



REVIEW ARTICLE

# Ethnomedicinal uses of *Moringa oleifera* Lam. and the phytochemicals in regulating Type 2 Diabetes and inflammation

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 OPEN ACCESS

## ARTICLE HISTORY

Received: 15 March 2024

Accepted: 07 May 2024

Available online

Version 1.0 : 08 June 2024

Version 2.0 : 17 June 2024



## Additional information

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

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**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](https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting)

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## CITE THIS ARTICLE

Tripathy CS, Mishra A, Behera SK, Parida S. Ethnomedicinal Uses of *Moringa oleifera* Lam. and the Phytochemicals in Regulating Type 2 Diabetes and Inflammation. Plant Science Today. 2024; 11(sp1): 197-206. <https://doi.org/10.14719/pst.3549>

## Abstract

Leaves and young pods of *Moringa oleifera* Lam. are not only used as vegetables, but different parts such as stem, stem barks, gum-resin, root, flower, seed pod, pod husk, seeds, and roots are also used in the traditional system of medicine. Chemical compounds such as alkaloids, phenolics, and terpenoids as excretory or waste products are produced by plants through the metabolic pathways. These chemical compounds have antibiotic, antimicrobial, and anti-insecticidal activity for their self-defense from a wide variety of pathogens. The ethnomedicinal uses and the scientific assessment of *M. oleifera* Lam. are essential, as it is a traditional food with numerous medicinal properties. *Moringa* leaves are an excellent nutritional supplement that contains crucial amino acids, minerals, vitamins, proteins, and other bioactive phytochemicals. In particular, the high nutrient content of the leaves benefits pregnant women and infants. It is also an effective diabetic, analgesic, and antimicrobial agent. This review mainly highlights the ancient medicinal uses of different plant parts such as leaves, flowers, fruit pods, seeds, seed oil, stem bark, gums, and roots; its mineral contents, phytochemical composition, and pharmacological potential, especially antidiabetic, antimicrobial, and analgesic activity, emphasizing the molecular mechanisms associated with anti-inflammatory and anti-diabetic activity.

## Keywords

anti-inflammatory; antimicrobial; ethnomedicinal; molecular mechanisms; *Moringa oleifera*; phytochemicals

## Introduction

*Moringa oleifera* Lam. (Synonym: *Moringa zeylanica* Burmann.) is an angiospermic plant belonging to the family Moringaceae. *Moringa* is a soft wood, fast-growing, drought-resistant perennial tree native to the Indian subcontinent. This plant is endemic to northwestern India and is a widely cultivated deciduous plant with drought-resistant ability (1). Commonly *Moringa* is called a drumstick tree, horse radish tree, or benzolive tree. Leaves and slender pods are cooked as vegetables and used in traditional systems of medicine. *M. oleifera* Lam. is recognized as a miracle tree or wonder tree. The genus *Moringa* term comes from the Tamil word Murungai, known for the twisted pod, and generally refers to slender pods (2). The name of the species “oleifera” comes from the Latin word oleum which means oil, and ferre means to carry (3). *M. oleifera* Lam. is generally referred to as a solution for all diseases and is known to cure more than 300 diseases and therefore termed a

Miracle tree or Wonder tree (4). Its leaves are used as leafy vegetables all over India as a part of the diet and in the treatment of diseases in India from the time of Shushruta. In Odia, it is known as the sajana saga and also called as drum stick greens in English language (5). *M. oleifera* Lam. is an affordable source of essential functional bioactive compounds such as alkaloids, anthraquinones, flavonoids, glucosinolates, phenolic acids, natural sugars, saponins, phytosteroids, tannins, terpenes having promising applications in medicines, preparation of functional foods, biodiesel production and purification of water (6). *Moringa* is used for ailments such as heartburn, asthma, flu, bone-setting, and syphilis in rural communities in Uganda (6). This article describes the latest information from the published articles on the traditional uses of *Moringa*, its nutritional composition, antimicrobial activity, and critical pharmacological properties with specific importance to the molecular mechanisms associated with anti-diabetic and anti-inflammatory activity to bridge the gap.

### Ancient medicinal uses

In the traditional Indian System of Medicine, different parts such as leaves, stems, roots, flowers, fruits, seeds, barks, latex, gums, and sometimes the whole plant are used to cure various ailments. In the Paleolithic age, nearly 60000 years ago, plants are used for medicinal purposes (7, 8). Of 391,000 identified vascular plants, only 6% were investigated for their pharmacological properties and 15% for phytochemical constituents (9). *M. oleifera* Lam. possesses several medicinal properties and has been used in Indian Systems of Medicine (10, 11). This genus consists of 13 species. In western Africa, leaf powder was consumed as an antihelmintic. Pods and flowers are also reported to be used as antihelmintic. Zeatin in *Moringa* enhances cultivated crop growth and yield (12).

### Leaf

The historical records show that *Moringa* leaf and pods were used in the diet of Indians, people of Greek (commonly known as Hellenistic), and Egyptians for thousands of years for skin care and to improve their mental ability. Leaf decoction was used by the ancient Martian warriors to relieve the pain and stress suffered from the war. Leaf decoction boosts the energy level of the warriors (12, 13). Stress reducer used as an ointment in open wounds, rubbed in the temple for migraines, used to control blood glucose, used to reduce inflammation of glandular fluids, for piles, typhoid fever, chest infection, asthma, sore throat, anemia, type 2 diabetes, skin infections, headaches, cholera, cough, respiratory disorders, cholera, scurvy, eye and ear infections and boost immune system (14–16). The leaf extract was also reported to manage the thyroid and level of cholesterol (17). Alteration of monoamine levels and electrical activity in the brain is known to be induced by *Moringa* leaf extracts to protect against Alzheimer's disease (18). In India, *Moringa* leaves have been used as an anti-diabetic, diuretic, reducing anxiety, diarrhea, colitis, and gonorrhoea (19, 20). Fresh young leaves are used to treat skin infections in India, Nicaragua, and Guatemala. *Moringa* leaf powder is known for its analgesic effect and is one of

the ingredients in the Ayurvedic pain relief oil, namely "Murivenna" and stem bark is also one of the essential ingredients used in Kottamchukkadi Thailam" (19).

### Flower

*Moringa* flower has high medicinal value as a painkiller, diuretic, and anticarcinogenic and is used to heal swelling and muscular diseases, cysts, and spleen expansion (10, 11); reduces cholesterol level, lipids, lipoprotein, and atherosclerosis index (21). Flower treats intestinal worms, hysteria, muscle disease, and inflammation (19). In India, flowers are cooked or fried and consumed as vegetables, and in Bangladesh, flowers are used to make curry with green peas and potatoes. In Africa, it is consumed as a vegetable or used to make infusions (22).

### Fruit pods and seeds

Fruit pods are used to reduce joint pain and enhance liver function. Anti-hypertensive compounds have been isolated from the slender pods (23). The boiled pods are consumed without any deficit of nutritional content (24). After baking the seeds of certain *Moringa* varieties, humans taste them as peanuts (25). Seeds are also used to treat ailments like scurvy, fever, tumors, warts, prostrate, and problems in the urinary bladder. Seeds also are used as laxatives. Powders from seeds act as natural coagulants and are used to purify water. Cationic protein derived from *M. oleifera* Lam. seeds is helpful in water purification because it has coagulant properties. Natural water resources are quickly poisoned by inappropriate waste treatment from manufacturing sites. Therefore, eco-friendly waste treatment methods have been implemented using *Moringa oleifera* seeds as abatement agents for water treatment. Seed is known to treat hyperthyroidism, gout, and rheumatism. Many people in China and Taiwan use *Moringa* seeds to treat tinea and athlete's feet. In mammals, visual signals are conducted by retinal ganglion cells from the eye to the brain. Glutamate is known to cause DNA damage and causes neurological and retinal disorders. Retinol ganglion cells were treated for 2 hours with *Moringa* seed extract and did not show DNA damage. In contrast, glutamate-treated retinol ganglion cells showed a significant dose-dependent increase in DNA integrity (26).

### Seed oil

Seed oil is edible and was used to maintain skin health and in perfume preparation by the ancient Greek, Roman, and Egyptian civilizations (27, 28). Seed oil is also used in cosmetic goods, and the value of *Moringa* oil is phenomenal. It is also used to care for hair and body. *Moringa* oil has been used in skin preparations and lotions (15, 29). It has nutritional and moisturizing properties, which makes it a better massage oil because of the presence of palmitoleic, linoleic, and unsaturated fatty acids. The oils are known for accumulating and conserving volatiles and are valuable for the perfume industry. The oil is glossy yellow. It has a low tendency to degrade, become stinky and oily, and is used as a lubricating oil for high-end machinery like reloaders (25, 30). Seed oil is extracted by the people of Romans, Greeks, and Egyptians for making perfume and skin lotion and also to prepare lubricants for

machinery. The seed oil contains tocopherols, identical to olive oil in chemical and physical properties (29), and is pleasant to taste and highly edible. It also has behenic acid (C22:0), lignoceric acid (C24:0), and traces of lauric acids (31). This product also contains behenic acid (C22:0). Seed oil enhances wound healing (32).

### Stem Bark

The stem bark treats eye problems and hysterical patients and protects against spleen widening and neck tuberculosis formation, tumors, and healing ulcers. Stem bark juice is a pain reliever in the ears, relieves sinus headaches, and has antifungal properties (33). Stem bark reduces stomach problems, aids digestion, controls hypertension and joint pain, and treats anemia (19).

### Gums

*Moringa* gum is collected from the matured shoots. It is mixed with sesame oil to get rid of headaches, cough, gastrointestinal issues, cholera, breathing problems, and sometimes birth control, as well as treat leprosy (33). In India, gum is used to reduce headache pain and treat gastroenteritis. Gum is also used to treat fever, asthma, dental caries, dysentery, rheumatism, and syphilis (4).

### Root

A cardiopulmonary tonic, used as a muscle relaxant, abortive, treating rheumatism, vertebral pains, pain in the lower back or the kidney and diarrhea, carminative, anti-inflammatory, stimulant to paralysis (34). In India, the roots are used as laxatives to treat edema or swelling of the feet, hiccups, toothache, earache, asthma, gout, rheumatism, liver diseases, kidney stones, and spleen diseases (4, 8). The root bark treats skin diseases, scurvy,

and digestive disorders and prevents snake venom from spreading in the bloodstream. The root bark has also been used to reduce upper respiratory tract infection and as an aborticide (8).

### Mineral contents and nutritional properties of *M. oleifera* Lam.

*Moringa* is used as traditional medicine in over 80 countries to eliminate mineral nutritional deficiencies and treat common ailments like osteoporosis. Phytochemical analyses of this plant showed the presence of simple sugars and other distinct bioactive compounds such as isothiocyanates and glucosinolates (24, 35). A large amount of vitamins A, C, E, B2, B3, B6, B9, C, D, E, and K and proteins, especially amino acids viz. cysteine, tryptophan, lysine, and methionine along with minerals like iron, calcium, phosphorus and copper content signifies the nutritional value as an ideal dietary supplement in *Moringa* leaves (36, 37). Major elements present in this plant are Ca, Cu, Fe, K, Mn, Mg, and Zn (38–41). Essential amino acids present in *Moringa* leaves (42) are known to prevent aging disorders. Leaves are rich sources of minerals, particularly iron and potassium, and vitamins used to improve milk production in nursing mothers; they also act as an anticancer, anti-diabetic, and antimicrobial agent and are known to fight malnutrition because of their nutritional properties (43, 44).

### Phytochemical composition and pharmacological potential of *M. oleifera* Lam.

In modern times, drugs are derived from ancestral knowledge, and phytochemical compounds are the treasures of active pharmaceuticals (45). *Moringa* is also

**Table 1.** Phytochemicals of *M. oleifera* Lam. and their pharmacological activities Provide

Plant parts	Phytochemicals	Recommendation	Reference
Leaves	<i>Moringa</i> leaves contain phenolic of 120 mg/g such as gallic acid equivalent, total flavonoid, flavonol (40.5 and 12.25 mg/g respectively in terms of Quercetin equivalent), Ferric reducing antioxidant power, palmitoyl chloride, tetratadecanoic acid octadecanoic acid, gamma sitosterol, <i>cis</i> -vaccenic acid, cetene	Diabetes, Quercetin is known for anticancer	(53)
	$\alpha$ -tocopherol and $\gamma$ -tocopherol	Antioxidant	(54)
	Thiocarbamate	Antimicrobial activity	(55)
Seeds	<i>Moringa</i> seeds contain about 76% polyunsaturated fatty acids (linoleic acid, linolenic acid, oleic acids, pterigospermin, flavonoids, saponin, tannins, and triterpenoids)	Showed antimicrobial properties	(56)
	Coumarins, cardiac glycosides	analgesic	(57)
	Moringines (alkaloids)	anti-inflammatory	(58)
	alkaloids	Seed extracts cure neurogenerative disorders	(26)
Flowers	Pterigospermin, phenolics, and lectins,	antipyretic	(59)
	Proteinaceous compound	Inhibit larval trypsin of <i>Aedes aegypti</i> ; anti-inflammatory	(60)
	Phenolics equivalent to gallic acid, flavonoids	Showed anti-proliferative against HCT-8 and MDA-MB-231 cancer cell lines	(61)
Stem Barks	Flavonoids	antioxidant activity	(62)
	Alkaloids, diterpenoids, triterpenoids, flavonoids, cardiac glycosides, alkaloids, tannins, saponins, and cardiac glycosides were found to be present in pod husks	Antimicrobial potential against Gram-negative bacteria such as <i>K. pneumonia</i> 1, <i>S. typhimurium</i> 1, and <i>P. aeruginosa</i>	(52)
Roots	Gallic tannins, alkaloids	Antifertility,	(63)
	anthraquinones, reducing sugars, catechol tannins	nontoxic in a single dose in Swiss albino mice	(64)

known for its medicinal benefits, which include asthma, digestion disorders, inflammation, headaches, fevers, and rheumatism. Kaempferol-3-glucoside is reportedly extracted from polar solvent leaf extracts and chlorogenic acid in nonpolar extract (46, 47). It was reported that leaves have the highest total phenolic contents (48). Phenolic profiling of different *Moringa* extracts showed 63 phenolic acids, mostly hydroxyl cinnamic, flavones, flavonols, anthocyanins, lignans, tyrosols, alkali phenols, and five stilbenes (49, 50). Significant enzyme-inhibiting activity of *M. oleifera* Lam. leaves has also been shown and is a new horizon for pharmaceutical and food industries (51). Alkaloids, diterpenoids, triterpenoids, flavonoids, alkaloids, tannins, saponins, and cardiac glycosides were present in pod husks (52). Different phytochemicals in *M. oleifera* Lam. and their pharmacological activities are depicted in Table 1.

### Antimicrobial activity

*M. oleifera* Lam. has been reported for antimicrobial and antioxidant activity due to different bioactive secondary metabolites, viz. flavonoids, carotenoids, phenolics, and high amounts of ascorbic acid. Proteins, peptides, phenolics, and flavonoids derived from the leaves have been reported to possess antifungal and antimicrobial properties (65, 66). The impact of drumstick leaf extract at different concentrations on cooked ground buffalo meat has been reported to extend the shelf life of meat products significantly based on thiobarbituric acid content (TBA) over control instead of adding the artificial additives to increase the storage period (67, 68, 69). The antimicrobial activity of all parts of *Moringa oleifera* Lam. was investigated (70).

### Antibacterial activity

Leaves, fruits, and seeds extracted in different solvents, i.e., water, ethanol, ethyl acetate, and methanol, have shown anti-microbial activity against *Pseudomonas aeruginosa* (71, 72). Antibacterial activity was demonstrated because of flavorings, particularly myricetin and quercetin, which inhibit nucleic acid synthesis in bacteria (73, 74). Aqueous and ethanolic leaf extracts of *M. oleifera* Lam. showed activity against the bacterial species. *Escherichia coli*, *Bacillus subtilis*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *S. epidermidis*, *Streptococcus mutans* and *Proteus vulgaris*. Water, ethanol, ethyl acetate, chloroform, and methanol extracts of *Moringa* showed antibacterial activity against some Gram-positive and negative bacteria. Methanolic leaf extract and methanol: water in equal (v/v) proportion revealed antibacterial activity against *B. cereus* and *Listeria innocua* (75).

### Antifungal activity

*Moringa* aqueous leaf extract is reported to be used for inhibiting a few fungal species viz., *Aspergillus niger*, *A. italicum*, *A. flavus*, *Candida albicans*, *C. glabrata* and *C. tropicalis*, *Fusarium* species and *Rhizoctonia stolonifera* (76). *Moringa* pod husks are effective against *Candida albicans*. It was also reported that *Moringa* acetone extracts from winter-collected leaves showed higher antifungal activity against *C. candida* than summer-season

leaf extracts, possibly due to higher phenol content in that season (77). It was reported that the activity of aqueous *Moringa* leaf extracts against *Penicillium spp.* and ethanol extract against *C. albicans*, *Penicillium spp.*, and *Mucor*. Fungal mycelia growth decreased with an increase in the *Moringa* root extract concentrations, and root extract showed complete antifungal activity against *Fusarium oxysporum*, *F. solani*, *Alternaria alternata*, *A. solani*, *Rhizoctonia solani*, *Sclerotium rolfsii* and *Macrophomina phaseolina* (78).

### Antidiabetic effect

Antidiabetic properties of *Moringa* have been reported in many studies (79, 80). *Moringa* is used to manage diabetes (type 1 and type 2). Diabetes is a metabolic disorder marked by high glucose levels in the blood. Insulin is not produced in Type 1 diabetic patients, while Type 2 diabetes is generally due to the dysfunction of the Beta cells of the pancreas, which does not recognize the glucose level in the blood, resulting in high blood glucose levels (81). It was also reported that fasting blood sugar dropped in streptozotocin-induced diabetic rats when nourished with *Moringa* seed powder 70. Oral administration of *Moringa* aqueous leaf extract in albino rats reduced blood sugar levels by 26.7 percent in fasting and 30 percent lower in glucose tolerance after 3 hours of glucose consumption. Administration for continuous 21 days showed a 69.2 percent reduction in fasting blood glucose level and 51.2 percent in postprandial blood glucose level (82, 83).

In type 2 diabetes,  $\beta$  cells get disrupted, resulting in glucose entry into mitochondria, releasing the reactive oxygen species (ROS) and causing apoptosis of  $\beta$  cells. This, in turn, results in hyperglycemia by reducing insulin secretion, causing type 2 diabetes. The antioxidants like flavonoids present in *Moringa* can be responsible for decreasing the ROS in the mitochondria of  $\beta$  cells, preventing cell damage, and keeping diabetes under control. High glucose in the blood enters the  $\beta$  cells for glycolysis and forms ROS, resulting in apoptosis of  $\beta$  cells, leading to reduced insulin secretion and thereby resulting in hyperglycemia and Type 2 diabetes (Fig. 1). Cell apoptosis is ceased by the antioxidants present in *Moringa* that react with ROS preventing cell damage *Moringa* was also reported to treat insulin-dependent diabetes (84). *In silico* molecular docking of 5 bio-molecular phytochemicals of *Moringa* showed to target diabetes mellitus mutated protein (85).

### Analgesic activity

A study on the anti-inflammatory and anti-hyperalgesic properties of *Moringa* leaf extract was carried out using various experimental models in rats (46). Non-polar to polar leaf extracts at different doses from 30 100 mg/kg showed a significant lowering in the inflammatory response in formalin test-induced nociception, edema in paw induced by carrageenan, and subcutaneous injection of collagen-induced arthritis in experimental rat models. Extracts from flowers, roots, and seeds have already been reported for anti-inflammatory properties (86-88). *M.*

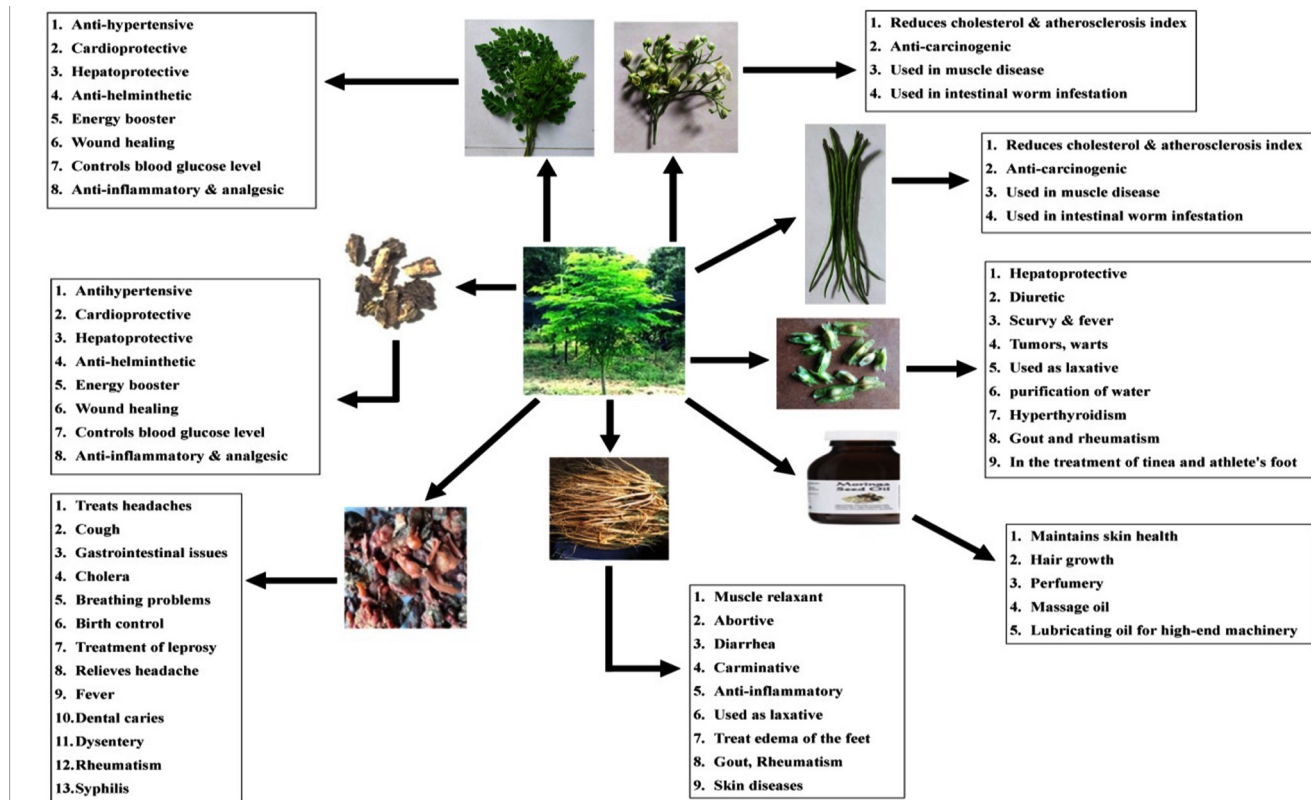


Fig. 1. Medicinal properties of different parts of *Moringa oleifera* Lam.

*oleifera* Lam. has potential analgesic and anti-inflammatory activities like antirheumatic, anti-arthritis, and anti-migraine (89-90). Leaf extracts also exhibited analgesic potency similar to indomethacin (91). The molecular mechanism for anti-inflammatory activity may be assigned to the regulation of neutrophils and the c-Jun N-terminal kinase pathway. The active anti-inflammatory ingredients are phenols, tannins, alkaloids, carotenoids, vanillin, moringine, flavonoids,  $\beta$ -sitosterols, hydroxymellein,  $\beta$ -sitostenone and 9-octadecenoic acid (49). Bark extracts were also comparable with diclofenac in terms of their anti-inflammatory properties in the same model, and the root has also been reported for anti-inflammatory properties (62).

#### Molecular mechanisms associated with anti-inflammatory/analgesic activity

Cytokines are peptides important in the immune responses to infection, trauma, inflammation, and reproduction. Cytokines also regulate the growth and maturation of cell populations. Cytokines cannot enter the cell through the lipid bilayer of the cells but act through cell surface receptors. Chemokines, interleukins, interferons, lymphokines, and tumor necrosis factors are different types of cytokines that act as immune-modulating agents in autocrine, paracrine, and endocrine signaling. Cytokines are produced by immune cells such as B lymphocytes, T-lymphocytes, mast cells, and macrophages. They are also produced by fibroblasts, endothelial cells, and different stromal cells. Interleukins (ILs) are a group of cytokines important in cell signaling. Interleukins play a major role in immune system function, and unusual deficiencies of a number of them have been identified, many of which are associated with autoimmune

disorders (92). Helper CD4 T lymphocytes, including monocytes, macrophages, and endothelial cells, produce the majority of interleukins. They assist the growth and differentiation of B and T lymphocytes and hematopoietic cells. Interleukin 1 is responsible for producing inflammation, fever, and sepsis. The inflammation process is interrupted by an Interleukin 1  $\alpha$  (IL-1 $\alpha$ ) inhibitor. IL-1 $\alpha$  is called hematopoietin 1 of the interleukin 1 family and is expressed by the IL 1A gene. IL-1 $\alpha$  inhibitors are being developed to treat the diseases. Activated macrophages, epithelial cells, neutrophils, and endothelial cells produce IL-1 $\alpha$ . IL-1 $\alpha$  plays an important role in regulating the immune responses. IL-1 $\alpha$  binds to the Interleukin 1 receptor and activates tumour necrosis factor- $\alpha$ . Major anti-inflammatory cytokines include IL-1 receptor antagonist, IL-4, IL-6, IL-10, IL-11 and IL-13. Additionally, tumour necrosis factor- $\alpha$  and IL-18 also function as pro-inflammatory cytokine inhibitors. Amongst these, interleukin 10 (IL-10), known as human cytokine synthesis inhibitory factor (CSIF), is an anti-inflammatory cytokine that is encoded by the IL 10 gene. IL-10 blocks the expression of pro-inflammatory genes, which encode cytokines, cell surface molecules, chemokines, and other molecules responsible for the multiplication of inflammation and has attracted the researcher as a tool to regulate inflammatory diseases. Two IL-10 receptors and two IL-10 receptor-2 proteins form a receptor complex that transmits IL-10 signals. *Moringa* has been shown to have a nephroprotective effect in heavy metals exposure, reducing oxidative stress and inflammation in renal tissue (93). The production and expression of NO, prostaglandin E2 (PGE2), interleukin-6 (IL-6) IL-1, tumour necrosis factor- $\alpha$  (TNF- $\alpha$ ), nuclear factor-kappa B (NF-B), inducible NO synthase (iNOS), and cyclooxygenase-2 (COX-2) were

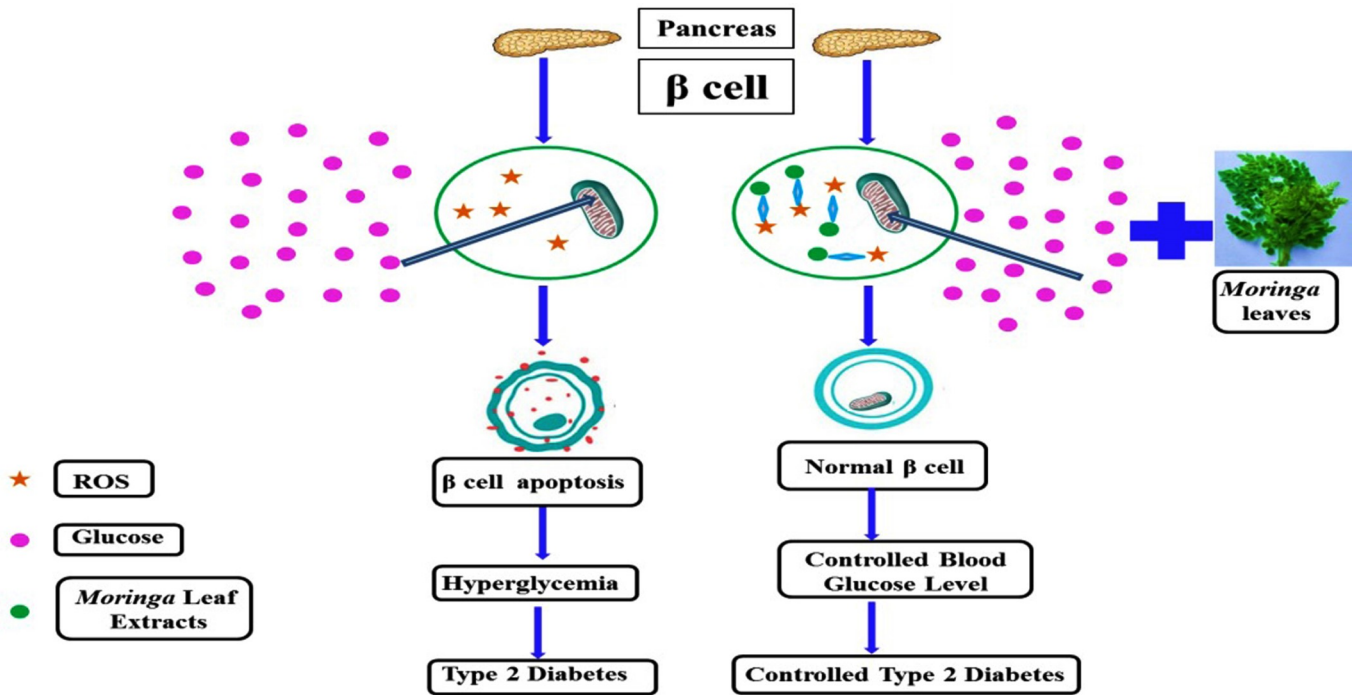


Fig. 2. Mechanism associated with high glucose level in hyperglycemia and impact of *Moringa* leaves on controlling Type 2 diabetes

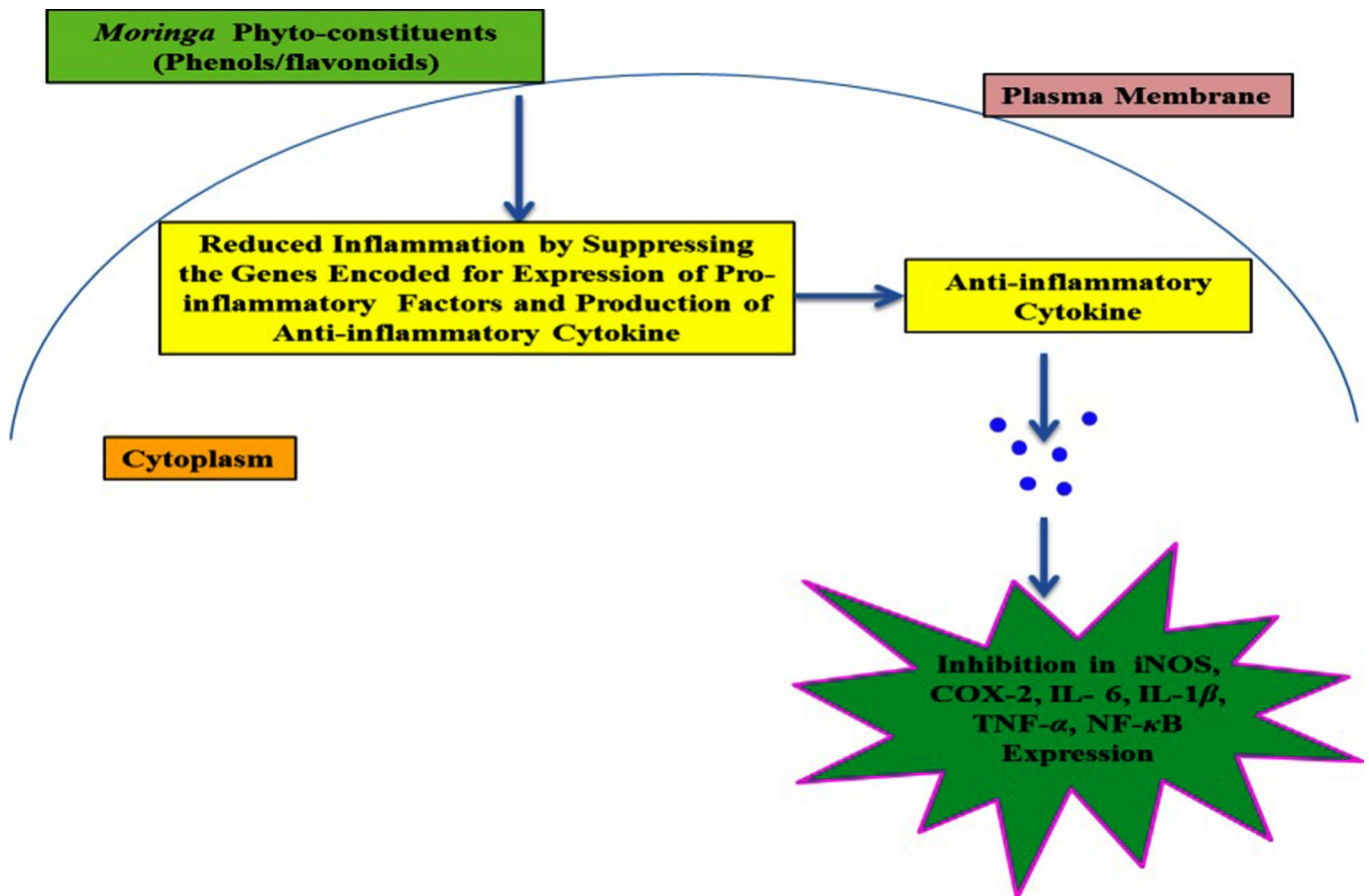


Fig. 3. Anti-inflammatory activity of *Moringa* phytochemicals

considerably reduced by a hydroethanolic extract of *M. oleifera* flower (Fig. 2). Anti-inflammatory properties of *Moringa* extracts have also been studied against lead acetate (PbAc) induced renal impairments in rats (94). Renal inflammation was triggered by PbAc due to overproduced and upregulated pro-inflammatory cytokines such as tumor necrosis factor-alpha (TNF $\alpha$ ) and IL1 $\beta$ . Administration of *Moringa* extract exerted anti-

inflammatory activity in the renal tissue deciphered by decreased levels of TNF $\alpha$ , IL1 $\beta$ , and NF- $\kappa$ B (93).

### Conclusion

*M. oleifera* Lam. tree has been shown to possess tremendous medicinal value because of various phytochemicals. Further studies are needed to explore the underlying mechanisms of these bioactive phytochemical

constituents in considering *Moringa* as a dietary supplement for preventing and managing other deadly diseases. Besides these, *M. oleifera* Lam. leaves are also used in making bakery products such as cookies, snacks, bread, and rice crackers. In contrast, seed flour is used in making bread to enhance its nutritional value and also as a dietary supplement because of its significant amount of iron, calcium, and protein. Further work is also needed to implement *Moringa* in water management in purifying water as animal feeds, compost production, biofuel production, preparation of beauty products, cosmetics, soil conservation, and greenhouse gas emissions reductions. *Moringa* can also be used in synthesizing nanoparticles (NPs) for the effective use of NPs in drug delivery, promising antimicrobial activity.

## Acknowledgements

We appreciate the permission to conduct the study and the support provided by Centurion University of Technology and Management, Odisha, India.

## Authors' contributions

CST did data collection, manuscript preparation, and formatting, AM helped in data collection and writing, SKB conceptualized the work, SP designed the work, manuscript writing, correction, and analysis. All authors read and approved the final manuscript.

## Compliance with ethical standards

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

**Ethical issues:** None.

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