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Holistic Review on Shigru (Moringa Oleifera Lam.) With Special Reference to Its Nutritional and Therapeutic Dimensions

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ABSTRACT: Moringa oleifera Lam., commonly known as Shigru, is an important medicinal and nutritional plant with a long history of traditional use and increasing scientific interest. The plant is valued for its nutritional richness and diverse phytochemical constituents, including flavonoids, phenolic compounds, glucosinolates, isothiocyanates, vitamins, minerals, and other bioactive compounds. These constituents may contribute to a broad spectrum of biological activities.

The present holistic review integrates the traditional Ayurvedic perspective with contemporary evidence concerning the nutritional, phytochemical, pharmacological, and therapeutic dimensions of M. oleifera. Available experimental and clinical literature indicates antioxidant, anti-inflammatory, antidiabetic, hepatoprotective, cardioprotective, antimicrobial, immunomodulatory, and neuroprotective potential. These effects have been associated with modulation of oxidative stress, inflammatory pathways, glucose and lipid metabolism, and cellular protective mechanisms. The nutritional profile of Shigru also supports its potential application as a functional food and nutraceutical resource.

However, the strength of evidence varies among therapeutic areas, and a substantial proportion of the available evidence remains preclinical. Limitations related to variation in plant material, extraction methods, phytochemical standardization, dosage, bioavailability, and limited well-designed human clinical trials restrict definitive therapeutic conclusions. Therefore, further standardized clinical investigations are required to establish appropriate dosage, formulation, efficacy, safety, and long-term use.

Overall, Moringa oleifera represents a promising bridge between Ayurvedic knowledge, nutrition science, and modern pharmacology. An integrated evidence-based approach may facilitate the development of safe, standardized, and scientifically validated applications of Shigru in preventive and supportive healthcare.

1. INTRODUCTION

Moringa oleifera Lam., commonly known as Shigru, is a multipurpose plant belonging to the family Moringaceae and is widely recognized for its nutritional, traditional medicinal, and pharmacological importance. It is native to the Indian subcontinent and is now cultivated extensively in tropical and subtropical regions. Different parts of the plant, including leaves, pods, seeds, flowers, bark, and roots, have traditionally been used both as food and for various health-related purposes (Anwar et al., 2007; Leone et al., 2015).

The nutritional importance of *M. oleifera* is primarily associated with its leaves, which contain proteins, essential amino acids, vitamins, minerals, dietary fibre, and various bioactive compounds. This nutritional profile has generated considerable interest in the plant as a potential functional food and nutraceutical resource. The nutritional composition, however, may vary according to geographical origin, cultivation conditions, plant maturity, processing, and the part of the plant examined (Gopalakrishnan et al., 2016; Moyo et al., 2011).

Phytochemical investigations have identified several important classes of constituents in *M. oleifera*, including flavonoids, phenolic compounds, glucosinolates, isothiocyanates, alkaloids, tannins, saponins, terpenoids, and phenolic acids. These constituents are considered important contributors to the biological activities reported for different plant parts. Differences in phytochemical composition may occur according to plant part, extraction procedure, geographical location, and processing conditions (Saini et al., 2016; Leone et al., 2015).

Experimental research has reported a broad range of pharmacological activities associated with *M. oleifera*. These include antioxidant, anti-inflammatory, antidiabetic, hepatoprotective, cardioprotective, antimicrobial, immunomodulatory, and neuroprotective effects. Antioxidant and anti-inflammatory activities are of particular interest because oxidative stress and chronic inflammation are involved in the pathogenesis of several metabolic and chronic disorders (Vergara-Jimenez et al., 2017; Waterman et al., 2014).

Evidence concerning metabolic effects has also increased. Experimental studies have demonstrated glucose-lowering and related metabolic effects of *M. oleifera*, while limited human investigations have explored its potential role in glycaemic control. Nevertheless, the available clinical evidence remains insufficient to establish *M. oleifera* as a replacement for established medical treatment, highlighting the need for further well-designed clinical studies (Jaiswal et al., 2009; Mbikay, 2012).

Similarly, hepatoprotective and cellular antioxidant effects have been demonstrated in experimental models. These findings suggest that bioactive constituents of *M. oleifera* may contribute to protection against oxidative and chemical injury; however, translation of such preclinical findings into established clinical applications requires further investigation (Hamza, 2010; Sreelatha & Padma, 2011).

The growing scientific literature on Shigru therefore provides an opportunity to examine its traditional use alongside contemporary nutritional and pharmacological evidence. Comprehensive reviews have highlighted the diversity of its phytoconstituents and biological activities while also emphasizing limitations related to standardization, dosage, bioavailability, toxicity assessment, and the limited number of high-quality human clinical trials (Stohs & Hartman, 2015; Pareek et al., 2023).

Therefore, the present holistic review aims to integrate the Ayurvedic perspective, phytochemical profile, nutritional composition, pharmacological and therapeutic activities, mechanisms of action, clinical evidence, safety considerations, and existing research gaps related to *Moringa oleifera* (Shigru). Such an integrated approach may help bridge traditional Ayurvedic knowledge with contemporary scientific evidence and support the future development of standardized, safe, and evidence-based nutritional and therapeutic applications of Shigru.

2. AYURVEDIC PERSPECTIVE OF SHIGRU

Shigru is described in the Ayurvedic materia medica as an important medicinal plant and is traditionally associated with properties relevant to digestive, inflammatory, metabolic, and other systemic disorders. Classical Ayurvedic literature describes the plant through its rasa, guna, virya, vipaka, and karma, providing a conceptual framework for understanding its therapeutic applications. The Ayurvedic description of Shigru should therefore be considered alongside contemporary pharmacological evidence rather than interpreted as a direct equivalent of modern biomedical mechanisms.

In the Ayurvedic tradition, the therapeutic significance of Shigru is related particularly to its tikshna, laghu, and ruksha attributes and its reported actions on Kapha and Vata disorders. Its traditional applications include conditions involving impaired digestion, inflammation, pain, swelling, and metabolic disturbances. These descriptions provide an important foundation for understanding the historical use of the plant and for developing research questions that can subsequently be evaluated using contemporary scientific methods.

The classical description of medicinal plants in Ayurveda is based on a holistic understanding of the interaction between dosha, agni, dhatu, srotas, and disease processes. Consequently, the therapeutic interpretation of Shigru should not be restricted to a single pharmacological action. Its traditional use can instead be viewed as a multidimensional framework involving digestion, metabolism, inflammation, tissue nourishment, and systemic balance.

Modern phytochemical research provides a possible scientific context for several of these traditional applications. Flavonoids, phenolic compounds, glucosinolates, isothiocyanates, and other constituents identified in *M. oleifera* have demonstrated antioxidant and anti-inflammatory activities in experimental studies (Leone et al., 2015; Saini et al., 2016; Vergara-Jimenez et al., 2017). However, such associations should be interpreted cautiously because the presence of a particular phytochemical does not by itself establish clinical efficacy.

The traditional and contemporary perspectives therefore complement each other. Ayurvedic literature provides historical knowledge regarding the identification, properties, and therapeutic applications of Shigru, whereas modern research provides experimental approaches for investigating its phytochemistry, biological mechanisms, efficacy, and safety. Integrating these perspectives may help generate scientifically testable hypotheses while preserving the traditional context of the plant.

Importantly, traditional use should not be regarded as equivalent to established clinical efficacy. Contemporary evidence remains heterogeneous, and many reported pharmacological activities are supported predominantly by in-vitro or animal studies. Recent reviews of *M. oleifera* have similarly emphasized the need for standardized preparations, better characterization of active constituents, appropriate dose determination, and adequately designed human studies before definitive therapeutic recommendations can be made (Pareek et al., 2023; Worku & Tolossa, 2024).

3. PHYTOCHEMICAL PROFILE

3.1 Major Phytochemical Classes

Moringa oleifera possesses a chemically diverse profile comprising primary nutrients as well as secondary metabolites. Phytochemical investigations have identified flavonoids, phenolic acids, glucosinolates, isothiocyanates, alkaloids, tannins, saponins, terpenoids, sterols, carotenoids, and other phenolic constituents in different parts of the plant. The qualitative and quantitative distribution of these compounds varies according to plant part, geographical origin, cultivar, maturity, harvesting conditions, and extraction procedure (Saini et al., 2016; Liu et al., 2022).

Among these constituents, flavonoids and phenolic compounds are particularly important because of their reported antioxidant and free-radical-scavenging properties. Compounds such as quercetin and kaempferol derivatives, together with several phenolic acids, have been identified in *M. oleifera* leaves. Their presence is considered one of the contributors to the antioxidant potential of the plant (Saini et al., 2016; Hassan et al., 2021).

Another characteristic group is the glucosinolate–isothiocyanate system. *M. oleifera* contains distinctive glucosinolates, including glucomoringin, which can give rise to corresponding isothiocyanate derivatives. These compounds have attracted considerable interest because of their biological activities and potential relevance to oxidative stress, inflammation, cellular defence, and chronic disease mechanisms (López-Rodríguez et al., 2020).

The plant also contains alkaloids, saponins, tannins, terpenoids, carotenoids, sterols, and other secondary metabolites. These compounds may act individually or synergistically with phenolic constituents and glucosinolate-derived compounds, potentially contributing to the broad biological activity reported for different *Moringa* preparations (Bhattacharya et al., 2018; Camilleri & Blundell, 2024).

3.2 Bioactive Compounds

Several individual compounds and compound classes have been investigated for their biological relevance. Quercetin and kaempferol derivatives are among the frequently reported flavonoids, whereas phenolic acids contribute to the overall phenolic profile. Glucomoringin and its isothiocyanate derivatives are particularly characteristic of *M. oleifera* and have received increasing attention in mechanistic research (Saini et al., 2016; Maldini et al., 2014).

Analytical studies using chromatographic and mass-spectrometric techniques have demonstrated the chemical complexity of *Moringa* leaves and confirmed the coexistence of phenolic compounds and glucosinolates. Such analytical characterization is important because biological activity can vary substantially depending on the chemical composition of the extract being investigated (Maldini et al., 2014).

The biological importance of these compounds is not limited to antioxidant activity. Experimental literature suggests that *Moringa* phytochemicals may influence inflammatory signalling, cellular antioxidant defence, glucose metabolism, lipid metabolism, and other physiological pathways. However, these effects should be interpreted according to the specific compound, dose, extract, experimental model, and route of administration rather than assuming that all *Moringa* preparations have equivalent biological effects (Liu et al., 2022; Camilleri & Blundell, 2024).

3.3 Molecular Mechanisms

The therapeutic relevance of *Moringa* phytochemicals is increasingly being investigated at the molecular level. Phenolic compounds and flavonoids may contribute to antioxidant defence by reducing reactive oxygen species and influencing endogenous antioxidant systems. Inflammatory responses may also be modulated through effects on signalling pathways involved in cytokine production and transcriptional regulation (Vergara-Jimenez et al., 2017; Camilleri & Blundell, 2024).

Glucosinolate-derived isothiocyanates represent another mechanistically important group. Experimental evidence indicates that these compounds can influence cellular defence mechanisms, including pathways involved in antioxidant and detoxification responses. Their potential biological effects have been studied in relation to inflammation, metabolic disorders, and other chronic disease processes (López-Rodríguez et al., 2020).

Importantly, molecular mechanisms reported for *M. oleifera* should not be interpreted as proof of clinical efficacy. Much of the mechanistic literature is derived from cell culture and animal models, and the extent to which individual phytochemicals reach biologically relevant concentrations in humans remains an important research question (Liu et al., 2022).

3.4 Therapeutic Relevance

The phytochemical diversity of *M. oleifera* provides a plausible biochemical basis for its reported antioxidant, anti-inflammatory, antidiabetic, hepatoprotective, cardioprotective, antimicrobial, and neuroprotective activities. Reviews of the plant consistently identify phenolic compounds, flavonoids, glucosinolates, and isothiocyanates as important contributors to these effects (Saini et al., 2016; Hassan et al., 2021; Camilleri & Blundell, 2024).

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4. NUTRITIONAL COMPOSITION OF *MORINGA OLEIFERA*

Moringa oleifera is considered a nutritionally valuable plant because its leaves contain a combination of proteins, carbohydrates, dietary fibre, lipids, vitamins, minerals, amino acids, and bioactive phytochemicals. Among the different plant parts, the leaves are particularly important because of their relatively high nutritional density and their traditional use as a food ingredient (Moyo et al., 2011; Gopalakrishnan et al., 2016).

4.1 Macronutrients

Moringa leaves contain appreciable amounts of protein and provide several essential and non-essential amino acids. The reported protein content varies according to geographical origin, cultivar, maturity, environmental conditions, and analytical method. Therefore, nutritional values reported for *Moringa* should be interpreted as approximate values rather than fixed concentrations (Moyo et al., 2011; Gopalakrishnan et al., 2016).

The leaves also contain carbohydrates and dietary fibre, while the lipid content is comparatively lower than the protein and carbohydrate fractions. Dietary fibre may contribute to the nutritional and functional-food value of *Moringa*, particularly in relation to gastrointestinal and metabolic health (Moyo et al., 2011; Leone et al., 2015).

Moringa seeds differ from leaves in their nutritional composition and contain appreciable amounts of protein and lipid. Moringa seed oil is particularly rich in unsaturated fatty acids and has been investigated for nutritional and functional applications (Anwar et al., 2007; Leone et al., 2015).

4.2 Vitamins

Moringa leaves contain several vitamins and provitamin compounds, including provitamin A carotenoids, vitamin C and vitamin E, together with several B-group vitamins. These micronutrients contribute to normal physiological functions and antioxidant defence. However, vitamin concentrations can vary substantially according to cultivation conditions, maturity, harvesting, storage, and processing (Gopalakrishnan et al., 2016; Saini et al., 2016).

The presence of carotenoids and other antioxidant-associated compounds further contributes to the nutritional interest of *Moringa* leaves. Nevertheless, the nutritional contribution of these compounds depends not only on their concentration in the plant but also on their stability and bioavailability following processing and consumption (Saini et al., 2016).

4.3 Minerals

M. oleifera leaves provide several essential minerals, including calcium, potassium, magnesium, phosphorus, iron, zinc, copper, and manganese. These minerals participate in diverse physiological processes, including bone metabolism, oxygen transport, electrolyte balance, enzymatic reactions, and cellular function (Moyo et al., 2011; Gopalakrishnan et al., 2016).

The mineral profile may vary according to soil composition, geographical location, plant maturity, and environmental conditions. Consequently, *Moringa* should be considered a potential dietary source of minerals rather than a standardized source with identical mineral concentrations across all preparations (Leone et al., 2015).

4.4 Amino Acids and Other Nutritionally Relevant Constituents

Moringa leaves contain a broad spectrum of amino acids, including essential amino acids, which contributes to their nutritional quality. The combination of plant protein, amino acids, fibre, vitamins, and minerals makes *Moringa* leaf material attractive for use in food supplementation and fortification strategies (Moyo et al., 2011; Gopalakrishnan et al., 2016).

In addition to nutrients, *Moringa* contains flavonoids, phenolic compounds, glucosinolates, isothiocyanates, and other phytochemicals. These compounds are not conventional nutrients but are important contributors to the plant's functional and nutraceutical potential (Saini et al., 2016; Vergara-Jimenez et al., 2017).

4.5 Nutritional and Functional-Food Relevance

The combination of macronutrients, micronutrients, dietary fibre, and bioactive phytochemicals supports the classification of *M. oleifera* as a potentially useful functional-food and nutraceutical resource. *Moringa* leaf powder has therefore been investigated for incorporation into different food products and nutritional interventions, particularly in contexts where dietary diversification and micronutrient intake are important (Thurber & Fahey, 2009; Oyeyinka & Oyeyinka, 2018).

However, nutritional richness should not automatically be equated with therapeutic efficacy. The biological effect of a *Moringa* preparation depends on the plant part, preparation method, dose, bioavailability, processing conditions, and individual nutritional status. Further standardized studies are therefore required to determine the actual nutritional and functional benefits of different *Moringa* preparations (Stohs & Hartman, 2015; Liu et al., 2022).

4.6 Factors Affecting Nutritional Composition

The nutritional composition of *M. oleifera* is not constant. Geographical origin, soil conditions, climate, cultivar, plant maturity, harvesting stage, drying, storage, and processing methods can influence the concentration and stability of nutrients and phytochemicals (Leone et al., 2015; Saini et al., 2016).

5. PHARMACOLOGICAL AND THERAPEUTIC ACTIVITIES

Moringa oleifera has been investigated for a broad range of pharmacological activities, particularly in experimental and preclinical studies. These reported effects have been associated with its diverse phytochemical constituents, including phenolic compounds, flavonoids, glucosinolates, isothiocyanates, vitamins, minerals, and other bioactive molecules. However, the strength of evidence varies considerably among therapeutic areas, and many reported activities remain to be confirmed through well-designed human clinical studies (Leone et al., 2015; Saini et al., 2016; Vergara-Jimenez et al., 2017).

5.1 Antioxidant Activity

The antioxidant potential of M. oleifera has been attributed mainly to its phenolic and flavonoid constituents. These compounds may contribute to free-radical scavenging and modulation of endogenous antioxidant defence mechanisms. Experimental studies have demonstrated antioxidant activity in Moringa leaf extracts, although the magnitude of this activity varies according to plant part, extraction procedure, phytochemical composition, and experimental conditions (Siddhuraju & Becker, 2003; Sreelatha & Padma, 2011).

The antioxidant activity of Moringa may be relevant to its reported protective effects against oxidative cellular injury. Nevertheless, antioxidant activity demonstrated in chemical or experimental models cannot be directly equated with clinical antioxidant efficacy in humans.

5.2 Anti-inflammatory Activity

M. oleifera has demonstrated potential anti-inflammatory activity in experimental studies. Water-extractable isothiocyanates obtained from Moringa leaves have been reported to attenuate inflammatory responses in vitro, suggesting that these compounds may contribute to the anti-inflammatory properties of the plant (Waterman et al., 2014). Phenolic compounds and flavonoids may also participate in the regulation of oxidative and inflammatory processes (Vergara-Jimenez et al., 2017).

The interaction between oxidative stress and inflammation may partly explain the broad biological effects reported for Moringa. However, further clinical research is required to determine whether these experimentally observed effects translate into meaningful therapeutic benefits in humans.

5**.3 Antidiabetic Activity**

The antidiabetic potential of M. oleifera has been investigated in experimental models as well as in a limited number of human studies. Moringa leaf preparations have demonstrated glucose-lowering effects in experimental hyperglycaemic models, indicating possible effects on glucose metabolism (Jaiswal et al., 2009). A review of the available evidence has also suggested potential benefits in chronic hyperglycaemia and dyslipidaemia, although the evidence remains insufficient to support Moringa as a replacement for established antidiabetic therapy (Mbikay, 2012).

Human studies have produced variable findings. Some investigations have reported favourable effects on postprandial glucose or selected glycaemic parameters, whereas a randomized controlled trial in therapy-naïve patients with type 2 diabetes did not demonstrate significant improvement in glycemic control (Leone et al., 2018; Taweerutchana et al., 2017).

5.4 Hepatoprotective Activity

Hepatoprotective effects of M. oleifera have been reported mainly in experimental models of hepatic injury. Hamza (2010) reported that Moringa seed extract produced ameliorative effects against experimentally induced liver fibrosis in rats. Such effects may be associated with the antioxidant and anti-inflammatory properties of its bioactive constituents.

Although these findings provide a basis for further investigation, the available evidence remains predominantly preclinical. Well-designed human studies are required before hepatoprotective efficacy can be established clinically.

5.5 Cardioprotective Activity

The cardioprotective potential of M. oleifera has been investigated in relation to oxidative stress, inflammation, lipid metabolism, and other cardiovascular risk-associated processes. Its flavonoids, phenolic compounds, and other antioxidant constituents provide a plausible biochemical basis for potential cardiovascular protective effects (Leone et al., 2015; Vergara-Jimenez et al., 2017).

Experimental findings suggest that Moringa may influence metabolic and oxidative parameters associated with cardiovascular health. However, evidence from human clinical studies remains limited, and further research is required to establish its clinical relevance in cardiovascular disease prevention or management.

5.6 Antimicrobial Activity

Different extracts and preparations of M. oleifera have demonstrated antimicrobial activity against selected pathogenic microorganisms. Leaf juice and extracts have shown inhibitory effects against several human pathogenic bacteria, suggesting the presence of antimicrobial phytoconstituents (Rahman et al., 2009).

Phenolics, flavonoids, tannins, and other secondary metabolites may contribute to these effects. However, antimicrobial activity varies according to the plant part, extraction method, extract concentration, and microorganism tested. Therefore, experimental antimicrobial findings should not be directly interpreted as evidence for clinical antimicrobial efficacy (Saini et al., 2016).

5.7 Neuroprotective Activity

The neuroprotective potential of M. oleifera has received increasing scientific attention because oxidative stress and chronic inflammation are important contributors to neuronal injury. The antioxidant and anti-inflammatory properties of Moringa phytochemicals may contribute to cellular defence against oxidative and inflammatory damage (Vergara-Jimenez et al., 2017).

Recent reviews have highlighted experimental evidence suggesting possible neuroprotective effects of Moringa and its bioactive constituents. Nevertheless, the available evidence is predominantly preclinical, and well-controlled human studies are required to determine its potential relevance to neurological and cognitive health (Worku & Tolossa, 2024).

5.8 Immunomodulatory Activity

M. oleifera has also demonstrated potential immunomodulatory effects in experimental investigations. Its phytoconstituents may influence oxidative and inflammatory processes that are closely associated with immune responses. The observed effects, however, may vary according to plant part, preparation, dose, and experimental model (Leone et al., 2015; Vergara-Jimenez et al., 2017).

At present, the evidence is insufficient to define specific clinical applications of Moringa as an immunomodulatory agent. Further mechanistic studies and appropriately designed human trials are therefore necessary.

5.9 Overall Therapeutic Relevance

Taken together, the available literature indicates that M. oleifera possesses a diverse pharmacological profile encompassing antioxidant, anti-inflammatory, antidiabetic, hepatoprotective, cardioprotective, antimicrobial, neuroprotective, and immunomodulatory activities. These effects may arise from the combined actions of multiple phytoconstituents rather than from a single active compound or molecular pathway (Saini et al., 2016; Vergara-Jimenez et al., 2017).

6. MECHANISMS OF ACTION

The biological effects of *Moringa oleifera* are considered to result from the combined actions of several phytoconstituents rather than from a single compound or molecular pathway. Phenolic compounds, flavonoids, glucosinolates, isothiocyanates, vitamins, and other bioactive constituents may influence oxidative stress, inflammatory responses, metabolic processes, and cellular defence mechanisms. However, most mechanistic evidence has been generated from in-vitro and animal studies and should therefore be interpreted cautiously when considering human therapeutic applications (Saini et al., 2016; Vergara-Jimenez et al., 2017).

6.1 Modulation of Oxidative Stress

Oxidative stress occurs when the generation of reactive oxygen species exceeds the capacity of endogenous antioxidant defence systems. Phenolic compounds and flavonoids present in *M. oleifera* may contribute to the reduction of oxidative stress through free-radical scavenging and modulation of antioxidant defence mechanisms. Experimental studies have demonstrated antioxidant activity of Moringa extracts and reductions in oxidative damage in experimental models (Siddhuraju & Becker, 2003; Sreelatha & Padma, 2011).

The antioxidant activity of Moringa may therefore represent an important mechanism underlying some of its reported protective effects. However, antioxidant activity demonstrated through chemical assays or experimental models cannot automatically be interpreted as equivalent clinical efficacy in humans.

6.2 Regulation of Inflammatory Signalling

Inflammatory signalling represents another important mechanism proposed for the biological activity of *M. oleifera*. Glucosinolate-derived isothiocyanates and other phytoconstituents have demonstrated anti-inflammatory effects in experimental models. Water-extractable isothiocyanates from Moringa leaves have been reported to attenuate inflammatory responses in vitro, supporting a possible role for these compounds in the modulation of inflammatory processes (Waterman et al., 2014).

The close relationship between oxidative stress and inflammation may partly explain the broad biological activities reported for Moringa. Modulation of excessive inflammatory responses may contribute to its experimentally observed hepatoprotective, metabolic, cardiovascular, and neuroprotective effects (Vergara-Jimenez et al., 2017). Nevertheless, the relevance of these mechanisms to clinical outcomes requires further investigation.

6.3 Nrf2-Associated Cellular Defence

Nuclear factor erythroid 2-related factor 2 (Nrf2) is an important transcription factor involved in the regulation of endogenous antioxidant and cytoprotective responses. Experimental research on Moringa-derived phytochemicals, particularly isothiocyanate-related compounds, suggests that modulation of cellular antioxidant defence pathways may contribute to protection against oxidative and inflammatory injury.

Activation of antioxidant and detoxification mechanisms may provide a mechanistic link between the phytochemical composition of Moringa and its reported cytoprotective effects. However, the precise contribution of individual constituents and their biological relevance at physiologically achievable concentrations require further investigation (Liu et al., 2022).

6.4 Modulation of Metabolic Pathways

The reported antidiabetic and metabolic effects of *M. oleifera* are likely to involve multiple biological pathways rather than a single mechanism. Experimental studies suggest possible effects on glucose utilization, insulin-related responses, oxidative stress, and lipid metabolism (Jaiswal et al., 2009; Mbikay, 2012).

These mechanisms may collectively contribute to the metabolic effects observed in experimental and limited clinical studies. However, metabolic responses can be influenced by dose, preparation, nutritional status, disease state, and individual variability. Therefore, the proposed mechanisms should currently be regarded as potential pharmacological mechanisms rather than established clinical effects.

6.5 Modulation of Cellular Protection and Inflammation

Moringa phytochemicals may also influence cellular protective mechanisms through interactions between antioxidant, inflammatory, and metabolic pathways. Phenolic compounds, flavonoids, and isothiocyanates may collectively contribute to cellular defence by reducing oxidative injury and modulating inflammatory responses (Saini et al., 2016; Vergara-Jimenez et al., 2017).

This interconnected activity may help explain why Moringa has been investigated across several therapeutic areas rather than being associated with a single pharmacological action. Nevertheless, differences in phytochemical composition among preparations make it difficult to determine whether all Moringa products produce comparable biological effects.

6.6 Integrated Mechanistic Perspective

The available evidence suggests that the biological effects of *M. oleifera* may arise from interconnected mechanisms involving oxidative-stress regulation, inflammatory modulation, cellular antioxidant defence, metabolic regulation, and protection against cellular injury. Rather than acting through a single molecular target, multiple phytoconstituents may exert complementary or potentially synergistic effects.

This multidimensional mechanism is compatible with the broader nutritional and therapeutic perspective of Moringa. However, variability in plant material, extraction procedures, phytochemical composition, dosage, bioavailability, and experimental models remains an important limitation. Further research using standardized preparations, pharmacokinetic approaches, mechanistic studies, and well-designed human clinical trials is required to determine which mechanisms are most relevant to human health.

7. CLINICAL EVIDENCE, SAFETY AND RESEARCH GAPS

7.1 Clinical Evidence

Human clinical evidence regarding Moringa oleifera remains limited compared with the extensive preclinical literature. Available studies have primarily investigated its potential effects on glycaemic control and selected metabolic parameters. Although some findings are encouraging, differences in preparation, dosage, duration, participant characteristics, and study design limit direct comparison between studies.

7.2 Effect on Postprandial Glucose

Leone et al. (2018) investigated the effect of Moringa leaf powder on postprandial blood glucose in Saharawi adults with diabetes and healthy participants. A meal supplemented with 20 g of Moringa leaf powder was compared with a control meal. In participants with diabetes, the Moringa-supplemented meal produced a lower postprandial glycaemic response at several time points and a lower overall meal glucose response. These findings provide preliminary human evidence for a possible beneficial effect on postprandial glycaemia (Leone et al., 2018).

7.3 Clinical Evidence in Prediabetes

(Gómez-Martínez et al., 2022) conducted a double-blind, randomized, placebo-controlled trial in adults with prediabetes. Participants received 2.4 g/day of dried Moringa leaf powder or placebo for 12 weeks. The Moringa group demonstrated favourable changes in fasting blood glucose and HbA1c compared with placebo. No significant differences were observed between groups in the assessed hepatic and renal function markers, supporting short-term tolerability in the study population (Gómez-Martínez et al., 2022)

7.4 Evidence in Type 2 Diabetes

Taweerutchana et al. (2017) evaluated Moringa oleifera leaf capsules in therapy-naïve patients with type 2 diabetes in a randomized placebo-controlled study. The study did not demonstrate significant improvements in glycaemic control compared with placebo. These findings indicate that the clinical effects of Moringa may not be consistent across different patient populations and preparations (Taweerutchana et al., 2017).

7.5 Safety and Tolerability

Available short-term human studies generally indicate that Moringa leaf preparations were tolerated at the doses investigated. In the randomized type 2 diabetes study, no adverse effects attributable to Moringa were reported during the intervention period (Taweerutchana et al., 2017). Similarly, the 12-week prediabetes trial did not demonstrate significant differences between Moringa and placebo groups in the assessed hepatic and renal function markers Gómez-Martínez et al., 2022)

However, these findings should not be interpreted as proof of long-term safety. Human trials have generally involved relatively small samples and short intervention periods. Longer studies with systematic adverse-event monitoring are required, particularly for concentrated extracts and prolonged supplementation.

7.6 Overall Assessment of Clinical Evidence

Overall, human evidence suggests that M. oleifera may have potential as a nutritional or complementary intervention, particularly in relation to postprandial glucose and selected glycaemic or cardiometabolic parameters. However, clinical findings are not completely consistent, as demonstrated by the absence of significant glycaemic improvement in the randomized type 2 diabetes trial compared with favourable findings in prediabetes and postprandial glucose studies (Taweerutchana et al., 2017; Leone et al., 2018; Gómez-Martínez et al., 2022)

7.7 Evidence Limitations and Research Gaps

A major limitation of current Moringa research is the variability of plant material and preparations. Differences in plant part, geographical origin, cultivation conditions, maturity, extraction method, processing, and phytochemical composition can substantially influence the biological activity of the resulting preparation (Leone et al., 2015; Saini et al., 2016).

Furthermore, a considerable proportion of the available evidence is derived from in-vitro and animal studies. Human clinical trials remain relatively few and are generally characterized by small sample sizes and short intervention periods. Consequently, the translation of promising experimental findings into established clinical applications remains uncertain (Stohs & Hartman, 2015; Liu et al., 2022).

Future research should therefore emphasize standardized preparations, characterization of active constituents, dose-response relationships, bioavailability, pharmacokinetic evaluation, long-term safety, possible drug interactions, and adequately powered randomized controlled trials. Integration of Ayurvedic principles with modern clinical methodology may also help develop evidence-based applications of Shigru.

8. DISCUSSION

The available evidence indicates that Moringa oleifera (Shigru) possesses considerable nutritional and pharmacological potential. Its leaves provide proteins, minerals, vitamins, fibre, and diverse phytochemicals, while experimental studies have reported antioxidant, anti-inflammatory, metabolic, hepatoprotective, cardioprotective, antimicrobial, and neuroprotective activities (Gopalakrishnan et al., 2016; Saini et al., 2016).

The antioxidant and anti-inflammatory properties appear particularly important because oxidative stress and chronic inflammation are common mechanisms involved in several metabolic and chronic disorders. Phenolic compounds, flavonoids, and isothiocyanates may contribute to these effects through modulation of cellular antioxidant and inflammatory pathways (Waterman et al., 2014; Vergara-Jimenez et al., 2017).

Human evidence, however, is less extensive than experimental evidence. Clinical studies have reported mixed findings in relation to glycaemic control. While some studies observed beneficial effects on postprandial glucose or selected metabolic parameters, a randomized trial in patients with type 2 diabetes did not demonstrate significant improvement in glycaemic control (Taweerutchana et al., 2017; Leone et al., 2018). This variation may reflect differences in dose, preparation, duration, participant characteristics, and study design.

From an Ayurvedic perspective, the traditional use of Shigru can be considered alongside its emerging nutritional and pharmacological evidence. However, traditional indications and modern biomedical outcomes should not be considered identical without appropriate clinical validation. Integrating classical Ayurvedic concepts with standardized phytochemical characterization and contemporary clinical methodology may provide a useful framework for future research.

Overall, M. oleifera appears to have stronger evidence as a nutritional and complementary health resource than as an established standalone therapeutic agent. The major research priorities are standardization of preparations, determination of bioavailability and appropriate dose, long-term safety assessment, and adequately powered human clinical trials.

9. CONCLUSION

Moringa oleifera Lam. (Shigru) is an important medicinal and nutritional plant with considerable potential at the interface of traditional Ayurveda and modern scientific research. Its leaves provide proteins, minerals, vitamins, dietary fibre, and diverse bioactive phytoconstituents that may contribute to its nutritional and biological activities (Gopalakrishnan et al., 2016; Saini et al., 2016).

Experimental evidence supports antioxidant, anti-inflammatory, metabolic, hepatoprotective, cardioprotective, antimicrobial, and neuroprotective potential. However, the majority of available evidence remains preclinical, while human clinical studies are relatively limited and show variable results (Vergara-Jimenez et al., 2017; Taweerutchana et al., 2017).

Therefore, M. oleifera should currently be considered a promising nutritional and complementary health resource rather than an established replacement for conventional therapy. Future research should focus on standardized preparations, appropriate dosage, bioavailability, long-term safety, and well-designed clinical trials. Integration of Ayurvedic knowledge with modern scientific validation may help establish safe, reproducible, and evidence-based applications of Shigru.

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