Research in Pharmacy 2024, 14: 25-37
doi: 10.25081/rip.2024.v14.9060
https://updatepublishing.com/journal/index.php/rip

Review Article

ISSN: 2231-539X

Bioactive metabolites of *Moringa oleifera* (Sahjan) with functional activities

Shifat Fatima, Minhaj Akhtar Usmani, Arvind K. Srivastava*

Department of Food & Nutrition, Era University, Lucknow-226003, Uttar Pradesh, India

Received: July 24, 2024
Revised: August 30, 2024
Accepted: August 31, 2024
Published: September 30, 2024

***Corresponding Author:**
Arvind K. Srivastava
E-mail: drarv55cdri@rediffmail.com

ABSTRACT

Moringa oleifera, an arboreal member of the Moringaceae family native to the Indian subcontinent, has emerged recently as a promising source of bioactive metabolites with diverse functional activities. *M. oleifera* is not only a rich source of protein and many of the trace elements like calcium, iron and Vitamin A and C and the bioactive metabolites present in *M. oleifera* include flavonoids, alkaloids, glucosinolates, terpenoids, and phenolic compounds. Additionally, the secondary metabolites of *M. oleifera*, exhibit various therapeutic potentials like antioxidant, anti-inflammatory, antibacterial, neuroprotective, and anticancer effects. These findings underscore the importance of further research to fully harness the medicinal potential of these bioactive compounds, emphasizing the need to explore their molecular pathways and synergistic effects.

KEYWORDS: *Moringa oleifera*, Bioactive metabolites, Nutritional Components, Therapeutic potentials

INTRODUCTION

Exploring the therapeutic potential of natural chemicals derived from plants, especially those with a long history of traditional medicinal usage, has gained traction in recent years. *Moringa oleifera* is a powerful source of bioactive metabolites with a wide range of functional activities among the many botanical resources available (Mangundayao & Yasurin, 2017; Wang *et al.*, 2022). Owing to its unrivaled abundance of bioactive metabolites, *M. oleifera*, an arboreal member of the Moringaceae family, has attracted significant attention in scientific circles. Native to the Indian subcontinent, *M. oleifera* is a hardy and adaptable plant species that can thrive in a variety of agroclimatic circumstances (Ravishankar *et al.*, 2014; Singh *et al.*, 2023). Although *M. oleifera*'s nutritional value has long been recognized, more recent scientific studies have shown a complex web of phytochemicals inside the plant's many sections.

Different parts of the Moringa plant, including the leaves, seeds, pods, flowers, bark, and roots, contribute to its therapeutic significance. The leaves are particularly notable for their high concentration of vitamins, minerals, and essential amino acids, making them a nutritional powerhouse. They are also rich in flavonoids, which have demonstrated strong antioxidant properties, helping to counteract free radicals and reduce oxidative stress (Paliwal *et al.*, 2011). The seeds, which contain ben oil, are known for their coagulating properties that can purify water and for their antimicrobial activities that can support traditional medicine (Chelliah *et al.*, 2017). The pods, commonly referred to as drumsticks, are used as a vegetable and are a good source of vitamin C and dietary fiber (Shah *et al.*, 2022).

A remarkable variety of secondary metabolites, such as flavonoids, alkaloids, glucosinolates, terpenoids, and phenolic compounds, are present in *M. oleifera* (Shanmugavel *et al.*, 2018). These phytochemicals have a multitude of therapeutic potential for human health in addition to supporting the plant's defense mechanisms. Understanding these substances' complex interactions in biological systems depends on their molecular elucidation. For example, the flavonoids found in *M. oleifera* have been linked to strong antioxidant activity, indicating the ability to counteract free radicals and lessen oxidative stress (Paliwal *et al.*, 2011). Another family of bioactive chemicals, alkaloids, has demonstrated antibacterial qualities (Chelliah *et al.*, 2017), supporting the plant's traditional applications in traditional medicine.

The goal of this review's thorough analysis is to provide light on the biosynthetic processes that underlie the creation of each class of bioactive metabolites found in *M. oleifera*, as well as their structural variety. Additionally, a thorough investigation will be conducted into the physiological

activities linked to these metabolites, which include anti-inflammatory and anticancer effects as well as antibacterial and neuroprotective capabilities. It's expected that by exploring the biochemistry of *M. oleifera*, we will be able to better understand the plant's pharmacological potential and open up new research avenues for the exploitation of these bioactive metabolites in the creation of innovative therapeutic interventions. By means of this comprehensive investigation, we want to make a significant contribution to the current discussion regarding the application of *M. oleifera* as a source of bioactive chemicals that have significant effects on human health and welfare.

MORINGA OLEIFERA: AN OVERVIEW OF PLANT

Taxonomy and Botanical Characteristics

Often called the horseradish tree or drumstick tree, *Moringa oleifera* Lam. is a member of the Moringaceae family. With a varied botanical profile, this quickly growing deciduous tree is classified under the order Brassicales in taxonomy. Because of its ability to adapt to a wide range of climatic circumstances, *M. oleifera* is known to thrive in areas with a tropical to subtropical climate.

M. oleifera has a well-established taxonomic categorization, and its scientific nomenclature reflects important characteristics of the plant (Table 1) (Mallenakuppe *et al.*, 2015). There are thirteen identified species in the genus "Moringa," with *M. oleifera* being the most studied and used. "Oleifera" is the species epithet that highlights the plant's remarkable ability to extract oil, which is indicative of its past applications in the manufacturing of edible oil.

From a botanical perspective, *M. oleifera* is distinguished by its unique compound leaf structure and medium-sized, thin stem that can grow up to 12 meters tall. Usually tripinnate, the leaves have several leaflets paired along the petiole, giving them a feathery look. The tree has fragrant, hermaphrodite blooms in axillary clusters, which eventually develop into long, pendulous seed pods that are filled with oil-rich seeds (Figure 1) (Patel *et al.*, 2010; Boopathi & Abubakar, 2021).

Geographical Distribution

Renowned for both its culinary and medicinal qualities, *M. oleifera* is found all over the world and thrives in a variety of conditions. Although it is native to the Indian subcontinent, *M. oleifera* has long been grown throughout South Asia, notably in Bangladesh, Pakistan, and India (Olson *et al.*, 2015). But this amazing tree's flexibility has allowed it to spread many tropical and subtropical regions. These days, it can be seen growing throughout the Caribbean, Southeast Asia, Africa, Central and South America, and even certain desert portions of the Middle East (Jahn, 2005).

Because *M. oleifera* is tolerant of a wide range of environmental conditions, including semi-arid and dry areas, it has been able to establish a global presence. The tree's extensive range is also facilitated by its capacity to grow in a variety of soil types, including clayey and well-drained sandy soils. Because of its flexibility, *M. oleifera* is now a valued resource for communities dealing with difficult agricultural conditions (Basra *et al.*, 2018).

Table 1: Taxonomic classification of *M. oleifera* (Mallenakuppe *et al.*, 2015)

Kingdom	Plantae
Division	Magnoliophyta (Angiosperms)
Class	Magnoliopsida
Order	Brassicales
Family	*Moringa*ceae
Genus	*Moringa*
Species	*Moringa oleifera*

Figure 1: Moringa oleifera: leaves and flower

Geographical Distribution of *M. oleifera* in India

M. oleifera is widely cultivated and naturalized in many tropical and subtropical regions of India. Its robust growth and adaptability to various climates make it an important plant in Indian agriculture and traditional medicine.

Major Growing Regions

Southern India

Tamil Nadu: Tamil Nadu is one of the largest producers of *M. oleifera* (Balasubramaniam & Easwaran, 2019). The regions of Theni, Dindigul, and Karur are particularly notable for large-scale cultivation (Anitha *et al.*, 2020). The state's climate, characterized by moderate to high temperatures and sufficient rainfall, is ideal for the growth of *Moringa*.

Karnataka: In Karnataka, districts like Chitradurga, Tumkur, and Bellary are known for *Moringa* cultivation (Lavanya & Pattar, 2017). The plant thrives well in the semi-arid regions of the state.

Andhra Pradesh and Telangana: These states also contribute significantly to *Moringa* production, with districts like Anantapur and Kurnool being key areas (Rukmani *et al.*, 2018a).

Western India

Maharashtra: The Vidarbha and Marathwada regions are prominent for growing *Moringa*, benefiting from the warm climate and dry conditions which suit the plant's requirements (Rukmani *et al.*, 2018b).

Eastern India

Odisha: Odisha has suitable conditions for *moringa*, especially in the western and southern parts of the state (Mallick *et al.*, 2020).

Northern India

Uttar Pradesh: Certain regions in Uttar Pradesh, particularly the eastern parts, grow *Moringa* (Devkota & Bhusal, 2020), although it is not as widespread as in the southern and western parts of the country.

Bihar: Moringa is cultivated in some districts of Bihar, mainly for its nutritional and medicinal benefits (Rukmani *et al.*, 2018c).

NUTRITIONAL COMPONENTS INCLUDING TRACE ELEMENTS AND VITAMINS

In comparison with other vegetable crops, *Moringa* is renowned for its high nutritional content (Table 2). *M. oleifera* also possesses a variety of bioactive metabolites that greatly enhance its medicinal value. Its high vitamin content is a key component of its nutritional profile. *M. oleifera* leaves are a great source of vitamin A, which is important for maintaining vision, as well as vitamin C and other B-vitamins that are essential for energy metabolism and the immune system. Because of its abundance of nutrients, *M. oleifera* may be able to help with vitamin A insufficiency, which is a common issue in many areas (Leone *et al.*, 2015).

In addition to vitamins, *M. oleifera* boasts a noteworthy mineral composition. Calcium, magnesium, iron, and potassium are among the key elements found in abundance. Calcium and magnesium contribute to bone health, iron aids in hemoglobin synthesis, and the high potassium content underscores the potential cardiovascular benefits of incorporating *M. oleifera* into the diet (Anwar *et al.*, 2007; Leone *et al.*, 2015). Furthermore, the plant's leaves are a reservoir of essential amino acids, forming the building blocks of proteins. With a complete profile of amino acids, *M. oleifera* stands as a valuable protein source, especially for populations with limited access to animal-derived proteins, addressing concerns related to malnutrition and protein deficiency (Anwar *et al.*, 2007; Sreelatha & Padma, 2009).

Specialized Metabolites

M. oleifera is well known for having a large number of specific metabolites, each of which adds to the unique bioactivity of the plant. Among these, lectins, saponins, and isothiocyanates stand out as important components of this botanical entity's complex pharmacological profile (Valdés-Rodríguez *et al.*, 2023).

Isocyanates of sulfur

In *M. oleifera*, sulfur-containing chemicals called isothiocyanates, which are produced from glucosinolates, constitute a significant class of bioactive intermediaries (Hasin, 2017). These substances are involved in the plant's defense against herbivores and have drawn attention for their possible anticancer qualities. Several isothiocyanates, including glucomoringin-derived moringin, are produced by the hydrolysis of glucosinolate. This highlights the complex metabolic pathways in *M. oleifera* that produce these beneficial components.

Lectins

Essential to *M. oleifera*'s biological processes are lectins, which are proteins that bind carbohydrates (Nubi *et al.*, 2021). These proteins have been shown to have immunomodulatory qualities and are essential to the plant's defensive mechanisms (Adamu *et al.*, 2021).

BIOACTIVE METABOLITES IN *MORINGA OLEIFERA*

Phytochemical Composition and their functional activities (Table 3)

Alkaloids

Alkaloids are nitrogen-containing chemicals that are found in a variety of plant components, including the leaves, seeds, and roots of *M. oleifera* (Valdés-Rodríguez *et al.*, 2003; Alamgir, 2018). They represent a substantial category of bioactive metabolites within the plant. Among the noteworthy substances found in *M. oleifera*'s alkaloid profile are pyrimidine alkaloids, moringine, and moringinine, all of which have unique structural characteristics. The anti-inflammatory activities of moringine, for example, demonstrate the medicinal significance of these alkaloids. Furthermore, the alkaloid moringinine has shown antibacterial activity, indicating a potential function in the plant's defensive mechanisms (Onyekaba *et al.*, 2013). Moringine is noteworthy because it has been linked to

Table 2: Nutritional composition of *Moringa* in comparision with other vegetable crops

Micronutrients	Tomato	Cabbage	*Moringa*	Amaranth	Slippery Cabbage	Sweet Potato Leaf
β-carotene (mg)	0.40	0.00	15.28	9.23	5.11	6.82
Vitamin C (mg)	19	22	459	113	82	81
Vitamin E (mg)	1.16	0.05	25.25	3.44	4.51	4.69
Iron (mg)	0.54	0.30	10.09	5.54	1.40	1.88
Folates (µg)	5	ND	93	78	177	39
Antioxidant Activity (TE)	323	496	2858	394	560	870

Table 3: Summary of Phytochemical Composition of *M. oleifera* and their functional activities

S. No.	Phytochemical Class	Bioactive Metabolite	Functional Activities	Referenes
1	Alkaloids	Moringine Moringinine	Anti-inflammatory, cardiovascular effects Antimicrobial	Bhattacharya *et al.*, 2018; Ravindra *et al.*, 2019
2	Flavonoids	Quercetin Kaempferol	Antioxidant, anti-inflammatory Anticancer, anti-inflammatory	Khazdair *et al.*, 2021; Al-Khayri *et al.*, 2022
3	Glucosinolates	Glucomoringin Isothiocyanates	Anticancer, detoxification Antimicrobial, antioxidant	Melrose *et al.*, 2019; Lopez-Rodriguez *et al.*, 2020; Olayanju *et al.*, 2024
4	Polyphenols	Chlorogenic Acid Rutin	Antioxidant, anti-inflammatory Vasoprotective, anti-inflammatory	Rastogi *et al.*, 2024
5	Terpenoids	β-Carotene Quercetin	Antioxidant, immune system support Antioxidant, anti-inflammatory	Singh *et al.*, 2020; Xu *et al.*, 2024

hypotensive effects, which may have consequences for the cardiovascular system (Dangi *et al.*, 2002). The significance of these alkaloids in the therapeutic potential of *M. oleifera* is shown by their diverse structures and pharmacological actions.

In addition to moringine and moringinine, *M. oleifera* contains other notable alkaloids that contribute to its pharmacological profile. For instance, niaziridin, another alkaloid found in the plant, exhibits potent antifungal and antibacterial properties. Research has shown that niaziridin can inhibit the growth of various pathogens, making it a valuable compound for addressing microbial infections (Dwivedi *et al.*, 2019).

Another important alkaloid, niazimicin, has been studied for its anticancer properties. Niazimicin has been observed to induce apoptosis in cancer cells and inhibit the proliferation of tumor cells, suggesting its potential use in cancer therapy (Xie *et al.*, 2021). The presence of such compounds highlights the broad spectrum of therapeutic effects *M. oleifera* can offer.

Moreover, the antioxidant properties of these alkaloids contribute to their overall health benefits. Antioxidants are crucial in neutralizing free radicals, thereby preventing oxidative stress and cellular damage. Studies have shown that the alkaloids in *M. oleifera* can significantly enhance the body's antioxidant defense system, which is vital for maintaining overall health and preventing chronic diseases.

The alkaloid profile of *M. oleifera* also includes compounds with analgesic and anti-spasmodic effects (Khan & Khan, 2021). For example, moringinine has been reported to relieve pain and reduce muscle spasms, making it useful in managing conditions such as arthritis and muscle injuries (Sahoo *et al.*, 2020). These properties further establish the plant's role in traditional medicine for treating a variety of ailments.

Furthermore, the versatility of *M. oleifera*'s alkaloids extends to their use in metabolic health. Studies have indicated that these compounds can help regulate blood sugar levels, making them beneficial for managing diabetes. The alkaloids enhance insulin secretion and improve glucose uptake, thus aiding in maintaining normal blood sugar levels (Jaiswal *et al.*, 2009).

In summary, the alkaloids found in *M. oleifera*, including pyrimidine alkaloids, moringine, moringinine, niaziridin, and niazimicin, are integral to the plant's medicinal value. Their diverse structures and pharmacological actions, such as anti-inflammatory, antibacterial, antifungal, anticancer, antioxidant, analgesic, anti-spasmodic, and hypoglycemic effects, underscore the therapeutic potential of *M. oleifera*. These bioactive metabolites make *M. oleifera* a promising natural source for developing various health-promoting and disease-preventing applications.

Flavonoids

One important family of polyphenolic chemicals found in large quantities in *M. oleifera*'s phytochemical repertory are flavonoids (Sreelatha & Padma, 2009). These secondary metabolites are widely dispersed throughout different plant tissues and are distinguished by their varied chemical structures. Quercetin, kaempferol, rutin, and isoquercetin are only a few of the chemicals that make up *M. oleifera*'s flavonoid profile. These substances have been found using analytical methods like mass spectrometry and high-performance liquid chromatography (HPLC), highlighting the plant's ability to synthesize a complex variety of flavonoids. Remarkably, the flavonoids found in *M. oleifera* have demonstrated strong antioxidant capabilities, reducing oxidative stress in biological systems and neutralizing reactive oxygen species (Sreelatha & Padma, 2009).

Research has shown that one of *M. oleifera*'s main flavonoids, quercetin, greatly contributes to the plant's antioxidant activity (Anwar *et al.*, 2007). These flavonoids' potential as antioxidants is particularly interesting because of the potential health benefits for humans, including the potential to reduce chronic diseases linked to oxidative damage. Furthermore, flavonoids have shown anti-inflammatory properties, indicating that they may be useful in controlling inflammatory pathways and immunological responses (Leone *et al.*, 2015).

One important aspect of *M. oleifera*'s flexibility and resilience is the synthesis and abundance of flavonoids, which support the plant's defense systems and provide potential opportunities for medicinal uses. This section delves into the structural variety of flavonoids derived from *M. oleifera*, examining their mechanisms of biosynthesis and elucidating their potential physiological significance in human health.

Glucosinolates

Glucosinolates are a family of secondary metabolites with a wide range of biological actions, and *M. oleifera* stands out for

having a substantial amount of them. These sulfur-containing substances are essential to the plant's defense systems and have drawn a lot of interest due to possible health advantages. The anticancer activities of *M. oleifera* have been linked to its glycosides, which have been shown in studies to suppress cancer cell growth and trigger apoptosis (Sreelatha & Padma, 2009; Leone *et al.*, 2015). It has been extensively established that several glucosinolates exist, including glucosinalbin and glucomoringin, each of which has a distinct chemical structure that enhances their bioactivity (Mutar *et al.*, 2021).

Furthermore, studies suggest that *M. oleifera* glucosinolates may possibly have anti-inflammatory and antioxidant qualities, highlighting its possible therapeutic value (Leone *et al.*, 2015; Karim *et al.*, 2016). Determining the molecular underpinnings of these glucosinolates' bioactivity requires an understanding of their biosynthesis and structural quirks.

Glucosinolates are hydrolyzed by the enzyme myrosinase, which converts them into various biologically active compounds, such as isothiocyanates, nitriles, and thiocyanates (Prieto *et al.*, 2019). Isothiocyanates, in particular, have garnered attention for their potent anticancer properties. For example, benzyl isothiocyanate and phenethyl isothiocyanate, derived from glucomoringin, have been shown to induce apoptosis in cancer cells and inhibit tumor growth in animal models (Fahey *et al.*, 2001). These compounds exert their effects by modulating various cellular pathways, including the activation of tumor suppressor genes and the inhibition of cell proliferation signaling pathways.

The anti-inflammatory properties of *M. oleifera* glucosinolates are also noteworthy. Isothiocyanates have been found to inhibit the production of pro-inflammatory cytokines and enzymes, such as TNF-α and COX-2, which play key roles in the inflammatory response (Olayanju *et al.*, 2024). This inhibition helps reduce inflammation and may provide therapeutic benefits in conditions such as arthritis and other inflammatory diseases.

Antioxidant activities of glucosinolates and their hydrolysis products are another significant aspect of their bioactivity. Isothiocyanates can activate the Nrf2 pathway, a critical regulator of cellular antioxidant responses (Naidu *et al.*, 2018). Activation of Nrf2 leads to the expression of various antioxidant enzymes, including glutathione S-transferase and heme oxygenase-1, which help protect cells from oxidative damage (Jaiswal, 2004). This mechanism underscores the potential of *M. oleifera* glucosinolates in preventing oxidative stress-related diseases, such as cardiovascular diseases and neurodegenerative disorders.

Additionally, the potential antimicrobial properties of glucosinolates should not be overlooked. Studies have demonstrated that isothiocyanates possess broad-spectrum antimicrobial activity against various bacterial and fungal pathogens (Romeo *et al.*, 2018). This antimicrobial effect can be particularly beneficial in managing infections and promoting overall plant health.

The diverse range of bioactivities exhibited by glucosinolates from *M. oleifera* highlights their significance in both plant defense and human health. Ongoing research aims to further elucidate the precise mechanisms of action of these compounds and their potential applications in medicine and agriculture. Understanding the biosynthesis pathways of glucosinolates and their conversion to bioactive products is essential for optimizing their use in therapeutic and agricultural contexts.

In conclusion, the substantial amount of glucosinolates in *M. oleifera*, such as glucosinalbin and glucomoringin, contributes significantly to the plant's medicinal potential. These compounds, through their hydrolysis products like isothiocyanates, offer a wide range of health benefits, including anticancer, anti-inflammatory, antioxidant, and antimicrobial activities. Further research into the molecular mechanisms and biosynthetic pathways of glucosinolates will enhance our understanding of their bioactivities and therapeutic applications.

Polyphenols

Among *M. oleifera*'s bioactive metabolites, polyphenols are a notable class that greatly influences the plant's pharmacological profile. Numerous phenolic rings are present in these molecules, which are well known for their antioxidant qualities. Among the notable polyphenols found in *M. oleifera* are rutin, kaempferol, quercetin, and chlorogenic acid. Numerous studies have linked the flavonoid quercetin, which has strong anti-inflammatory and antioxidant activities, to possible health benefits (Sreelatha & Padma, 2009; Ragasa *et al.*, 2015). Similarly, significant amounts of chlorogenic acid, which is well-known for its capacity to scavenge free radicals, have been found in the leaves of *M. oleifera* (Jaiswal *et al.*, 2009).

The complex interactions among these polyphenolic chemicals highlight the comprehensive phytochemical makeup of *M. oleifera*, which may work in concert to provide a range of health benefits. The following sections will explore the biosynthesis processes, structural clarification, and various functional actions that these polyphenols confer on *M. oleifera*.

Terpenoids

The rich phytochemical tapestry of *M. oleifera* includes a remarkable component in the form of terpenoids, a diversified class of secondary metabolites. These molecules, which come from the isoprenoid pathway, have different bioactive characteristics and come in a variety of forms, such as monoterpenes, sesquiterpenes, diterpenes, and triterpenes. Terpenoids serve as strong defense mechanisms against a variety of stressors, which greatly aids in the plant's adaptive responses. The pharmacological potential of *M. oleifera* terpenoids, which includes anti-inflammatory, antioxidant, and antibacterial actions, is a part of their bioactivity.

In a groundbreaking investigation, (Ragasa *et al.*, 2015) researchers separated and characterized terpenoids from *M. oleifera* leaves, exposing the existence of a variety of terpenoid

substances with noteworthy biological properties. Furthermore, the work of (Leone *et al.*, 2015) offers a thorough analysis of the pharmacological characteristics, genetic factors, and cultivation of *M. oleifera*, illuminating the part terpenoids play in the plant's therapeutic profile. Moreover, the study conducted by (Sreelatha & Padma, 2009) highlights the antioxidant properties of *M. oleifera*, emphasizing the roles played by terpenoids.

To properly utilize the therapeutic potential of terpenoids in *M. oleifera*, a detailed investigation is necessary, taking into account their structural diversity and functional relevance.

Mechanisms of Action: Molecular Pathways of Bioactive Metabolites Found in *M. oleifera*

The bioactive metabolites found in *M. oleifera*, such as alkaloids, flavonoids, glucosinolates, polyphenols, terpenoids, and saponins, exert their therapeutic effects through various molecular pathways. Alkaloids like moringine and moringinine demonstrate anti-inflammatory and antimicrobial properties by modulating key signaling pathways such as the nuclear factor-kappa B (NF-κB) pathway. By inhibiting NF-κB activation, these compounds reduce the production of pro-inflammatory cytokines and mediators, thereby mitigating inflammation. Additionally, moringinine exhibits antibacterial activity by disrupting bacterial cell wall synthesis and interfering with essential metabolic processes within microbial cells.

Flavonoids such as quercetin and kaempferol are known for their potent antioxidant and anticancer properties. These compounds exert their effects by scavenging free radicals and upregulating the expression of antioxidant enzymes through the activation of the nuclear factor erythroid 2–related factor 2 (Nrf2) pathway (Imran *et al.*, 2019; Kopustinskiene *et al.*, 2020). This leads to a reduction in oxidative stress and protection of cellular components from damage (Agati & Tattini, 2010). In terms of anticancer activity, glucosinolates and their derivatives, such as isothiocyanates, induce apoptosis and inhibit the proliferation of cancer cells by modulating the expression of tumor suppressor genes and inhibiting oncogenic pathways like the PI3K/Akt and MAPK pathways (Zhang *et al.*, 2018; ul Islam *et al.*, 2021; Zughaibi *et al.*, 2021). Furthermore, polyphenols like chlorogenic acid and rutin contribute to cardiovascular health by improving endothelial function and reducing inflammation, which is achieved through the modulation of nitric oxide (NO) synthesis (Duarte *et al.*, 2014) and inhibition of inflammatory cytokines (Leyva-López *et al.*, 2016). These diverse molecular mechanisms underscore the multifaceted therapeutic potential of *M. oleifera*'s bioactive metabolites.

Terpenoids, including β-carotene, are another significant class of bioactive metabolites in *M. oleifera*, known for their antioxidant and immune-supportive functions. β-Carotene, a precursor to vitamin A, is vital for maintaining healthy vision, skin integrity, and immune function. It acts as a free radical scavenger, protecting cells from oxidative damage by neutralizing reactive oxygen species (ROS). Additionally, β-carotene influences gene expression related to immune responses and cellular differentiation by activating retinoic acid receptors (RARs) and retinoid X receptors (RXRs) (Zhao *et al.*, 2016). This regulatory role is crucial for the differentiation of immune cells and the maintenance of mucosal barriers, which are essential for an effective immune response. Overall, the diverse mechanisms of action of these bioactive metabolites highlight the therapeutic versatility of *M. oleifera* and its potential in promoting health and preventing diseases through multiple biochemical pathways.

THERAPEUTIC POTENTIALS OF *MORINGA OLEIFERA*

M. oleifera, has been extensively studied for its broad range of pharmacological activities. Various parts of the plant, including leaves, seeds, roots, and flowers, have been reported to possess numerous therapeutic properties. Here, we summarize the key pharmacological activities of *M. oleifera* documented in scientific literature.

Properties of Antioxidants: The strong antioxidant activity of the bioactive metabolites of *M. oleifera* is one of their main functional characteristics. Key components of the plant's antioxidant capability have been found, including phenolic substances like chlorogenic acid and flavonoids like quercetin and kaempferol that efficiently scavenge free radicals and reduce oxidative stress (Lin *et al.*, 2018; Dou *et al.*, 2019; Xu *et al.*, 2019).

Anti-inflammatory Effects: Numerous studies have been conducted on the anti-inflammatory characteristics of bioactive metabolites of *M. oleifera*, specifically isothiocyanates and flavonoids. The plant has long been used to treat inflammatory diseases because these chemicals have inhibitory effects on pro-inflammatory mediators (Jaja-Chimedza *et al.*, 2017; Xu *et al.*, 2019).

Antimicrobial Activity: The antibacterial properties of *M. oleifera*'s alkaloids and glucosinolates are highly effective against a variety of infections. The plant's bioactive components have inhibitory effects on viruses, bacteria, and fungi, indicating potential usefulness in antimicrobial therapies (Kheir *et al.*, 2014).

Anti-diabetic Potential: The bioactive ingredients of *M. oleifera*, especially quercetin and chlorogenic acid, have been linked to benefits against diabetes. Because of these metabolites' hypoglycemic characteristics, *M. oleifera* is being researched as a potential supplementary therapy for the treatment of diabetes (Wang *et al.*, 2022).

Immune Modulation: Anti-components from *M. oleifera*, like ascorbic acid and β-carotene, help regulate the immune system. According to Deshmukh *et al.* (2015), these metabolites have the ability to improve immunological responses, which may have implications for immunotherapies (Deshmukh *et al.*, 2015).

Anti-cancer Properties: Quercetin and β-carotene, two of *M. oleifera*'s bioactive metabolites, have shown anti-cancer effects. These substances show cytotoxic effects on cancer cells and

disrupt many signaling pathways, suggesting that *M. oleifera* may be useful in the prevention and treatment of cancer (Masarkar *et al.*, 2023).

Neuroprotective Effects: Flavonoids and isothiocyanates, two bioactive substances present in *M. oleifera*, have demonstrated neuroprotective properties. These metabolites have antioxidative and neurotropic qualities, which may have uses in the prevention of neurodegenerative diseases (Abdelsayed *et al.*, 2021; Azlan *et al.*, 2023).

Cardiovascular Benefits: The bioactive metabolites of *M. oleifera* include lipid-lowering and vasodilatory properties that support cardiovascular health. Quercetin and β-sitosterol are two compounds that have been linked to bettering cardiovascular health and lipid profiles (Deng *et al.*, 2020; Alia *et al.*, 2022).

Wound Healing: According to studies, quercetin and other phytochemicals found in *M. oleifera* are among the bioactive metabolites that may speed up the healing of wounds. These substances have antibacterial and anti-inflammatory properties that speed up tissue healing (Lim *et al.*, 2019; Shady *et al.*, 2022).

The discoveries mentioned above highlight the exceptional variety of bioactive metabolites in *M. oleifera* and their possible therapeutic uses for various medical ailments. Future studies in this area could lead to the creation of innovative pharmaceutical treatments based on the complex phytochemical makeup of this amazing plant.

USE OF *MORINGA* IN EDIBLES

M. oleifera is highly regarded for its versatility in culinary applications, enriching a variety of dishes with its exceptional nutritional profile. The *Moringa* plant's leaves, seeds, pods, and flowers can be incorporated into everyday meals, boosting their nutritional content significantly.

Moringa Leaves

Fresh Leaves: Fresh *Moringa* leaves can be used in salads, soups, and stir-fries. They contribute a slightly bitter, spinach-like flavor to dishes (Sultana, 2020).

Dried Powder: *Moringa* leaf powder is a convenient form that can be added to smoothies, juices, teas, and baked goods. It enhances the nutritional content without significantly altering the taste (Gopalakrishnan *et al.*, 2016).

Tea: Dried *Moringa* leaves can be brewed into a nutritious tea, providing a boost of antioxidants and vitamins (Islam *et al.*, 2021).

Moringa Pods (Drumsticks): The young, tender pods, commonly known as drumsticks, are often used in South Asian cuisine. They can be added to curries, stews, and soups. The pods are cooked until tender and then consumed for their rich nutritional content, including vitamin C and fiber (Sahay *et al.*, 2017).

Moringa Seeds

Oil Extraction: Moringa seeds are used to extract oil, known as ben oil, which is high in oleic acid and can be used for cooking and cosmetic purposes (Leone *et al.*, 2016).

Roasted Seeds: The seeds can be roasted and eaten as a snack. They have a slightly sweet and nutty flavor (Leone *et al.*, 2016).

Moringa Flowers

Moringa flowers are edible and can be used in salads, teas, and as a garnish. They provide a mild flavor and are rich in calcium and potassium (Milla *et al.*, 2021).

Moringa Root

In some cultures, *Moringa* root is used as a spice, similar to horseradish. However, it should be used cautiously due to potential toxicity in large amounts (Thakur *et al.*, 2024).

COMPOUNDS ISOLATED FROM THE MORINGA PLANTS AND THEIR THERAPEUTIC ACTIVITY

M. oleifera, a highly valued medicinal plant, contains a plethora of bioactive compounds. Each part of the plant, including leaves, seeds, bark, roots, and flowers, harbors unique phytochemicals that contribute to its therapeutic properties. Table 4 summarizing the key compounds isolated from *M. oleifera* and their therapeutic activities.

CLINICAL EFFICACY OF *MORINGA* PLANT PARTS AND PREPARATIONS

The various parts of the *Moringa* plant have been studied for their clinical efficacy in treating a range of conditions. Table 5 shows different parts of the *Moringa* plant, their preparations, and the clinical evidence supporting their uses.

TRADITIONAL USES

The history of *M. oleifera* is rooted in the customs of many different cultures, where it has been valued for its many medicinal uses. The plant's many parts have been used for millennia in traditional medicine to treat a wide range of medical issues. Highly valued for its remarkable nutritional diversity, *M. oleifera* is distinguished by its abundance of essential vitamins and minerals in its leaves, seeds, and pods. Interestingly, the leaves show up as a noteworthy source of vitamin C, beta-carotene, and several B vitamins, making them an important dietary supplement in areas where malnutrition is a problem (Mahmood *et al.*, 2010).

Because of its analgesic and anti-inflammatory qualities, *M. oleifera* is used in traditional medicine (Table 6). A variety of plant parts, such as bark, roots, and leaves, are expertly prepared as decoctions or poultices that reduce inflammation and relieve

Table 4: Key compounds isolated from *M. oleifera* and their therapeutic activities

Compound	Source	Therapeutic Activity	Reference (s)
Quercetin	Leaves	Antioxidant, anti-inflammatory, reduces blood pressure, improves heart health	Hassan *et al*., 2021
Chlorogenic Acid	Leaves	Antioxidant, reduces blood sugar, anti-diabetic, anti-cancer, neuroprotective	Hassan *et al*., 2021
Kaempferol	Leaves	Anti-inflammatory, anti-cancer, cardioprotective, supports brain health	Hassan *et al*., 2021
Niazimicin	Leaves, Seeds	Anti-cancer (skin and breast), anti-inflammatory	Udechukwu *et al*., 2018
Isothiocyanates	Seeds, Leaves, Roots	Anticancer, anti-inflammatory, antimicrobial, detoxification	Wu *et al*., 2021
Beta-sitosterol	Leaves, Seeds	Lowers cholesterol, enhances prostate health, boosts immune function, anti-inflammatory, anticancer	Patel *et al*., 2017
Ascorbic Acid (Vitamin C)	Leaves, Pods	Antioxidant, supports immune function, skin health, prevents cardiovascular diseases, cancer	Islam *et al*., 2021
Alpha-tocopherol (Vitamin E)	Leaves, Seeds	Antioxidant, protects cells from oxidative damage, beneficial for skin and cardiovascular health, anti-cancer	Pareek *et al*., 2022

Table 5: The different parts of the *Moringa* plant, their preparations, and the clinical evidence supporting their uses

Part of the Plant	Preparation/Formulation	Clinical Indications	Clinical Efficacy
Leaves	Powder, Capsules, Paste	Nutritional supplement, Anti-inflammatory, Antioxidant, Antidiabetic	Clinical trials have shown *Moringa* leaf powder to significantly reduce blood glucose levels in diabetic patients. It also improved lipid profiles and reduced inflammation markers in various studies (Owens *et al*., 2020).
Seeds	Oil (Ben Oil), Capsules	Skin conditions, Anti-inflammatory, Antimicrobial	Studies have demonstrated *Moringa* seed oil's efficacy in treating skin conditions like psoriasis and eczema due to its anti-inflammatory and antimicrobial properties (Cretella *et al*., 2020). Clinical trials have also shown its benefits in reducing cholesterol levels (Aborhyem *et al*., 2016).
Pods	Cooked, Powder	Digestive health, Nutritional supplement	Clinical studies indicate that *Moringa* pods help improve digestive health and nutrient absorption. They are also rich in fiber, which aids in digestion and overall gut health (El-Hack *et al*., 2018).
Bark	Decoction	Antipyretic, Anti-inflammatory	Clinical trials suggest that *Moringa* bark decoctions can effectively reduce fever and inflammation (Maurya & Singh, 2014). However, more extensive studies are needed to confirm these findings.
Flowers	Infusion, Sharbat	Respiratory issues, Digestive health	*Moringa* flowers have been clinically shown to have anti-inflammatory and antimicrobial properties, making them useful in treating respiratory infections and digestive issues (Tan *et al*., 2015).
Roots	Decoction, Paste	Digestive issues, Antimicrobial	Root extracts have demonstrated significant antimicrobial activity in clinical settings, particularly against H. pylori, a common cause of stomach ulcers (Choudhary *et al*., 2013).

Table 6: Traditional medical uses of moringa

Uses of moringa	References
Increased Mental Clarity	Arozal *et al*., 2022
Anti-inflammatory	Martínez-González *et al*., 2017
Enhances Skin Health	Athikomkulchai *et al*., 2020; Cretella *et al*., 2020
Normalizes Blood Sugar	Anwer *et al*., 2021; Wang *et al*., 2022
UTI (Urinary Tract Infection)	Abdalla *et al*., 2016; Arodes *et al*., 2022
Improves lipid metabolism	Barbagallo *et al*., 2016
Appetite Suppressant	Uwaifo *et al*., 2020
Anti-Fungal	Moyo *et al*., 2012; El-Mohamedy & Abdalla, 2014; Yoshimatsu *et al*., 2023; Sharma *et al*., 2024
Immune booster	Fajri *et al*., 2021; Bhattacharjee *et al*., 2020; Mehwish *et al*., 2022; Li *et al*., 2020
Improves Wound Healing	Al-Ghanayem *et al*., 2022; Muzammil *et al*., 2023; Mehwish *et al*., 2021; Muhammad *et al*., 2013
Anti-aging	Lim *et al*., 2024; Xu *et al*., 2022
Vision Improvement	Joshua *et al*., 2017; Alanazi *et al*., 2024
Detoxification	Ogbunugafor *et al*., 2012; Förster *et al*., 2016; Nisar *et al*., 2024
Stimulates Hair Growth	Junlatat & Sripanidkulchai, 2022; Bhargavi *et al*., 2023
Normalizes Blood Pressure	Acuram *et al*., 2019; Kumolosasi *et al*., 2021
Anti-Ulcer	Choudhary *et al*., 2013; El Mahdy *et al*., 2020; Latif *et al*., 2020; Ijioma *et al*., 2018
Nutrition for Infants 6 Months & Older and Pregnant and Nursing Mothers	Nnam *et al*., 2009; Chukwuebuka *et al*., 2015; Sumiatya *et al*., 2020; Fitriana *et al*., 2024; Dantas *et al*., 2024
Anti-depressant	Abadar *et al*., 2023; Fidelis *et al*., 2024
Eliminates Constipation	Jiang *et al*., 2020; Islam *et al*., 2020; Li *et al*., 2024

Table 7: Ayurvedic, unani preparation incorporating the parts of the plants

Preparation	System of Medicine	Moringa Part Used	Indications	Method of Preparation
Moringa Powder	Ayurvedic	Leaves	General tonic, boosts immunity, reduces inflammation, detoxification	Leaves are shade-dried and ground into a fine powder. Consumed with water, milk, or honey.
Moringa Oil (Ben Oil)	Ayurvedic	Seeds	Skin conditions, joint pain, anti-inflammatory	Seeds are cold-pressed to extract oil. Applied topically or used in formulations.
Sahjan Ka Saag	Ayurvedic	Leaves, Pods	Digestive aid, nutrient supplement, improves lactation	Leaves and pods are cooked as a vegetable dish, often with spices like turmeric and cumin.
Moringa Decoction	Unani	Bark, Leaves, Seeds	Fever, infections, inflammation	Boiling parts of the plant (bark, leaves, and seeds) in water strained and consumed.
Sharbat-e-Sahjan	Unani	Flowers, Leaves	Digestive health, general tonic, lactation enhancer	Flowers and leaves are boiled with sugar to make a sweet, cooling beverage.
Moringa Paste	Ayurvedic	Leaves	Skin infections, wounds, anti-inflammatory	Fresh leaves are ground into a paste, applied topically on the affected areas.
Moringa Capsule	Ayurvedic	Leaves, Seeds	Nutritional supplement, antioxidant, anti-diabetic	Leaves and seeds are dried, powdered, and encapsulated for oral consumption.
Moringa Ghrita	Ayurvedic	Leaves, Flowers	Respiratory issues, improves immunity	Leaves and flowers are boiled with ghee (clarified butter) and filtered.
Moringa Arq	Unani	Leaves, Seeds	Blood purifier, detoxification	Distillation of leaves and seeds to produce a water-based extract.

pain (Anwar *et al.*, 2007). Traditional medical practices have used extracts from *M. oleifera* to treat bacterial and fungal illnesses, capitalizing on the plant's natural antibacterial properties. This emphasizes its potential as an antibacterial agent found in nature (Cáceres *et al.*, 1992). Historically, *M. oleifera* has been used to treat digestive problems and stomach symptoms, with an emphasis on the effectiveness of its seeds in this regard (Fahey *et al.*, 2005). *M. oleifera* has found use in the treatment of diabetes in certain traditional medical systems. According to scientific research, the plant's bioactive components may contribute to the regulation of blood glucose levels (Jaiswal *et al.*, 2009).

AYURVEDIC, UNANI PREPARATION INCORPORATING THE PARTS OF THE PLANTS

Table 7 shows the ayurvedic, unani medicines preparation incorporating the parts of the plants.

FUTURE PERSPECTIVES AND RESEARCH DIRECTIONS

The thorough review article "A Comprehensive Review of Bioactive Metabolites of *M. oleifera* with Functional Activities" is a significant contribution to the field of natural products research as it provides insight into the diverse range of bioactive compounds that are generated from *M. oleifera*. Looking ahead, it is clear that there is a good chance that the medicinal potential of these bioactive metabolites will be further investigated and utilized. Subsequent studies ought to give precedence to comprehensive explorations of the molecular pathways that underlie the functional properties of *M. oleifera* substances, with the objective of elucidating their exact mechanisms of action at the cellular and biochemical levels. Furthermore, investigating the synergistic effects of several bioactive components may provide insightful information for the creation of innovative therapeutic approaches. Moreover, further research is necessary to fully understand the potential uses of these bioactive metabolites in a variety of sectors, including the pharmaceutical, nutraceutical, and cosmetics industries. Combining cutting-edge technology like bioinformatics and metabolomics can help us comprehend *M. oleifera*'s intricate metabolic profile on a deeper level. The article essentially lays the groundwork for a future research agenda that aims to fully utilize the potential of *M. oleifera*'s bioactive chemicals to address issues related to health and wellness, in addition to expanding our understanding of these compounds.

CONCLUSION

To sum up, the extensive analysis paper entitled "A Comprehensive Review of Bioactive Metabolites of *M. oleifera* with Functional Activities" offers a careful investigation of the wide variety of bioactive substances present in *M. oleifera* and the functional activities connected to them. The article goes into great detail about the many types of bioactive metabolites and explains their possible health advantages. These classes include polyphenols, flavonoids, alkaloids, and vitamins. The results of this study are noteworthy as they highlight the bioactive components' anti-inflammatory, anti-cancer, anti-microbial, and antioxidant characteristics. This highlights the diverse range of therapeutic applications that *M. oleifera* can offer. The review also emphasizes the need for more investigation to completely comprehend the processes underlying these functional activities and to look into the possible therapeutic and preventive medical uses of *M. oleifera*. In summary, this thorough analysis synthesizes the body of knowledge regarding the bioactive metabolites of *M. oleifera*, making it an invaluable tool for scientists, researchers, and medical professionals who are interested in using this amazing plant for therapeutic purposes.

ACKNOWLEDGEMENTS

We are grateful to Prof. Dr. Abbas Ali Mahdi, Vice Chancellor and Prof. Dr. Farzana Mahdi for their keen interest in this work.

REFERENCES

Abadar, J., Adkine, V., Ambhore, N., & Punam, S. (2023). Pharmacological evaluation of *Moringa oleifera* leaf extract for antidepressant activity: a review. *International Journal of Multidisciplinary Research, 9*(12), 152-154.

Abdalla, A. M., Alwasilah, H. Y., Mahjoub, R. A. H., Mohammed, H. I., & Yagoub, M. (2016). Evaluation of antimicrobial activity of *Moringa oleifera* leaf extracts against pathogenic bacteria isolated from urinary tract infected patients. *Journal of Advanced Laboratory Research in Biology, 7*(2), 47-51.

Abdelsayed, E. M., Medhat, D., Mandour, Y. M., Hanafi, R. S., & Motaal, A. A. (2021). Niazimicin: A thiocarbamate glycoside from *Moringa oleifera* Lam. seeds with a novel neuroprotective activity. *Journal of Food Biochemistry, 45*(12), e13992. https://doi.org/10.1111/jfbc.13992

Aborhyem, S., Ismail, H., Agamy, N., & Tayel, D. (2016). Effect of *Moringa oleifera* on lipid profile in rats. *Journal of High Institute of Public Health, 46*(1), 8-14. https://doi.org/10.21608/jhiph.2016.20201

Acuram, L. K., & Hernandez, C. L. C. (2019). Anti-hypertensive effect of *Moringa oleifera* Lam. *Cogent Biology, 5*(1), 1596526. https://doi.org/10.1080/23312025.2019.1596526

Adamu, U. M., Lawal, H., & Ramasamy, R. (2021). Immunomodulatory Functions of *Moringa oleifera* (Lam.). *Malaysian Journal of Medicine and Health Sciences, 17*(S10), 54-63.

Agati, G., & Tattini, M. (2010). Multiple functional roles of flavonoids in photoprotection. *New Phytologist, 186*(4), 786-793. https://doi.org/10.1111/j.1469-8137.2010.03269.x

Alamgir, A. N. M. (2018). Secondary metabolites: Secondary metabolic products consisting of C and H; C, H, and O; N, S, and P elements; and O/N heterocycles. In A. N. M. Alamgir (Eds.), *Therapeutic use of medicinal plants and their extracts: phytochemistry and bioactive compounds* (Vol. 2, pp. 165-309) Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-319-92387-1_3

Alanazi, I. S., Altyar, A. E., Zaazouee, M. S., Elshanbary, A. A., Abdel-Fattah, A.-F. M., Kamel, M., Albaik, M., & Ghaboura, N. (2024). Effect of *moringa* seed extract in chlorpyrifos-induced cerebral and ocular toxicity in mice. *Frontiers in Veterinary Science, 11*, 1381428. https://doi.org/10.3389/fvets.2024.1381428

Al-Ghanayem, A. A., Alhussaini, M. S., Asad, M., & Joseph, B. (2022). *Moringa oleifera* leaf extract promotes healing of infected wounds in diabetic rats: evidence of antimicrobial, antioxidant and proliferative properties. *Pharmaceuticals, 15*(5), 528. https://doi.org/10.3390/ph15050528

Alia, F., Putri, M., Anggraeni, N., & Syamsunarno, M. R. A. A. (2022). The potency of *Moringa oleifera* Lam. as protective agent in cardiac damage and vascular dysfunction. *Frontiers in Pharmacology, 12*, 724439. https://doi.org/10.3389/fphar.2021.724439

Al-Khayri, J. M., Sahana, G. R., Nagella, P., Joseph, B. V., Alessa, F. M., & Al-Mssallem, M. Q. (2022). Flavonoids as Potential Anti-Inflammatory Molecules: A Review. *Molecules, 27*(9), 2901. https://doi.org/10.3390/molecules27092901

Anitha, T., Balakumbagan, R., Irulandi, S., Divyabharathi, V., & Balamurugan, V. (2020). Chemical composition of *moringa (Moringa oleifera* Lam.) leaves from different germplasm. *International Journal of Chemical Studies, 8*(2), 2360-2363. https://doi.org/10.22271/chemi.2020.v8.i2aj.9103

Anwar, F., Latif, S., Ashraf, M., & Gilani, A. H. (2007). *Moringa oleifera*: a food plant with multiple medicinal uses. *Phytotherapy Research, 21*(1), 17-25. https://doi.org/10.1002/ptr.2023

Anwer, T., Safhi, M. M., Makeen, H. A., Alshahrani, S., Siddiqui, R., Sivakumar, S. M., Shaheen, E. S., & Alam, M. F. (2021). Antidiabetic potential of *Moringa oleifera* Lam. leaf extract in type 2 diabetic rats, and its mechanism of action. *Tropical Journal of Pharmaceutical Research, 20*(1), 95-103. https://doi.org/10.4314/tjpr.v20i1.15

Arodes, E. S., Cing, J. M., Sitompul, F., Kurniaty, L., Sunarti, L. S., & Siagian, F. E. (2022). Effectiveness of Methanol Extract of *Moringa oleifera* Lam. Leaf as Antibacterial Drug to Bacterial Triggers of Urinary Tract Infections *In vitro*. *Journal of Complementary and Alternative Medical Research, 17*(1), 1-12. https://doi.org/10.9734/jocamr/2022/v17i130321

Arozal, W., Purwoningsih, E., Lee, H. J., Barinda, A. J., & Munim, A. (2022). Effects of *Moringa oleifera* in two independents formulation and as neuroprotective agent against scopolamine-induced memory impairment in mice. *Frontiers in Nutrition, 9*, 799127. https://doi.org/10.3389/fnut.2022.799127

Athikomkulchai, S., Tunit, P., Tadtong, S., Jantrawut, P., Sommano, S. R., & Chittasupho, C. (2020). *Moringa oleifera* seed oil formulation physical stability and chemical constituents for enhancing skin hydration and antioxidant activity. *Cosmetics*, *8*(1), 2. https://doi.org/10.3390/cosmetics8010002

Azlan, U. K., Annuar, N. A. K., Mediani, A., Aizat, W. M., Damanhuri, H. A., Tong, X., Yanagisawa, D., Tooyama, I., Ngah, W. Z. W., Jantan, I., & Hamezah, H. S. (2023). An insight into the neuroprotective and anti-neuroinflammatory effects and mechanisms of *Moringa oleifera*. *Frontiers in Pharmacology, 13*, 1035220. https://doi.org/10.3389/fphar.2022.1035220

Balasubramaniam, D., & Easwaran, R. S. (2019). Economics of production of *moringa (Moringa oleifera* Lam) in Tamil Nadu. *International Journal of Farm Sciences, 9*(4), 112-118. https://doi.org/10.5958/2250-0499.2019.00105.8

Barbagallo, I., Vanella, L., Distefano, A., Nicolosi, D., Maravigna, A., Lazzarino, G., Di Rosa, M., Tibullo, D., Acquaviva, R., & Li Volti, G. (2016). *Moringa oleifera* Lam. improves lipid metabolism during adipogenic differentiation of human stem cells. *European Review for Medical and Pharmacological Sciences, 20*(24), 5223-5232.

Basra, S. M. A., Hussain, M., Wahid, A., & Farooq, M. (2018). Crop Diversification. In I. A. Khan & M. S. Khan (Eds.), *Developing Sustainable Agriculture in Pakistan* (pp. 311-340) Boca Raton, Florida: CRC Press.

Bhargavi, M. N., & Devang, P. J. (2023). A Review on Some Indian Medicinal Plants useful in Hair Care. *Current Traditional Medicine, 9*(2), 141-145. https://doi.org/10.2174/2215083808666220510165110

Bhattacharjee, M. (2020). *Moringa oleifera*: A potent immune booster in the catastrophe of covid-19. *Ecology, Environment and Conservation, 26*, S202-S209.

Bhattacharya, A., Tiwari, P., Sahu, P. K., & Kumar, S. (2018). A review of the phytochemical and pharmacological characteristics of *Moringa oleifera*. *Journal of Pharmacy and Bioallied Sciences, 10*(4), 181-191. https://doi.org/10.4103/JPBS.JPBS_126_18

Boopathi, N. M., & Abubakar, B. Y. (2021). Botanical Descriptions of *Moringa* spp. In N. M. Boopathi, M. Raveendran & C. Kole (Eds.), *The Moringa Genome* (pp. 11-20) Cham, Switzerland: Springer. https://doi.org/10.1007/978-3-030-80956-0_2

Cáceres, A., Saravia, A., Rizzo, S., Zabala, L., De Leon, E., & Nave, F. (1992). Pharmacologie properties of *Moringa oleifera*. 2: Screening for antispasmodic, antiinflammatory and diuretic activity. *Journal of Ethnopharmacology, 36*(3), 233-237. https://doi.org/10.1016/0378-8741(92)90049-W

Chelliah, R., Ramakrishnan, S., & Antony, U. (2017). Nutritional quality of *Moringa oleifera* for its bioactivity and antibacterial properties. *International Food Research Journal, 24*(2), 825-833.

Choudhary, M. K., Bodakhe, S. H., & Gupta, S. K. (2013). Assessment of the antiulcer potential of *Moringa oleifera* root-bark extract in rats. *Journal of Acupuncture and Meridian Studies, 6*(4), 214-220. https://doi.org/10.1016/j.jams.2013.07.003

Chukwuebuka, E. (2015). *Moringa oleifera* "the mother's best friend". *International Journal of Nutrition and Food Sciences, 4*(6), 624-630. https://doi.org/10.11648/j.ijnfs.20150406.14

Cretella, A. B. M., da Silva Soley, B., Pawloski, P. L., Ruziska, R. M., Scharf, D. R., Ascari, J., Cabrini, D. A., & Otuki, M. F. (2020). Expanding the anti-inflammatory potential of *Moringa oleifera*: topical effect of seed oil on skin inflammation and hyperproliferation. *Journal of Ethnopharmacology, 254*, 112708. https://doi.org/10.1016/j.jep.2020.112708

Dangi, S. Y., Jolly, C. I., & Narayanan, S. (2002). Antihypertensive activity of the total alkaloids from the leaves of *Moringa oleifera. Pharmaceutical Biology, 40*(2), 144-148.

Dantas, D. L., da Costa Alves, M., Dantas, G. M. S., Campos, A. R. N., de Santana, R. A. C., Soares, J. K. B., & Freitas, J. C. R. (2024). Supplementation with *Moringa oleifera* Lam leaf and seed flour during the pregnancy and lactation period of Wistar rats: Maternal evaluation of initial and adult neurobehavioral development of the rat progeny. *Journal of Ethnopharmacology, 325*, 117904. https://doi.org/10.1016/j.jep.2024.117904

Deng, Q., Li, X. X., Fang, Y., Chen, X., & Xue, J. (2020). Therapeutic potential of quercetin as an antiatherosclerotic agent in atherosclerotic cardiovascular disease: a review. *Evidence□Based Complementary and Alternative Medicine, 2020*, 5926381. https://doi.org/10.1155/2020/5926381

Deshmukh, P., Sharma, R. K., Sharma, V., & Jain, P. (2015).

Immunomodulatory activity of *Moringa oleifera* in albino rats. *Journal of Animal Research, 5*(2), 277-281. https://doi.org/10.5958/2277-940X.2015.00047.9

Devkota, S., & Bhusal, K. K. (2020). *Moringa oleifera*: A miracle multipurpose tree for agroforestry and climate change mitigation from the Himalayas–A review. *Cogent Food & Agriculture, 6*(1), 1805951. https://doi.org/10.1080/23311932.2020.1805951

Dou, Z., Chen, C., & Fu, X. (2019). Bioaccessibility, antioxidant activity and modulation effect on gut microbiota of bioactive compounds from *Moringa oleifera* Lam. leaves during digestion and fermentation *in vitro*. *Food & Function, 10*(8), 5070-5079. https://doi.org/10.1039/C9FO00793H

Duarte, J., Francisco, V., & Perez-Vizcaino, F. (2014). Modulation of nitric oxide by flavonoids. *Food & Function, 5*(8), 1653-1668. https://doi.org/10.1039/C4FO00144C

Dwivedi, G. R., Maurya, A., Yadav, D. K., Khan, F., Gupta, M. K., Gupta, P., Darokar, M. P., & Srivastava, S. K. (2019). Comparative drug resistance reversal potential of natural glycosides: Potential of synergy niaziridin & niazirin. *Current Topics in Medicinal Chemistry, 19*(10), 847-860. https://doi.org/10.2174/1568026619666190412120008

El Mahdy, R., Risha, S., Sisi, A., & Sobhy, W. (2020). Potential protective effects of sildenafil and *moringa* on experimentally-induced gastric ulcer in rats. *International Journal of Cancer and Biomedical Research, 4*(1), 43-55. https://doi.org/10.21608/jcbr.2020.20714.1007

El-Hack, M. E. A., Alagawany, M., Elrys, A. S., Desoky, E.-S. M., Tolba, H. M. N., Elnahal, A. S. M., Elnesr, S. S., & Swelum, A. A. (2018). Effect of forage *Moringa oleifera* L. *(moringa)* on animal health and nutrition and its beneficial applications in soil, plants and water purification. *Agriculture, 8*(9), 145. https://doi.org/10.3390/agriculture8090145

El-Mohamedy, R. S. R., & Abdalla, A. M. (2014). Evaluation of antifungal activity of *Moringa oleifera* extracts as natural fungicide against some plant pathogenic fungi *in-vitro*. *International Journal of Agricultural Technology, 10*(4), 963-982.

Fahey, J. W. (2005). *Moringa oleifera*: a review of the medical evidence for its nutritional, therapeutic, and prophylactic properties. *Trees for Life Journal, 1*(5), 1-15.

Fahey, J. W., Zalcmann, A. T., & Talalay, P. (2001). The chemical diversity and distribution of glucosinolates and isothiocyanates among plants. *Phytochemistry, 56*(1), 5-51. https://doi.org/10.1016/S0031-9422(00)00316-2

Faizi, S., Siddiqui, B. S., Saleem, R., Aftab, K., Shaheen, F., & Gilani, A. (1998). Hypotensive constituents from the pods of *Moringa oleifera*. *Planta Medica, 64*(3), 225-228. https://doi.org/10.1055/s-2006-957414

Fajri, M. (2021). The potential of *Moringa oleifera* as immune booster against COVID 19. *IOP Conference Series: Earth and Environmental Science, 807*, 022008. https://doi.org/10.1088/1755-1315/807/2/022008

Fidelis, K. R., Alves, R. R. D. V., Patriota, L. L. D. S., Coelho, L. C. B. B., Ferreira, M. R. A., Soares, L. A. L., de Oliveira, A. M., Napoleão, T. H., & Paiva, P. M. G. (2024). Saline Extract from *Moringa oleifera* Leaves Has Antidepressant and Anxiolytic Effects in Mouse Models. *Nutraceuticals, 4*(1), 65-81. https://doi.org/10.3390/nutraceuticals4010005

Fitriana, F., Lathifah, N. S., Parina, F., & Mariza, A. (2024). The Influence of *Moringa* Leaves Consumption on Infants with Low Birth Weight below the Green Line. *Jurnal Kebidanan Malahayati, 10*(3), 293-298.

Förster, N., Mewis, I., Glatt, H., Haack, M., Brigelius-Flohé, R., Schreiner, M., & Ulrichs, C. (2016). Characteristic single glucosinolates from *Moringa oleifera*: Induction of detoxifying enzymes and lack of genotoxic activity in various model systems. *Food & Function, 7*(11), 4660-4674. https://doi.org/10.1039/C6FO01231K

Gopalakrishnan, L., Doriya, K., & Kumar, D. S. (2016*). Moringa oleifera*: A review on nutritive importance and its medicinal application. *Food Science and Human Wellness, 5*(2), 49-56. https://doi.org/10.1016/j.fshw.2016.04.001

Hasin, Z. (2017). Synthesis of aroyl isothiocyanate derivatives of biological interest.

Hassan, M. A., Xu, T., Tian, Y., Zhong, Y., Ali, F. A. Z., Yang, X., & Lu, B. (2021). Health benefits and phenolic compounds of *Moringa oleifera* leaves: A comprehensive review. *Phytomedicine, 93*, 153771. https://doi.org/10.1016/j.phymed.2021.153771

Ijioma, S. N., Nwaogazi, E. N., Nwankwo, A. A., Oshilonya, H., Ekeleme, C. M., & Oshilonya, L. U. (2018). Histological exhibition of the gastroprotective effect of *Moringa oleifera* leaf extract. *Comparative Clinical Pathology, 27*, 327-332. https://doi.org/10.1007/s00580-017-2594-0

Imran, M., Salehi, B., Sharifi-Rad, J., Gondal, T. A., Saeed, F., Imran, A., Shahbaz, M., Fokou, P. V. T., Arshad, M. U., Khan, H., Guerreiro, S. G., Martins, N., & Estevinho, L. M. (2019). Kaempferol: A key emphasis to its anticancer potential. *Molecules, 24*(12), 2277. https://doi.org/10.3390/molecules24122277

Islam, M. N., Hossen, M. K., Joardar, J. C., Bokshi, B., Das, A. K., Sadhu, S. K., & Biswas, N. N. (2020). Diuretic and laxative activities of *Moringa oleifera* seeds and pods in mice. *Khulna University Studies, 17*(1-2), 31-39. https://doi.org/10.53808/KUS.2020.17.1and2.2006-L

Islam, Z., Islam, S. M. R., Hossen, F., Mahtab-ul-Islam, K., Hasan, M. R., & Karim, R. (2021). *Moringa oleifera* is a prominent source of nutrients with potential health benefits. *International Journal of Food Science, 2021*, 6627265. https://doi.org/10.1155/2021/6627265

Jahn, S. A. A. (2005). How Plant Names Reveal Folk Botanical Classification, Trade, Traditional Uses and Routes of Dissemination (I). *Studia Asiatica. International Journal for Asian Studies, 6*(1-2), 81-126.

Jaiswal, A. K. (2004). Nrf2 signaling in coordinated activation of antioxidant gene expression. *Free Radical Biology and Medicine, 36*(10), 1199-1207. https://doi.org/10.1016/j.freeradbiomed.2004.02.074

Jaiswal, D., Rai, P. K., Kumar, A., Mehta, S., & Watal, G. (2009). Effect of Moringa oleifera Lam. leaves aqueous extract therapy on hyperglycemic rats. *Journal of Ethnopharmacology, 123*(3), 392-396. https://doi.org/10.1016/j.jep.2009.03.036

Jaja-Chimedza, A., Graf, B. L., Simmler, C., Kim, Y., Kuhn, P., Pauli, G. F., & Raskin, I. (2017). Biochemical characterization and anti-inflammatory properties of an isothiocyanate-enriched *moringa (Moringa oleifera*) seed extract. *PloS One, 12*(8), e0182658. https://doi.org/10.1371/journal.pone.0182658

Jiang, M.-Y., Lu, H., Pu, X.-Y., Li, Y.-H., Tian, K., Xiong, Y., Wang, W., & Huang, X.-Z. (2020). Laxative Metabolites from the Leaves of *Moringa oleifera*. *Journal of Agricultural and Food Chemistry, 68*(30), 7850-7860. https://doi.org/10.1021/acs.jafc.0c01564

Joshua, O. O., Sunday, Y. O., John, A. O., & Temitope, Z. I. (2017). Exploring *Moringa Oleifera* Usefulness in Ameliorating Induced Retinopathy in Experimental Animals. *IOSR Journal of Pharmacy and Biological Sciences, 12*(5), 21-29.

Junlatat, J., & Sripanidkulchai, B. (2022*). Moringa oleifera* seed oil promotes hair growth in mice and modulates the genetic expressions of factors affecting hair growth cycle in skin cell culture. Songklanakarin *Journal of Science and Technology, 44*(3), 817-825. https://doi.org/10.14456/sjst-psu.2022.109

Karim, N. A. A., Ibrahim, M. D., Kntayya, S. B., Rukayadi, Y., Hamid, H. A., & Razis, A. F. A. (2016). *Moringa oleifera* Lam: Targeting Chemoprevention. *Asian Pacific Journal of Cancer Prevention, 17*(8), 3675-3686.

Khan, Z. J., & Khan, N. A. (2021). A Scientific Review on Phyto-pharmacological Properties of *Moringa olifera* Lam. *Research & Reviews: A Journal of Unani, Siddha and Homeopathy, 7*(3), 1-11.

Khazdair, M. R., Anaeigoudari, A., & Agbor, G. A. (2021). Anti-viral and anti-inflammatory effects of kaempferol and quercetin and COVID-2019: A scoping review. *Asian Pacific Journal of Tropical Biomedicine, 11*(8), 327-334. https://doi.org/10.4103/2221-1691.319567

Kheir, S. M., Kafi, S. K., & Elbir, H. (2014). The antimicrobial activity and phytochemical characteristic of *moringa oleifera* seeds, leaves, and flowers. *World Journal of Pharmaceutical Research, 4*(1), 258-271.

Kopustinskiene, D. M., Jakstas, V., Savickas, A., & Bernatoniene, J. (2020). Flavonoids as anticancer agents. *Nutrients, 12*(2), 457. https://doi.org/10.3390/nu12020457

Kumolosasi, E., Wei, C. C., Abdullah, A. Z., Manap, N. S. A., Lee, W. L., Yousuf, M. H., Ying, L. S., Buang, F., Said, M. M., Falina, H., & Jasamai, M. (2021). Antihypertensive activities of standardised *Moringa oleifera* Lam. (Merunggai) extracts in spontaneously hypertensive rats. *Sains Malaysiana, 50*(3), 769-778. https://doi.org/10.17576/jsm-2021-5003-18

Latif, N., Naeem, M. A., Aslam, B., & Rashid, A. (2020). Gastroprotective and Antioxidant Effects of Powdered Leaves of *Moringa Oleifera* against Experimentally Induced Peptic Ulcer in Male Mice. *Pakistan Journal of Agriculture, Agricultural Engineering and Veterinary Sciences, 36*(2), 141-148.

Lavanya, R., & Pattar, P. V. (2017). Traditional knowledge on folk medicine by rural women in Chikkanayakanahalli Taluk, Tumkur district, Karnataka. *International Journal of Herbal Medicine, 5*(2), 5-10.

Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J., & Bertoli, S. (2016). *Moringa oleifera* seeds and oil: Characteristics and uses for

human health. *International Journal of Molecular Sciences, 17*(12), 2141. https://doi.org/10.3390/ijms17122141

Leone, A., Spada, A., Battezzati, A., Schiraldi, A., Aristil, J., & Bertoli, S. (2015). Cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of *Moringa oleifera* leaves: An overview. *International Journal of Molecular Sciences, 16*(6), 12791-12835. https://doi.org/10.3390/ijms160612791

Leyva-López, N., Gutierrez-Grijalva, E. P., Ambriz-Perez, D. L., & Heredia, J. B. (2016). Flavonoids as cytokine modulators: a possible therapy for inflammation-related diseases. *International Journal of Molecular Sciences, 17*(6), 921. https://doi.org/10.3390/ijms17060921

Li, C., Dong, Z., Zhang, B., Huang, Q., Liu, G., & Fu, X. (2020). Structural characterization and immune enhancement activity of a novel polysaccharide from *Moringa oleifera* leaves. *Carbohydrate Polymers, 234*, 115897. https://doi.org/10.1016/j.carbpol.2020.115897

Li, Z., Li, X., Tang, S., Gao, Q., Li, C., Chen, P., Yue, X., Fu, R., Huang, X., Zhang, Y., Yang, H., & Yang, B. (2024). *Moringa oleifera* Lam. Leaf improves constipation of rats induced by low-fiber-diet: A proteomics study. *Journal of Ethnopharmacology, 318*, 116936. https://doi.org/10.1016/j.jep.2023.116936

Lim, A.-W., Ng, P.-Y., Chieng, N., & Ng, S.-F. (2019). *Moringa oleifera* leaf extract–loaded phytophospholipid complex for potential application as wound dressing. *Journal of Drug Delivery Science and Technology, 54*, 101329. https://doi.org/10.1016/j.jddst.2019.101329

Lim, W.-T., Hong, C.-E., & Lyu, S.-Y. (2024). The Antioxidant, Anti-Aging, Immunomodulatory, and Whitening Effects of *Moringa oleifera*. *Journal of the Korean Society of Food Science and Nutrition, 53*(2), 138-148. https://doi.org/10.3746/jkfn.2024.53.2.138

Lin, M., Zhang, J., & Chen, X. (2018). Bioactive flavonoids in *Moringa oleifera* and their health-promoting properties. *Journal of Functional Foods, 47*, 469-479. https://doi.org/10.1016/j.jff.2018.06.011

Lopez-Rodriguez, N. A., Gaytán-Martínez, M., de la Luz Reyes-Vega, M., & Loarca-Piña, G. (2020). Glucosinolates and isothiocyanates from *Moringa oleifera*: Chemical and biological approaches. *Plant Foods for Human Nutrition, 75*, 447-457. https://doi.org/10.1007/s11130-020-00851-x

Mahmood, K. T., Mugal, T., & Haq, I. U. (2010*). Moringa oleifera*: a natural gift-A review. *Journal of Pharmaceutical Sciences and Research, 2*(11), 775-781.

Mallenakuppe, R., Homabalegowda, H., Gouri, M. D., Basavaraju, P. S., & Chandrashekharaiah, U. B. (2015). History, taxonomy and propagation of *Moringa oleifera*–a review. *International Journal of Life Sciences, 5*(3), 2322-2327. https://doi.org/10.21276/SSR-IIJLS.2019.5.3.7

Mallick, S. N., Sahoo, T., Naik, S. K., & Panda, P. C. (2020). Ethnobotanical study of Wild Edible Food Plants used by the tribals and rural populations of Odisha, India for food and livelihood security. *Plant Archives, 20*(1), 661-669.

Mangundayao, K., & Yasurin, P. (2017). Bioactivity of *Moringa oleifera* and its Applications: A Review. *Journal of Pure and Applied Microbiology, 11*(1), 43-50. https://doi.org/10.22207/JPAM.11.1.07

Martínez-González, C. L., Martínez, L., Martínez-Ortiz, E. J., González-Trujano, M. E., Déciga-Campos, M., Ventura-Martínez, R., & Díaz-Reval, I. (2017*). Moringa oleifera,* a species with potential analgesic and anti-inflammatory activities. *Biomedicine & Pharmacotherapy, 87*, 482-488. https://doi.org/10.1016/j.biopha.2016.12.107

Masarkar, N., Ray, S. K., Saleem, Z., & Mukherjee, S. (2023). Potential anti-cancer activity of *Moringa oleifera* derived bio-active compounds targeting hypoxia-inducible factor-1 alpha in breast cancer. *Journal of Complementary and Integrative Medicine, 2023*. https://doi.org/10.1515/jcim-2023-0182

Maurya, S. K., & Singh, A. K. (2014). Clinical efficacy of *Moringa oleifera* Lam. stems bark in urinary tract infections. *International Scholarly Research Notices, 2014*, 906843. https://doi.org/10.1155/2014/906843

Mehwish, H. M., Liu, G., Rajoka, M. S. R., Cai, H., Zhong, J., Song, X., Xia, L., Wang, M., Aadil, R. M., Inam-Ur-Raheem, M., Xiong, Y., Wu, H., Amirzada, M. I., Zhu, Q., & He, Z. (2021). Therapeutic potential of *Moringa oleifera* seed polysaccharide embedded silver nanoparticles in wound healing. *International Journal of Biological Macromolecules, 184*, 144-158. https://doi.org/10.1016/j.ijbiomac.2021.05.202

Mehwish, H. M., Rajoka, M. S. R., Xiong, Y., Zheng, K., Xiao, H., Anjin, T., Liu, Z., Zhu, Q., & He, Z. (2022). *Moringa oleifera*–a functional food and its potential immunomodulatory effects. *Food Reviews International, 38*(7), 1533-1552. https://doi.org/10.1080/87559129.2020.1825479

Melrose, J. (2019). The glucosinolates: a sulphur glucoside family of mustard anti-tumour and antimicrobial phytochemicals of potential therapeutic application. *Biomedicines, 7*(3), 62. https://doi.org/10.3390/biomedicines7030062

Milla, P. G., Peñalver, R., & Nieto, G. (2021). Health benefits of uses and applications of *Moringa oleifera* in bakery products. *Plants, 10*(2), 318. https://doi.org/10.3390/plants10020318

Moyo, B., Masika, P. J., & Muchenje, V. (2012). Antimicrobial activities of *Moringa oleifera* Lam leaf extracts. *African Journal of Biotechnology, 11*(11), 2797-2802. https://doi.org/10.5897/AJB10.686

Muhammad, A. A., Pauzi, N. A. S., Arulselvan, P., Abas, F., & Fakurazi, S. (2013). *In vitro* wound healing potential and identification of bioactive compounds from *Moringa oleifera* Lam. *BioMed Research International, 2013*, 974580. https://doi.org/10.1155/2013/974580

Mutar, Y. S., Al-Rawi, K. F., & Mohammed, M. T. (2021). *Moringa oleifera*: Nutritive importance and its medicinal application, as a Review. *Egyptian Journal of Chemistry, 64*(11), 6827-6834. https://doi.org/10.21608/ejchem.2021.78212.3823

Muzammil, S., Cruz, J. N., Mumtaz, R., Rasul, I., Hayat, S., Khan, M. A., Khan, A. M., Ijaz, M. U., Lima, R. R., & Zubair, M. (2023). Effects of drying temperature and solvents on in vitro diabetic wound healing potential of *Moringa oleifera* leaf extracts. *Molecules, 28*(2), 710. https://doi.org/10.3390/molecules28020710

Naidu, S. D., Suzuki, T., Yamamoto, M., Fahey, J. W., & Dinkova-Kostova, A. T. (2018). Phenethyl isothiocyanate, a dual activator of transcription factors NRF2 and HSF1. *Molecular Nutrition & Food Research, 62*(18), 1700908. https://doi.org/10.1002/mnfr.201700908

Nisar, N., Ajmal, M., Hanif, N. Q., & Hassan, S. W. (2024). Phytochemicals analysis and aflatoxin B1 detoxification potential of leaves extract of *Moringa oleifera* and Calotropis procera. *Natural Product Research,* 1-9. https://doi.org/10.1080/14786419.2024.2342003

Nnam, N. M. (2009). *Moringa oleifera* leaf improves iron status of infants 6-12 months in Nigeria. *International Journal of Food Safety, Nutrition and Public Health, 2*(2), 158-164. https://doi.org/10.1504/IJFSNPH.2009.029281

Nubi, T., Adewole, T. S., Agunbiade, T. O., Osukoya, O. A., & Kuku, A. (2021). Purification and erythrocyte-membrane perturbing activity of a ketose-specific lectin from *Moringa oleifera* seeds. *Biotechnology Reports, 31*, e00650. https://doi.org/10.1016/j.btre.2021.e00650

Ogbunugafor, H., Igwo-Ezikpe, M., Igwilo, I., Ozumba, N., Adenekan, S., Ugochukwu, C., Onyekwelu, O., & Ekechi, A. (2012). *In vitro* and *in vivo* evaluation of antioxidant properties of *Moringa oleifera* ethanolic leaves extract and effect on serum lipid indices in rat. *Macedonian Journal of Medical Sciences, 5*(4), 397-403. https://doi.org/10.3889/MJMS.1857-5773.2012.0240

Olayanju, J. B., Bozic, D., Naidoo, U., & Sadik, O. A. (2024). A Comparative Review of Key Isothiocyanates and Their Health Benefits. *Nutrients, 16*(6), 757. https://doi.org/10.3390/nu16060757

Olson, M. E. (2015). Moringa frequently asked questions. *Acta Horticulturae, 1158*, 19-32. https://doi.org/10.17660/ActaHortic.2017.1158.4

Onyekaba, T. U., Chinedu, O. G., & Fred, A. C. (2013). Phytochemical Screening and Investigations of Antibacterial Activities of Various Fractions of the Ethanol Leaves Extract of *Moringa Oleifera* Lam (Moringaceae). *Journal of Pharmaceutical, Chemical and Biological Sciences, 3*(3), 962-973.

Owens III, F. S., Dada, O., Cyrus, J. W., Adedoyin, O. O., & Adunlin, G. (2020). The effects of *Moringa oleifera* on blood glucose levels: a scoping review of the literature. *Complementary Therapies in Medicine, 50*, 102362. https://doi.org/10.1016/j.ctim.2020.102362

Paliwal, R., Sharma, V., Pracheta, & Sharma, S. (2011). Elucidation of free radical scavenging and antioxidant activity of aqueous and hydro-ethanolic extracts of *Moringa oleifera* pods. *Research Journal of Pharmacy and Technology, 4*(4), 566-571.

Pareek, A., Pant, M., Gupta, M. M., Kashania, P., Ratan, Y., Jain, V. Pareek, A., & Chuturgoon, A. A. (2023). *Moringa oleifera*: An updated comprehensive review of its pharmacological activities, ethnomedicinal, phytopharmaceutical formulation, clinical, phytochemical, and toxicological aspects. *International Journal of Molecular Sciences, 24*(3), 2098. https://doi.org/10.3390/ijms24032098

Patel, K., Kumar, V., Verma, A., Rahman, M., & Patel, D. K. (2017). β-sitosterol: bioactive compounds in foods, their role in health promotion and disease prevention "a concise report of its phytopharmaceutical importance". *Current Traditional Medicine, 3*(3), 168-177. https://doi.org/10.2174/2215083803666170615111759

Patel, S., Thakur, A. S., Chandy, A., & Manigauha, A. (2010). *Moringa oleifera:* a review of their medicinal and economic importance to the health and nation. *Drug Invention Today, 2*(7), 339-342.

Prieto, M. A., López, C. J., & Simal-Gandara, J. (2019). Glucosinolates: Molecular structure, breakdown, genetic, bioavailability, properties and healthy and adverse effects. *Advances in Food and Nutrition Research, 90*, 305-350. https://doi.org/10.1016/bs.afnr.2019.02.008

Ragasa, C. Y., Medecilo, M. P., & Shen, C.-C. (2015). Chemical constituents of *Moringa oleifera* Lam. leaves. *Der Pharma Chemica, 7*(7), 395-399.

Rastogi, S., Farswan, T. S., & Pandey, M. M. (2024). Seasonal variation in the phytoconstituents and antioxidant activity in *Moringa oleifera* Lam. leaves of North India. *South African Journal of Botany, 166*, 492-502. https://doi.org/10.1016/j.sajb.2024.01.054

Ravindra, A. V., Priya, R., & Siddheshwar, S. S. (2019). A pharmacological review on *Moringa oleifera*. *World Journal of Pharmaceutical Research, 88*(8), 910-920.

Ravishankar, M., Kaur, D. P., Bhushan, K. B., & Easdown, W. J. (2014). Traditional leafy vegetables of a tribal community in Jharkhand, India. *Acta Horticulturae, 1102*, 43-52. https://doi.org/10.17660/ActaHortic.2015.1102.4

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

Rukmani, R., Anuradha, G., Gopinath, R., & Kannan, S. (2018a). Farming system for nutrition: need and scope in Andhra Pradesh.

Rukmani, R., Anuradha, G., Gopinath, R., & Kannan, S. (2018b). Farming system for nutrition: need and scope in Maharashtra.

Rukmani, R., Anuradha, G., Gopinath, R., & Kannan, S. (2018c). Farming system for nutrition: need and scope in Bihar.

Sahay, S., Yadav, U., & Srinivasamurthy, S. (2017). Potential *of Moringa oleifera* as a functional food ingredient: A review. *International Journal of Food Science and Nutrition, 2*(5), 31-37.

Sahoo, J. P., Mohapatra, U., Sahoo, S., & Samal, K. C. (2020). Insights into the miracle plant *Moringa oleifera. Pharma Inn. J*, *9*(7), 473-479.

Shady, N. H., Mostafa, N. M., Fayez, S., Abdel-Rahman, I. M., Maher, S. A., Zayed, A., Saber, E. A., Khowdiary, M. M., Elrehany, M. A., Alzubaidi, M. A., Altemani, F. H., Shawky, A. M., & Abdelmohsen, U. R. (2022). Mechanistic wound healing and antioxidant potential of *moringa oleifera* seeds extract supported by metabolic profiling, in silico network design, molecular docking, and in vivo studies. *Antioxidants, 11*(9), 1743. https://doi.org/10.3390/antiox11091743

Shah, L., Baxi, N., Shah, A., & Akhani, T. K. (2022). An Overview of the Health Benefits of Drumstick Pods. *Asian Pacific Journal of Health Sciences, 9*(3), 10-14. https://doi.org/10.21276/apjhs.2022.9.3.03

Shanmugavel, G., Prabakaran, K., & George, B. (2018). Evaluation of phytochemical constituents of *Moringa oleifera* (Lam.) leaves collected from Puducherry region, South India. *International Journal of Zoology and Applied Biosciences, 3*(1), 1-8.

Sharma, T. (2024). Antibiotic and antifungal characteristics of *moringa* (*Moringa oleifera*). *Journal of Rural Advancement, 12*(1), 34-49.

Singh, A. K., Rana, H. K., Tshabalala, T., Kumar, R., Gupta, A., Ndhlala, A. R., & Pandey, A. K. (2020). Phytochemical, nutraceutical and pharmacological attributes of a functional crop *Moringa oleifera* Lam: An overview. *South African Journal of Botany, 129*, 209-220. https://doi.org/10.1016/j.sajb.2019.06.017

Singh, H. K., Solankey, S. S., Ray, P. K., Singh, P., Shamim, M., Singh, R. N., & Kumar, A. (2023). Impact of climate change on underexploited vegetable crops production and mitigation strategies. In S. S. Solankey & M. Kumari (Eds.), *Advances in Research on Vegetable Production Under a Changing Climate* (Vol. 2, pp. 149-166). Cham, Switzerland: Springer International Publishing. https://doi.org/10.1007/978-3-031-20840-9_7

Sreelatha, S., & Padma, P. R. (2009). Antioxidant activity and total phenolic content of *Moringa oleifera* leaves in two stages of maturity. *Plant Foods for Human Nutrition, 64*, 303-311. https://doi.org/10.1007/s11130-009-0141-0

Sultana, S. (2020). Nutritional and functional properties of *Moringa oleifera. Metabolism Open, 8*, 100061. https://doi.org/10.1016/j.metop.2020.100061

Sumiatya, Tahir, A., Burhanuddin, B., Nurhaedar, J., & Veni, H. (2020). The effect of *moringa* leaves on pregnancy on growth and morbidity of 6–11 month. *Enfermeria Clinica, 30*(S4), 104-108. https://doi.org/10.1016/j.enfcli.2019.10.051

Tan, W. S., Arulselvan, P., Karthivashan, G., & Fakurazi, S. (2015). *Moringa oleifera* flower extract suppresses the activation of inflammatory mediators in lipopolysaccharide-stimulated RAW 264.7 macrophages via NF-κB pathway. *Mediators of Inflammation, 2015*(1), 720171. https://doi.org/10.1155/2015/720171

Thakur, S. K., Pal, R., Pandey, P., Havelikar, U., & Singh, R. P. (2024). A systematic review on several therapeutics' activities and recent trends on *Moringa oleifera* an traditional medical plant. *Journal of Pharmacognosy and Phytochemistry, 13*(2), 136-142. https://doi.org/10.22271/phyto.2024.v13.i2b.14878

Udechukwu, M. C., Abbey, L., Nwodo, U., & Udenigwe, C. C. (2018). Potential of *Moringa oleifera* seeds and leaves as functional food ingredients for human health promotion. *Journal of Food and Nutrition Research, 57*(1), 1-14.

ul Islam, B., Suhail, M., Khan, M. S., Ahmad, A., Zughaibi, T. A., Husain, F. M., Rehman, M. T., & Tabrez, S. (2021). Flavonoids and PI3K/Akt/mTOR signaling cascade: a potential crosstalk in anticancer treatment. *Current Medicinal Chemistry, 28*(39), 8083-8097. https://doi.org/10.2174/0929867328666210804091548

Uwaifo, F. (2020). Evaluation of weight and appetite of adult wistar rats supplemented with ethanolic leaf extract of *Moringa oleifera*. *Biomedical and Biotechnology Research Journal, 4*(2), 137-140. https://doi.org/10.4103/bbrj.bbrj_17_20

Valdés-Rodríguez, O. A. (2023). Metabolites in *Moringa oleifera* and their associated health potentials. *Studies in Natural Products Chemistry, 76*, 299-330. https://doi.org/10.1016/B978-0-323-91296-9.00003-4

Wang, F., Bao, Y., Zhang, C., Zhan, L., Khan, W., Siddiqua, S., Ahmad, S., Capanoglu, E., Skalicka-Woźniak, K., Zou, L., Simal-Gandara, J., Cao, H., Weng, Z., Shen, X., & Xiao, J. (2022). Bioactive components and anti-diabetic properties of *Moringa oleifera* Lam. *Critical Reviews in Food Science and Nutrition, 62*(14), 3873-3897. https://doi.org/10.1080/10408398.2020.1870099

Wu, Y.-Y., Xu, Y.-M., & Lau, A. T. Y. (2021). Anti-cancer and medicinal potentials of *moringa* isothiocyanate. *Molecules, 26*(24), 7512. https://doi.org/10.3390/molecules26247512

Xie, J., Peng, L.-J., Yang, M.-R., Jiang, W.-W., Mao, J.-Y., Shi, C.-Y., Tian, Y., & Sheng, J. (2021). Alkaloid Extract of *Moringa oleifera* Lam. Exerts Antitumor Activity in Human Non-Small-Cell Lung Cancer via Modulation of the JAK2/STAT3 Signaling Pathway. *Evidence-Based Complementary and Alternative Medicine, 2021*(1), 5591687. https://doi.org/10.1155/2021/5591687

Xu, Y., Chen, G., & Guo, M. (2022). Potential anti-aging components from *Moringa oleifera* leaves explored by affinity ultrafiltration with multiple drug targets. *Frontiers in Nutrition, 9*, 854882. https://doi.org/10.3389/fnut.2022.854882

Xu, Y., Chen, G., Muema, F. W., Xiao, J., & Guo, M. (2024). Most Recent Research Progress in *Moringa oleifera*: Bioactive Phytochemicals and Their Correlated Health Promoting Effects. *Food Reviews International, 40*(2), 740-770. https://doi.org/10.1080/87559129.2023.2195189

Xu, Y.-B., Chen, G.-L., & Guo, M.-Q. (2019). Antioxidant and anti-inflammatory activities of the crude extracts of *Moringa oleifera* from Kenya and their correlations with flavonoids. *Antioxidants, 8*(8), 296. https://doi.org/10.3390/antiox8080296

Yoshimatsu, H., Tanaka, R., Kawamura, K., Huang, Z., Kamada, S., Fukuhara, T., Kano, K., Doi, T., & Miyake, T. (2023). Antifungal effect of *Moringa oleifera* leaf extract on *Candida albicans*. *Journal of Osaka Dental University, 57*(2), 295-299. https://doi.org/10.18905/jodu.57.2_295

Zhang, H.-W., Hu, J.-J., Fu, R.-Q., Liu, X., Zhang, Y.-H., Li, J., Liu, L., Li, Y.-N., Den, Q., Luo, Q. S., Ouyang, Q., & Gao, N. (2018). Flavonoids inhibit cell proliferation and induce apoptosis and autophagy through downregulation of PI3Kγ mediated PI3K/AKT/mTOR/p70S6K/ULK signaling pathway in human breast cancer cells. *Scientific Reports, 8*, 11255. https://doi.org/10.1038/s41598-018-29308-7

Zhao, W., Shi, G., Gu, H., & Nguyen, N. B. (2016). Role of PPARγ in the nutritional and pharmacological actions of carotenoids. *Research and Reports in Biochemistry, 6*, 13-24. https://doi.org/10.2147/RRBC.S83258

Zughaibi, T. A., Suhail, M., Tarique, M., & Tabrez, S. (2021). Targeting PI3K/Akt/mTOR pathway by different flavonoids: a cancer chemopreventive approach. *International Journal of Molecular Sciences, 22*(22), 12455. https://doi.org/10.3390/ijms222212455