WISELEAF SCIENTIFIC VENTURES

Chapter 2: Phytochemical Composition and Bioactive Constituents of *Moringa oleifera*

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Abstract:
Moringa oleifera, known as the "Miracle Tree," is a highly regarded plant for its rich nutrition and abundance of bioactive phytochemicals that provide many pharmaceutical properties. Each part of this plant (leaf, seed, flower, pod, bark, and root) contains different bioactive components that provide a variety of properties, including antioxidant, anti-inflammatory, antibiotic, antidiabetic, anticancer, hepatoprotective (liver protective), cardioprotective (heart protective), and neuroprotective (nervous system protective). The primary focus of this chapter is to provide an overview of the phytochemical profile of Moringa oleifera, specifically the distribution of bioactive components throughout the plant and their potential value medicinally. A second focus is to present an overview of traditional and advanced methods to extract and characterize the phytochemicals and the impact of environmental, geographic, and processing variables on the phytochemical content. A third focus will be to discuss the industrial, nutraceutical, pharmaceutical, and functional food applications of Moringa oleifera and provide future direction and challenges to the isolation, standardization, and commercialization of Moringa oleifera bioactive components. Overall, this chapter will summarize the current scientific data on the phytochemical richness of *Moringa oleifera* and the important role it can play in drug discovery, health promotion and sustainable therapeutic development.
Keywords: *Moringa oleifera*, phytochemicals, bioactive constituents, flavonoids, glucosinolates, phenolic compounds.

2.1 Introduction:

Moringa oleifera Lam., known commonly as the "Miracle Tree" or drumstick tree, is drought-resistant and quick-growing and originates from the Indian subcontinent; it is now grown extensively across tropical and subtropical areas of the world [1]. An increasing interest in scientific research and commercial use of moringa is due to its incredible nutritional value as well as its diverse composition of phytochemicals [2]. Almost every part of M. oleifera, from its branches to its leaves to its seeds and pods, contains an abundant variety of bioactive compounds such as flavonoids, phenolic acid, glucosinolate, isothiocyanate, alkaloid, saponin, tannin, vitamin, and mineral content. These different types of phytochemicals exhibit a wide range of biological activity, including but not limited to: Antioxidant, Anti-inflammatory, Antimicrobial, Antidiabetic, Anticancer, Cardioprotective. For these reasons, M. oleifera has become increasingly utilized as a nutraceutical, in functional foods, as an herbal medicine, and as a cosmetic ingredient [3]. In addition, improvements in phytochemical extraction and analytical methodologies have improved the knowledge of the therapeutic potential of M. oleifera and helped to establish quality standards for M. oleifera [4]. The aim of this Chapter will be to review the phytochemical composition of M. oleifera, including the various classes of bioactive components present in its anatomy, together with their pharmacological properties and possible uses in food supplements, pharmaceuticals, and industrial applications.

2.2 Botanical Overview of *Moringa oleifera*:

Moringa Oleifera, commonly known as Moringa, is part of the Moringaceae family of plants, which has only one genus consisting of 13 species (most of them very similar). Of all those species, Moringa Oleifera is by far the most popular and valuable for use by humans [5]. The Moringa plant originated in the sub-Himalayan regions of NW India but is now grown all over the world in tropical and subtropical environments due to its ability to thrive under a wide variety of climatic conditions and its many uses as a food source and/or medicinal plant [6]. Botanically speaking, Moringa Oleifera is a fast-growing, woody perennial tree that can be anywhere from 5 to 12 m tall when fully matured. It has a soft, brittle trunk that is covered with cork-like, grey-white bark and has a large umbrella-shaped canopy supported by long drooping branches. The leaves of the Moringa tree are arranged alternately on the stem and are either bi-pinnately or tri-pinnately arranged. Each leaf measures anywhere from 20 to 60 cm long and has numerous oval-shaped leaflets that are each very nutrient-dense and contain many different types of Phytochemicals [7]. Moringa trees produce beautiful cream-coloured flowers that are fragrant and found in clusters growing from the axillary buds. They are perfect for pollination by insects, which helps to ensure that Moringa trees produce fruit. Moringa fruit is long, drooping, and triangular-shaped. The pods can measure anywhere from 20 to 60 cm or longer. Each pod contains several dark-brown globular seeds, which are each covered in three side-skins (i.e., paper-like wings), aiding in the dispersal of the seeds by the wind. M. oleifera is a highly adaptable tree, capable of withstanding droughts due to its long taproot. It grows best in well-drained soils (sandy or loamy) having a pH of between 5.0 to 9.0 and temperatures from 25 degrees Celsius to 35 degrees Celsius. Because of the fast-growing manner in which M. oleifera grows, the great ease with which it can be cultivated, and its ability to grow in a wide range of climatic conditions, it has become an important multipurpose tree for food, medicine, agriculture, and industrial uses all over the world [7].

2.3 Bioactive Constituents in Different Parts of *Moringa oleifera*:

The different parts of Moringa oleifera (i.e., tree) have a different distribution of bioactive constituents which leads to the variation in nutritional and medicinal properties amongst the different parts, e.g. Leaves are high in flavonoids, phenolic acids, glucosinolates, vitamins, and minerals; seeds contain fixed oils, sterols, tocopherols, and bioactive peptides; pods are rich in dietary fibre, carotenoids, and Vitamin C; and flowers have high levels of flavonoids and phenolic compounds. The bark and root contain various phytochemicals (e.g., alkaloids, tannins, saponins, terpenoids, and glucosinolates) that have pharmacological properties. As a result, M. oleifera has a significant number of different phytochemicals that can be used as bioactive compounds in pharmaceutical and nutraceutical industries, and therefore M. oleifera is an excellent source of bioactive compounds for functional food applications.

2.3.1 Leaves- The leaves of the moringa plant (Moringa oleifera) contain many bioactive substances like flavonoids (quercetin and kaempferol) and so on (for example, quercetin and

kaempferol), which are very high in concentration in moringa leaves. Flavonoids have strong antioxidant properties, and anti-inflammatory effects, and are also known to help reduce inflammation. In summary, glucosinolates, isothiocyanate, carotenoids, vitamins (A, C, and E), and essential minerals found in moringa infusions are all important for their antioxidant, anti-inflammatory, antimicrobial, antidiabetic, and hepatoprotective properties [8, 9].

2.3.2 Seeds- High concentrations of Fixed Oil rich in oleic acid, Glucosinolates, Isothiocyanates, Tocopherols, Sterols, Proteins, and Bio-active peptides are found in the seeds. Due to antioxidant, antimicrobial, anti-inflammatory and Water Purification properties, seed extracts have been studied and developed for use in pharmaceutical, nutraceutical, and environmental areas [10].

2.3.3 Pods- Vitamin C, dietary fibre, carotenoids, polyphenols, flavonoids, amino acids and essential minerals are contained in immature pods to make them very nutritious. In addition to their nutritional benefits, these bioactive compounds also provide antioxidant activity and support cardiovascular health, immune function and digestive health [11].

2.3.4 Flowers- Moringa flower contains flavonoids, phenolic compounds, amino acids, nectar sugars, and the essential minerals that are known to exhibit antioxidant, anti-inflammatory, hypo-cholesterolemic, and antimicrobial properties. The Moringa flowers are considered to be functional foods in many locations around the world [12].

2.3.5 Bark- Alkaloidal compounds (moringine and moringinine), tannins, saponins, terpenoids, and phenolic compounds are the phytochemicals present in the bark. Many of these compounds exhibit antimicrobial, anti-inflammatory, analgesic properties, antihypertensive activity, as well as cardioprotective abilities. Traditionally, the extract of the bark has been used to treat fever, infection, and inflammatory conditions [9].

2.3.6 Roots- The alkaloids, glucosinolates, isothiocyanates, terpenoids, sterols, and phenolic compounds found in the root of this plant are abundant. The extracts from the root have been reported to have antimicrobial, antioxidant, anti-inflammatory, and analgesic properties. However, due to the presence of compounds such as spirochin, which may produce toxic effects when consumed in excess amounts, it is advisable to limit the quantity consumed [13].

2.4 Pharmacological Significance of Major Bioactive Constituents:

Moringa oleifera contains various bioactive constituents. The flavonoids, phenolic acids, glucosinolates, isothiocyanates, alkaloids, tannins, saponins and carotenoids of the tree contribute to its pharmacological activities. The phytochemicals possess antioxidant properties by neutralising free radicals and reducing oxidative stress, as well as providing anti-inflammatory properties by inhibiting pro-inflammatory cytokines and signalling pathways. These phytochemicals also exhibit antidiabetic, antimicrobial, anticancer, cardioprotective, hepatoprotective, and neuroprotective actions through regulation of glucose metabolism; inhibition of pathogenic microorganisms; suppression of tumor cell growth; protection of the heart liver and brain; and enhancement of the cellular defence system. The synergistic effects

of these compounds have made M. oleifera popular for use in the development of functional foods, nutraceuticals, and plant-based therapeutics. Thus, M. oleifera is considered to be one of the most important medicinal plants with a high degree of potential for the prevention and management of many chronic and degenerative diseases [2, 4, 14]. The various pharmacological activity of this plant is shown in **Figure 1**.

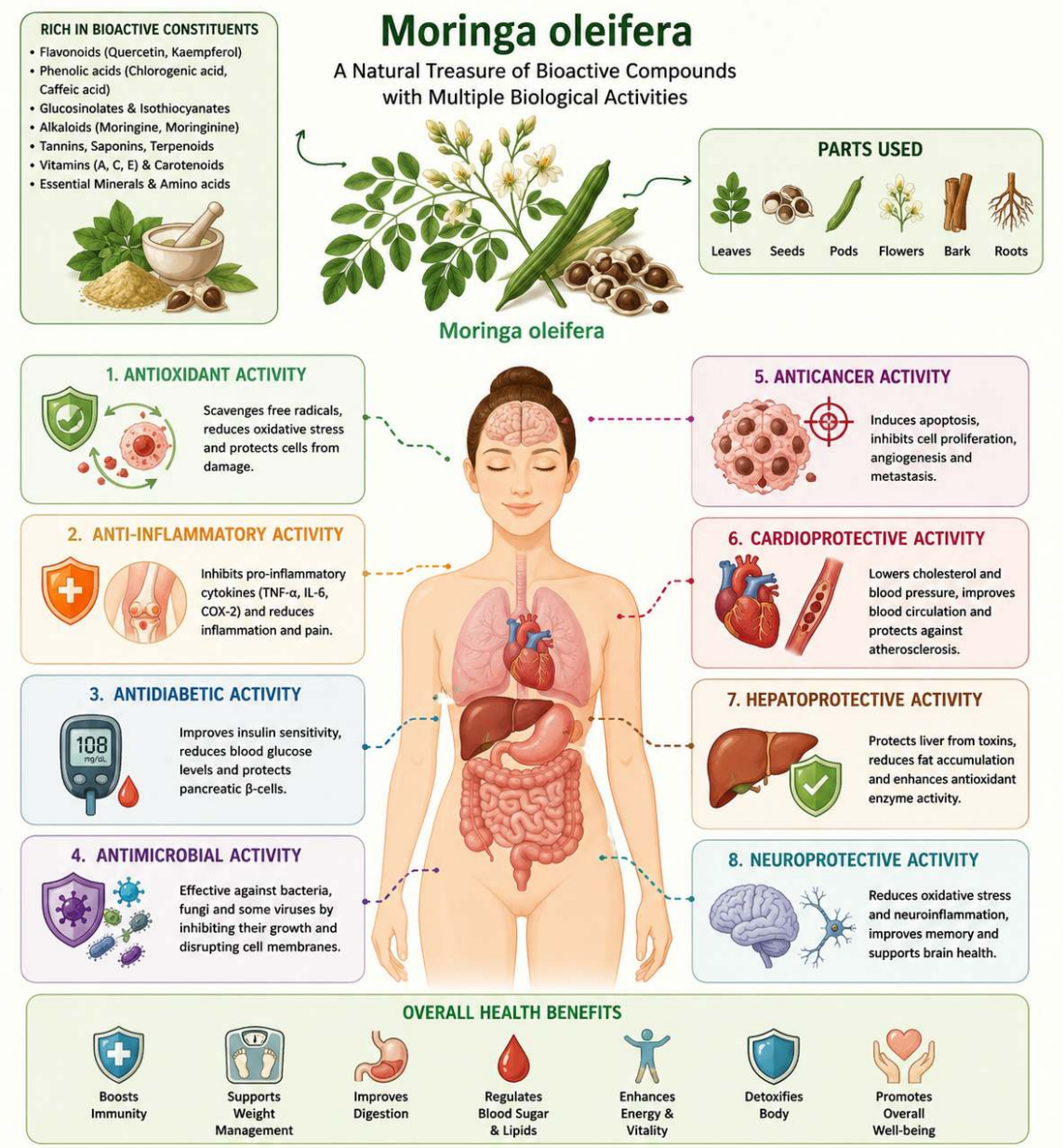


Figure 1: Pharmacological activity of *Moringa oleifera.*

- **Antioxidant Activity-** Moringa oleifera, is high in flavonoids, (including quercetin and kaempferol), phenolic acids (for instance, chlorogenic acid), and vitamins C and E (tocopherols), which remove or inactivate reactive oxygen species (ROS) and decrease the

level of oxidative stress. The activity of these antioxidant compounds protects the cellular structures from damage due to free-radical activity, thereby decreasing the likelihood of developing chronic diseases and promoting good health.

- **Anti-inflammatory Activity-** The bioactive components of Moringa oleifera contain isothiocyanates, flavonoids, and polyphenols that can inhibit TNF-α, and IL-6, while COX-2, and NF-κB signaling pathways are all pro-inflammatory mediators. These compounds have anti-inflammatory properties as well as being effective at reducing the production of reactive oxygen species (ROS), so consumption or application of M. oleifera would provide the potential to treat or support the treatment of inflammatory disorders, including arthritis and cardiovascular diseases.
- **Antidiabetic Activity-** By increasing insulin sensitivity, blocking the breakdown (Digestion) of carbohydrates, and reducing the amount of sugar that is produced by the liver, Chlorogenic acid, Quercetin, and Isothiocyanates work together to increase the utilization of glucose in the body. They have also been shown to help reduce oxidative stress caused by having diabetes, which has led to improved glycemic control.
- **Antimicrobial Activity-** Many phytochemicals, such as isothiocyanates, Pterygo-spermin, flavonoids, and phenolic compounds, exhibit broad-spectrum antimicrobial activity (against Gram-positive and Gram-negative bacteria, fungi, and certain viruses). The phytochemicals disrupt the integrity of microbial cell membranes, inhibit enzyme activity, and prevent microbial growth.
- **Anticancer Activity-** Numerous plant-based food sources provide bioactive compounds that are anticancer agents. They include quercetin, niazimicin, glucosinolates, and isothiocyanates. Bioactive compounds can slow or stop the proliferation of cancer cells via apoptosis, angiogenesis inhibition, and regulation of the cellular life cycle. In addition to possibly decreasing tumor formation and growth by limiting oxidative stress and inflammation, bioactive compounds can also limit the inflammatory response associated with cancer.
- **Cardioprotective Activity-** Cardiovascular system benefits as a result of flavonoids; polyphenols; phytosterols lowering lipid peroxidation; cholesterol in serum; regulating blood pressure and enhancing endothelial function. All of these compounds work together to provide protection from cardiovascular issues through antioxidant activities, anti-inflammatory properties, and by preventing the development of atherosclerotic disease.
- **Hepatoprotective Activity-** Several chemical substances found in Moringa Oleifera, including some phenolic compounds (quercetin and chlorogenic acid), as well as vitamins C and E, have been shown to protect the liver from both oxidants and toxins. Moreover, these agents increase the activity of many antioxidant enzymes, lower the deposition of fats in the liver, and stimulate regeneration of the liver; thus, M. oleifera may be helpful for the prevention of hepatic disease.

- **Neuroprotective Activity-** There are several compounds such as flavonoids, phenolic acids and isothiocyanates, which have been found to have neuroprotective properties through some of these mechanisms; 1) Antioxidative effects through reduced oxidative stress, 2) Inhibition of neuroinflammation, and 3) Stimulation of the body's own antioxidant defenses. These bioactive substances may be able to improve cognition and potentially have therapeutic value for neurodegenerative diseases like Alzheimer's disease or Parkinson's disease (neurodegenerative diseases).

2.5 Factors Affecting Phytochemical Composition:

Phytochemical contents of Moringa oleifera may vary depending on several things including, but not limited to geography, the environment, when the moringa is harvested, and how it's handled after being harvested. Different types of climates, soil, and elevation produce different levels of phenolic and flavonoid compounds; in addition to other bioactive molecules. Environmental factors can influence the production of secondary metabolites as well (i.e. temperature, sunlight, availability of water). The time of harvest will also have an effect on the quantity of phytochemicals contained within the plant; generally speaking, younger leaves have a higher concentration of anti-oxidants than those that are older. In addition, there are several ways that phytochemicals can be processed and stored during their journey from farm to consumer. These processing methods and storage conditions greatly affect the stability and preservation of phytochemicals and therefore the value of the M. oleifera plant as a food or medicine source for human use [15, 16].

- **Geographic Variation-** Moringa oleifera has a different type of chemicals based on where it is growing because of factors including soil type, elevation above sea level (altitude), rainfall amounts, and climate. Research has indicated that when grown in separate nations, Moringa plants will have a variance in phenols, flavanoids, glucosinolates and antioxidant potential. For instance, moringa leaves grown in India are found to be higher in quercitin and cholorogu acid than those grown in Africa which will have a different medicinal and nutritional properties.
- **Environmental Factors-** Phytochemical production in Moringa oleifera is majorly affected by environmental factors, including temperature, light levels, availability of water and nutrient status of soil. High levels of drought stress and greater amounts of light may enhance production of secondary metabolites (e.g., polyphenols, flavonoids) as a protective response to oxidative stress. However, excessive amounts of moisture and a lack of nutrients may result in lesser quantities of bioactive compounds and thus will negatively impact the medicinal potential.
- **Harvesting Stage-** The plant maturity stage during harvest greatly impacts how much phytochemicals are present in Moringa oleifera. For example, young Moringa leaves have much higher levels of phenolics, Vitamin C, and flavonoids than mature leaves; this is due to age-related metabolic changes that occur with increasing plant maturity that affect both

the synthesis and accumulation of these bioactive compounds. As a result, it is important to harvest at the correct stage of maturity to achieve the highest possible nutritional quality and medicinal value of Moringa.

- **Processing and Storage-** Phytochemical stability in Moringa oleifera is influenced by post-harvest processing and storage conditions. The drying method that is used for the Moringa plant, as well as the drying temperature, exposure to light during drying, and length of time that the product is stored have all been shown to contribute to degradation of phenolic compounds, carotenoids, and vitamin C. It is generally recommended that antioxidant compounds be preserved by choosing shade drying as the drying method and using low temperature during processing. Improper storage conditions, including high humidity and high temperatures, have been shown to accelerate the process of oxidation and decrease the nutritional quality and medicinal value of the plant.

2.6 Industrial and Therapeutic Applications:

Moringa oleifera is well known for its numerous uses in both industry and medicine, with its rich mix of bioactive compounds that include flavonoids, phenolic acids, glucosinolates, vitamins and minerals. In industry, M. oleifera has many applications as a nutritional additive and natural preservative in the food sector due to its high levels of antioxidants. The oil extracted from M. oleifera seeds (known as ben oil) is used in both cosmetics and pharmaceuticals for the production of soap, lotion and hair-care products; because it offers excellent moisturising and oxidative stability properties. Finally, the seeds of M. oleifera are also utilized as natural coagulants when purifying water, in order to eliminate impurities and microbial contaminants from the supplied drinking water [1].

Medicinally, M. oleifera has many beneficial effects due to its medicinal properties; some of them are anti-oxidant, anti-inflammatory, antimicrobial, anti-diabetic, anti-hypertensive, liver protecting and anti-cancer. Research has shown that M. oleifera represents one of the plants that can be used to treat diseases, particularly chronic diseases including Type 2 diabetes, heart disease and diseases associated with damage to cells caused by free-radicals (oxidative stress). The plant's medicinal value is increased by containing many beneficial compounds like quercetin, chlorogenic acid and isothiocyanates. Thus, M. oleifera is a valuable herb for uses in daily life [15].

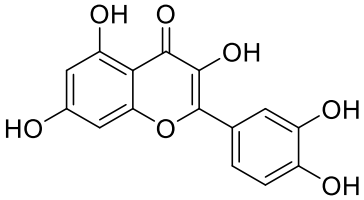
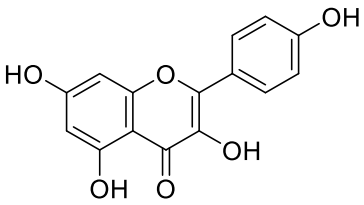
2.7 Challenges and Future Perspectives:

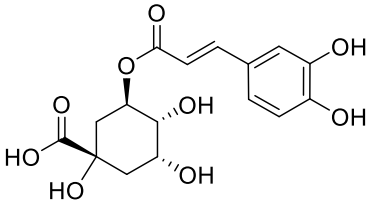
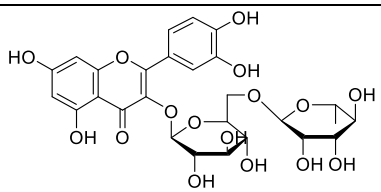
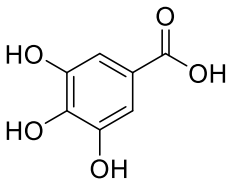
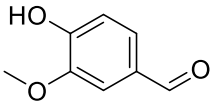
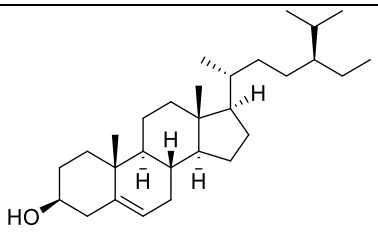
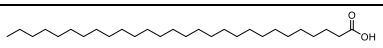
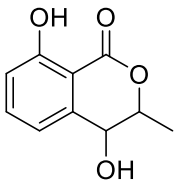
While there has been increasing interest in *Moringa oleifera* as a source of bioactive compounds for use in pharmaceutical, nutraceutical, and industrial applications, there are many obstacles to fully utilising M. oleifera. One of the main challenges facing the development of M. oleifera-based products is the very large variations in chemical make-up across different locations (due to differences in growing conditions and harvesting methods), making it impossible to standardise these products. This presents a challenge not just for standardising and ensuring consistency of these products, but also for evaluating the effectiveness and quality

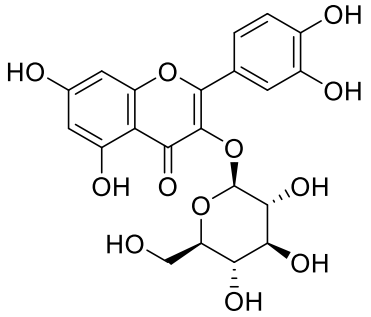
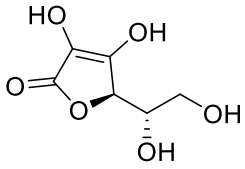
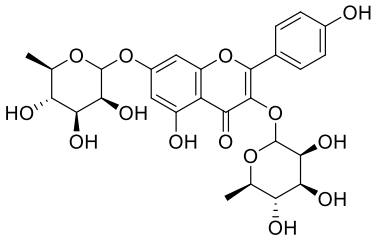
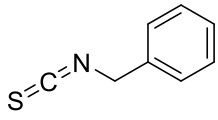
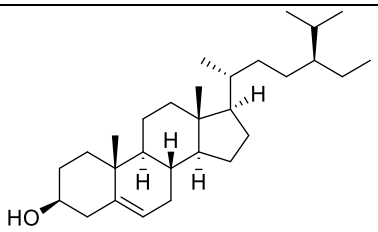
of these products. Furthermore, the bioavailability, metabolism, and biological activity of numerous phytochemicals are poorly characterised. Most of the scientific evidence supporting the use of M. oleifera as a medicinal treatment is derived from laboratory studies, while there is limited evidence from well-controlled clinical trials conducted with human participants. Also, the commercialisation of M. oleifera products is hampered by a lack of standardised extraction processes and quality control.

Research going forward should look into doing a complete repertoire of phytochemical profiles through metabolomics, HR Mass Spectrometry and NMR Spectroscopy utilizing high conscious advanced analytical techniques. More clinical studies are needed to help prove that the bioactive components of M. oleifera are safe, effective, and have therapeutic properties. With that in mind, there needs to be standardized methods of growing, extracting, and being sure of the quality of all the products made from M. oleifera. There are also new forms of nano-formulated, green, extraction technologies, and biotechnological-based methods that could provide improved absorption and utility of M. oleifera in the industry. Continued interdisciplinary research will allow for good evidence that M. oleifera has an important role in the area of medicine and as a functional plant so it can be used toward creating a healthier person and sustainable developments in various industries around the world. The various phytoconstituents present on the different parts of *Moringa oleifera* are listed below **Table 1**.

Table 1: List phytoconstituents present on the different parts of *Moringa oleifera* with their chemical structure and biological significance.

SL no.	Different parts of *Moringa oleifera*	Name of Phytoconstituents present	Chemical Structure	Biological Significance	Reference
1	Leaves	Quercetin		Potent antioxidant, anti-inflammatory, anticancer, cardioprotective	[4]
		Kaempferol		Antioxidant, antimicrobial, anti-inflammatory, neuroprotective	[17]

		Chlorogenic acid		Antioxidant, antidiabetic, hepatoprotective	[4]
		Rutin		Antioxidant, vascular protective, anti-inflammatory	[4]
		Gallic acid		Antioxidant, antimicrobial, anticancer	[2]
2	**Bark**	Vanillin		Antioxidant, antimicrobial, anti-inflammatory	[18]
		β-Sitosterol		Hypocholesterolemic, anti-inflammatory, anticancer	[19]
		Octacosanoic acid		Anti-inflammatory, antimicrobial	[2]
		4-Hydroxy-mellein		Antioxidant, antimicrobial	[20]

3	**Flowers**	Isoquercitrin		Antioxidant, hepatoprotective, anti-inflammatory	[21]
		Ascorbic acid		Powerful antioxidant, immune enhancer, collagen synthesis	[2]
		Kaempferitrin		Antidiabetic, antioxidant, anti-inflammatory	[18]
4	**Seeds**	Benzyl-isothiocyanate		Anticancer, antimicrobial, anti-inflammatory	[22]
		β-Sitosterol		Cholesterol-lowering, anti-inflammatory, immune-modulatory	[17]

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