisms12091847

49. Hema K, Anishia SR, Rajeswari S, Padmavathy V, Sujatha S, Thiyagu M. Green synthesis and multifunctional applications of *Moringa oleifera*-enhanced TiO_2 nanocomposites. J Environ Nanotechnol. 2025;14(1):7–17. https://doi.org/10.13074/jent.2025.03.2511225

50. Sivaranjani V, Philominathan P. Synthesize of titanium dioxide nanoparticles using *Moringa oleifera* leaves and evaluation of wound healing activity. Wound Med. 2016;12:1–5. https://doi.org/10.1016/j.wndm.2015.11.002

51. Nikpasand A, Parvizi MR. Evaluation of the effect of titanium dioxide nanoparticles/gelatin composite on infected skin wound healing: an animal model study. Bull Emerg Trauma. 2019;7(4):366–72.

https://doi.org/10.29252/beat-070405

52. Silveira C, Shimabuku QL, Fernandes Silva M, Bergamasco R. Iron-oxide nanoparticles by the green synthesis method using *Moringa oleifera* leaf extract for fluoride removal. Environ Technol. 2018;39 (22):2926–36. https://doi.org/10.1080/09593330.2017.1369582

53. Aisida SO, Madubuonu N, Alnasir MH, Ahmad I, Botha S, Maaza M, et al. Biogenic synthesis of iron oxide nanorods using *Moringa oleifera* leaf extract for antibacterial applications. Appl Nanosci. 2020;10 (1):305–15. https://doi.org/10.1007/s13204-019-01099-x

54. Prucek R, Tuček J, Kilianová M, Panáček A, Kvítek L, Filip J, et al. The targeted antibacterial and antifungal properties of magnetic nanocomposite of iron oxide and silver nanoparticles. Biomaterials. 2011;32(21):4704–13. https://doi.org/10.1016/j.biomaterials.2011.03.039

55. Tovar GI, Briceño S, Suarez J, Flores S, González G. Biogenic synthesis of iron oxide nanoparticles using *Moringa oleifera* and chitosan and evaluation on corn germination. Environ Nanotechnol Monit Manag. 2020;14:100350. https://doi.org/10.1016/j.enmm.2020.100350

56. Pal S, Mondal S, Maity J, Mukherjee R. Synthesis and characterization of ZnO nanoparticles using *Moringa oleifera* leaf extract: investigation of photocatalytic and antibacterial activity. Int J Nanosci Nanotechnol. 2018;14(2):111–9.

57. Srivastava V, Choubey AK. Kinetic and isothermal study of transition metal doping on adsorptive property of zinc oxide nanoparticles synthesized via green route using *Moringa oleifera* leaf extract. Mater Res Express. 2020;6(12):125017. https://doi.org/10.1088/2053-1591/ab7158

58. Irfan M, Munir H, Ismail H. *Moringa oleifera* gum based silver and zinc oxide nanoparticles: green synthesis, characterization and antibacterial potential against MRSA. Biomater Res. 2021;25(1):5661–70. https://doi.org/10.1186/s40824-021-00219-5

59. Kalaiyarasi C, Poonkothai M, Abirami S, Alaguprathana M, Marraiki N, Zaghloul NSS. Zinc oxide nanoparticles fabrication using *Moringa oleifera* Lam. seed extract: impact on phytotoxic, photocatalytic and antimicrobial activities. Appl Nanosci. 2023;13(3):2187–97. https://doi.org/10.1007/s13204-021-02113-x

60. Sahakitpichan P, Mahidol C, Disadee W, Ruchirawat S, Kanchanapoom T. Unusual glycosides of pyrrole alkaloid and 4′-hydroxyphenylethanamide from leaves of *Moringa oleifera*. Phytochemistry. 2011;72(8):791–5. https://doi.org/10.1016/j.phytochem.2011.02.021

61. Leone A, Fiorillo G, Criscuoli F, Ravasenghi S, Santagostini L, Fico G, et al. Nutritional characterization and phenolic profiling of *Moringa oleifera* leaves grown in Chad, Sahrawi refugee camps and Haiti. Int J Mol Sci. 2015;16(8):18923–37. https://doi.org/10.3390/ijms160818923

62. Vongsak B, Sithisarn P, Gritsanapan W. Simultaneous HPLC quantitative analysis of active compounds in leaves of *Moringa oleifera* Lam. J Chromatogr Sci. 2014;52(7):641–5. https://doi.org/10.1093/chromsci/bmt093

63. Habtemariam S, Varghese G. Extractability of rutin in herbal tea preparations of *Moringa stenopetala* leaves. Beverages. 2015;1 (3):169–82. https://doi.org/10.3390/beverages1030169

64. Manguro LOA, Lemmen P. Phenolics of *Moringa oleifera* leaves. Nat Prod Res. 2007;21(1):56–68. https://doi.org/10.1080/14786410601035811

65. Atawodi SE, Atawodi JC, Idakwo GA, Pfundstein B, Haubner R, Wurtele G, et al. Evaluation of the polyphenol content and antioxidant properties of methanol extracts of the leaves, stem and root barks of *Moringa oleifera* Lam. J Med Food. 2010;13(3):710–6. https://doi.org/10.1089/jmf.2009.0057

66. Amali Muhammad A, Fakurazi S, Arulselvan P, See CP, Abas F. Evaluation of wound healing properties of bioactive aqueous fraction from *Moringa oleifera* Lam. on experimentally induced diabetic animal model. Drug Des Devel Ther. 2016;2016:1715–30. https://doi.org/10.2147/DDDT.S96968

67. Waterman C, Rojas-Silva P, Tumer TB, Kuhn P, Richard AJ, Wicks S, et al. Isothiocyanate-rich *Moringa oleifera* extract reduces weight gain, insulin resistance and hepatic gluconeogenesis in mice. Mol Nutr Food Res. 2015;59(6):1013–24. https://doi.org/10.1002/mnfr.201400679

68. Tumer TB, Rojas-Silva P, Poulev A, Raskin I, Waterman C. Direct and indirect antioxidant activity of polyphenol- and isothiocyanate-enriched fractions from *Moringa oleifera*. J Agric Food Chem. 2015;63(5):1505–13. https://doi.org/10.1021/jf505014n

69. Verma AR, Vijayakumar M, Mathela CS, Rao CV. *In vitro* and *in vivo* antioxidant properties of different fractions of *Moringa oleifera* leaves. Food Chem Toxicol. 2009;47(9):2196–201. https://doi.org/10.1016/j.fct.2009.06.005

70. Teixeira EMB, Carvalho MRB, Neves VA, Silva MA, Arantes-Pereira L. Chemical characteristics and fractionation of proteins from *Moringa oleifera* Lam. leaves. Food Chem. 2014;147:51–4. https://doi.org/10.1016/j.foodchem.2013.09.135

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.