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Moringa oleifera Linn: Extraction, Phytochemistry Constituent and Pharmacology Activity: A Review

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ABSTRACT

Moringa oleifera, commonly known as the "miracle tree", belongs to the Moringaceae family and is a plant that has functional food and nutraceutical properties. Various parts of this plant are rich sources of carbohydrates, proteins, amino acids, lipids, vitamins, polyphenols and minerals. This review is a comprehensive summary of the extraction method, phytoconstituents, traditional uses, and pharmacological activity of this plant, namely as an antioxidant, antimicrobial and antifungal, anti-inflammatory, anti-diabetic and anti-obesity, antiviral. This is because Moringa leaves contain flavonoids and phenolics. In addition, Moringa leaves contain a large number of phytochemicals which are excellent for the development of functional products applied in various industries including pharmaceutical, cosmetic, nutraceutical and food.

Keywords: Bioactivity; *Moringa oleifera*; Nutraceutical; phytoconstituent; separation methods

INTRODUCTION

Moringa oleifera Lam is known as the horseradish tree or drumstick tree and commonly known as the "miracle tree" because this plant has been taken into account as a functional food and nutraceutical, and has been used to improve the quality of human health (Falowo et al., 2018), (Trigo et al., 2023; Sharma et al., 2020; Tanga, 2022; Wei et al., 2023). The height of this tree ranges from 5 - 12 meters, and it has a fruit (pod) length of about 50 cm; when ripe, the fruit has 10 - 50 seeds inside, three-pinnate compound leaves with leaflets 12-18 mm long, and yellow leaf stalks, which are yellow or white without red stripes (Figure 1). This plant grows best in temperatures between 25 and 35°C (Basuny & Al-marzouq, 2016; R. Liu et al., 2022).

In Indonesia, the plant known as *Kelor* has been used for thousands of years by various civilizations including India, Greece, and Egypt, as a traditional herbal medicine in the Ayurveda, Unani, and Siddha systems of medicine. This plant is known *as-sigru'* in Ayurveda and is used during and after the body cleansing process known as Pancha(na) karma, and the leaves of *M. oleifera* serve as a laxative to relieve constipation, lower cholesterol, and lose weight (Li et al., 2024). This plant can reduce malnutrition because of its abundant protein, vitamin, mineral, and carbohydrate content. As well as the sole origin of various non-nutritional molecules often known as phytochemicals. Plants that have abundant natural compounds are exploited in a variety of applications, both directly and indirectly, to improve the welfare of human and domestic animal populations. The applications mentioned above serve to improve the welfare of human society and domestic animals. The majority of these compounds are often known as phytomolecules, which are synthesized in plants through primary and secondary metabolic pathways (Gharsallah et al., 2023). Therefore, its use has been widespread in several areas of functional food and medicine, due to its low toxicity and side effects (Raja et al., 2016). In recent years, there has been a large body of research dedicated to the investigation of *M. oleifera*. The main emphasis of these investigations was directed towards investigating the isolation, purification, elucidation of the chemical structure, determination of physical properties, and evaluation of the biological activities associated with this plant. In addition, it is important to remember that its bioactivity is influenced by various factors, including phytochemical content, glycosidic bond arrangement, and chemical modifications, including extraction methods, purification techniques, and structural diversity (C. Chen et al., 2017; Tian et al., 2021). For this reason, it is important to thoroughly describe the extraction, phytochemical content, and

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Figure 1. Parts of plant *Moringa oleifera*

pharmacological activity from various angles and to present a comprehensive picture from a fresh perspective. Therefore, this review discusses recent developments in extraction methods, phytochemical contents, and pharmacological activities of leaves, seeds, roots, rows, and flowers. Additionally, this review provides a theoretical foundation and reference point for the continued development and application of *M. oleifera* by summarizing its challenges and prospective trends.

METHODS

During performing the review, we used several databases containing scientific literature published from 2014 to 2024. The databases used were ScienceDirect, PubMed, Scopus, and DOAJ. The keywords used for searching the information are "*Moringa oleifera*", OR "M. oleifera" OR "ethnobotanical *M. oleifera*" OR "phytochemistry *Moringa oleifera*" OR "extraction *Moringa oleifera*" OR "pharmacology *M. oleifera*" OR "bioactivity *Moringa oleifera*".

Extraction methods of bioactive compounds from *Moringa oleifera*

The extraction procedure is critical in the manufacture of natural products and for the identification of bioactive components (Yan et al., 2022). The amount and quality of bioactive chemicals that can be extracted from raw extracts vary depending on several factors, including the kind of solvent and extraction methods (Olvera-aguirre et al., 2022). The maximum extraction yield was obtained with aqueous extraction, which differed significantly from agitation and sonication. The utilization of a high temperature during the extraction process led to the facile lysis of cell membranes and the release of unintended substances, including carbohydrates. These unintended substances contributed to the increased yield of aqueous extract. In contrast, agitation yielded a considerably greater quantity of phytochemicals than the alternative methods (Kim et al., 2018; Olvera-aguirre et al., 2022).

The results of other research by microwave-assisted extraction (MAE) show a decrease in yield as the extraction temperature and power surpassed 50^{o}C and 700 watts, respectively. This can be attributed to the generation of high-energy microwaves by the magnetrons within the instrument. The increased extraction yield was observed at temperatures of 30-40^{o}C and microwave powers between 500 and 600 watts. The observed outcomes could potentially be attributed to the solvent's increased diffusion rate into the plant matrix, resulting in the leaching of phenols and other compounds into the solvent phase (Gunalan et al., 2023). Meanwhile, the MAE methodology offers a workable and respectable substitute for the high throughput extraction of *M. oleifera* oil with a high yield and great quality features compared to solvent-assisted extraction. However, as the quality features of the oil extracted by MAE and SAE procedures did not differ noticeably, therefore, the ultimate decision of extraction technique could be determined by the equipment's accessibility and availability (Nebolisa et al., 2023).

Kaempferol and quercetin from *M. oleifera* leaves were extracted by the pressurized hot water extraction (PHWE) method at the following extraction conditions: 125°C, 32.5 min, and 0.3 mL min^{-1} for temperature, time, and flow rate, respectively, resulting in the highest concentrations of 3.32 and 3.40 g per 100 g for kaempferol and quercetin, respectively (Nuapia et al., 2020). The increased amounts of kaempferol and quercetin extracted at low flow rates and high extraction temperatures and times can be ascribed to the increased diffusion rate of bioactive compounds from the leaf powder resulting from long contact and interaction times. extraction solvent with a powder sample matrix. In addition, high temperature reduces the polarity of water, thereby increasing the solubility of compounds with medium polarity (Wang et al., 2017). Rodríguez-pérez et al. (2015) reported that ultrasonic-assisted extraction (UAE) and solid-liquid extraction (maceration) protocols revealed that UAE by ethanol: water (50:50, v/v) produced the highest amount of phenolic components in leaf extracts. In addition, the effect of different extraction methods, namely maceration, homogenizer-assisted extraction, fast solid liquid dynamic extraction, MAE, and UAE, on leaf polyphenols with alcohol (methanol 100%) and hydroalcohol (methanol/water 50: 50, v/v) solvent composition, has been demonstrated. When compared with methanol/water extraction (50:50, v/v), 100% methanol extraction proved to be the most successful in recovering phenolic chemicals. Leaf extraction with the help of a homogenizer in 100% methanol produced the most polyphenols (35.19 mg/g) and maximum oxygen radical absorption capacity (536.27 mol Trolox Equivalents/g) (Rocchetti et al., 2019).

Microwave-assisted extraction (MAE) was also proven to be an effective method for extracting polysaccharides (Chen et al., 2017). Polysaccharides from seeds are extracted by ethanol. *M. oleifera* seeds were extracted by 80% ethanol and 80°C hot water, and the results showed that ethanol at various concentrations could not only remove oil from seeds but also degrade proteins, thereby increasing the extraction yield (Yang et al., 2022). Other methods used for extraction are the Desulfoglucosinolate extraction method and the intact glucosinolate extraction method. Both are used to separate Glucosinolates, derivatives of β-thioglucoside N-hydroxysulfate, which are aglycones of alpha-amino acids found in plants (Robert et al., 2017). A study conducted by (Förster et al., 2015) showed that the desulfoglucosinolate extraction procedure resulted in glucosinolate artifacts and loss of acetate glucosinolates making it insufficient to analyze individual *M. oleifera* glucosinolates. The natural glucosinolate profile in leaves can be accurately determined by an optimized whole extraction method.

Phytochemistry of *Moringa oleifera*

Phytochemical content is a secondary metabolite compound obtained from plants, which is a compound that is responsible for being a source of biological activity (Altemimi et al., 2017; Parbuntari et al., 2019). he results of phytochemical screening of *M. oleifera* plants were obtained from leaves, stem bark, flowers, fruit, and seeds, namely secondary metabolite compounds such as flavonoids, phenolics, alkaloids, tannins, saponins, and terpenoids (Vergara-jimenez et al., 2017; Ruslin et al., 2021). Apart from containing phenolics, flavonoids, alkaloids, and carotenoids, it is also rich in protein, vitamins, and minerals (Zhang et al., 2024)

Various groups of phytochemical compounds have been isolated from M. oleifera, including phenolic compounds, alkaloids, flavonoids, and essential oils (Gu et al., 2020), while the leaves have bioactive metabolites such as flavonoids, saponins, tannins, catechol tannins, anthraquinones. , alkaloids (Kashyap et al., 2022). The flavonoid compounds contained are oleifera, namely quercetin, vanillin, myricetin, catechin, apigenin, luteolin, narigenin, and kaempferol and others (Singh et al., 2009; Kashyap et al., 2022). The two main flavonoids found are quercetin and kaempferol, which can be extracted by methanol or ethanol. Kaempferol is effective in preventing DNA damage and is dominant in cancer cell death (Lin et al., 2018; Qattan et al., 2022; Singh et al., 2023). Apart from that, tannin is an important component of the Moringa tree. The dry leaves and lateral roots of the Moringa tree contain the most tannin, while the seeds have the lowest percentage (Tshabalala et al., 2020; Ma et al., 2020). According to (Fahey, 2005), *M. oleifera* has many bioactive chemicals with many positive effects on health. All parts contain a class of substances called glucosinolates, including O-ethyl-4-(L-rhamnosyloxy) benzyl carbamate, 4-(L-rhamnopyranosyloxy) benzylglucosinolate, and 4-(L-rhamnosyloxy) benzyl isothiocyanate. This compound is known to have biological activities such as antihypertensive, anticancer, and antibacterial. Another class of phytoconstituents found in *M. oleifera* are phenolic compounds. Plant leaves show a dominance of quercetin and kaempferol in the form of 3-O-glycosides (Ziani et al., 2019). Quercetin and kaempferol have strong antioxidant properties. It has been experimentally demonstrated that the 3-O-glycoside form of quercetin, also known as isoquercitrin or isotrifoline, has hypotensive, antidyslipidemic, and anti-diabetic actions in obese Zucker rats (Rivera et al., 2008).

M. oleifera's leaves have also been reported as significant vitamin sources. More vitamin C was reportedly found in fresh leaves than in conventional sources like oranges (Leone et al., 2015). The high content of vitamin C is important because vitamin C helps to convert cholesterol into bile acids, capable of lowering blood cholesterol levels. It also has antioxidant properties that shield the body from the harmful effects of free radicals, pollutants, and toxins. The quantities of vitamin E in the leaves are comparable to those in nuts, especially in the form of -tocopherol. The primary role of vitamin E is as an antioxidant, but it also influences gene expression, suppresses cell growth, prevents platelet aggregation, promotes monocyte adhesion, and controls bone mass. The only vitamins in the B group found in *M. oleifera* leaves are thiamine, riboflavin, and niacin. The primary role of these vitamins is as co-factors of several enzymes involved in nutrition metabolism and energy production (Leone et al., 2015). Additionally, niazirin, niazirinin, 4-[(4'-O-acetyl-Lrhamnosyloxy) benzyl] isothiocyanate, niaziminin A, 3- and 5-caffeoylquinic acid, carotenoids, epicatechin, and o-coumaric acid were observed to be present in the leaves (Muhammad et al., 2016). Detailed features of other phytoconstituents present in *M. oleifera* are shown in Table I.

Traditionally use of *Moringa oleifera*

Traditionally *M. oleifera* is used as an antispasmodic, stimulant expectorant, and diuretic and to treat gastrointestinal motility disorders and diarrhea (Ruslin et al., 2021; Yadav et al., 2016; Hasan et al., 2019; Woldeyohannes et al., 2022). These leaves have been widely used by Indian people as written in Ayurveda for preventive and curative measures and can treat more than 300 diseases (Fidrianny et al., 2021). Because of its significant therapeutic properties, this plant has been a part of the Indian diet since antiquity (Table II) (Pareek et al., 2023). Various plant-based remedies are considered to have ethnomedicinal characteristics for illness treatment and have been utilized for generations. This plant's leaf, pod, bark, gum, flower, seed, seed oil, and root have all been used to treat a variety of diseases (Stohs & Hartman, 2015). Its use in treatments such as antihypertensive (Aekthammarat et al., 2019), anti-diarrheal (Misra et al., 2014), A poultice made from Moringa leaves is a quick remedy for inflammatory conditions such as glandular inflammation, headache, and bronchitis (Posmontier, 2011), The roots are conventionally used to treat kidney stones (Karadi et al., 2006), Moringa is also used to treat dysentery (Woldeyohannes et al., 2022). Meanwhile, in Nigeria, it is used to increase fertility in men and treat fertilization diseases in women (Singh et al., 2020). In several regions in Africa, *M. oleifera* is used to treatment diabetes, hypertension, and HIV/AIDS (Tanga, 2022), in addition, it is used to purify water (El-Haddad et al., 2019).

Pharmacological aspects of *M. oleifera*

M. oleifera plants are known to have pharmacological effects in all of their parts, including antioxidant, anti-obesity, anti-cancer, hepatoprotective, nephroprotective, neuroprotective, antibacterial, and antiviral activity, etc.

Antioxidant activity

The presence of phenolic compounds in the Moringa species confers higher antioxidant activity because these compounds can stabilize free radicals produced in cells by either donating or receiving electrons, therefore acting as an antioxidant molecule (Guillén-román et al., 2018; Dhibi et al., 2022; Siskawardani et al., 2021; Sohaib et al., 2022; Mwamatope et al., 2020; Ruslin et al., 2021; Zubaydah et al., 2021; Sabarudin et al., 2021). Antioxidant activity in Moringa oleifera is mostly influenced by the presence of beta carotene, vitamin C, calcium, and potassium compounds (Kumar et al., 2012; Siskawardani et al., 2021), Osajin, vitexin, cyaniding, Quercetin 3-β-D-Glucoside, Quercetin, Nictoflorin, Cynaroside, Astragalin, Isorhamnetin, kaempferol, and ficetin from leaves (Kumar et al., 2012; Fitriana et al., 2016; Rani et al., 2018; Padayachee & Baijnath, 2020; Farooq et al., 2021; Younis et al., 2022; Wei et al., 2023), tocopherols, myricetin, polyhydroxyflavonols aglycones (Lalas & Tsaknis, 2002; Anwar & Rashid, 2007; Al et al., 2016), Flavonols are another group of flavonoids reported in *Moringa oleifera*. Quercetin and kaempferol

Tabel I. Phytometabolites reported in different parts of *M. oleifera*

Part of plant	Phytochemistry content	Bioactivity	Ref
Leaves	Osajin, vitexin, cyaniding, Quercetin 3-β-D-Glucoside, Quercetin, Nictoflorin, Cynaroside, Kaempferol, ficetin	Antioxidant, antimicrobial, anti-tumor,	(Wei et al., 2023)
	Astragalin, Isorhamnetin, Kaempferol, Apigenin, Luteolin, Genistein, Myricetin, Epicatechin, Vicenin-2, Quercetin-3-O-glucoside, Quercetin-3-O-(6′′-malonyl) glucoside, Kaempferol-3-O-glucoside, Kaempferol-3-O-(6′′-malonyl) glucoside, Kaempferol-3-rutinoside, Kaempherol-3-O-α-rhamnoside, Kaempferide 3-O-(2′′,3′′-diacetylglucoside), Kaempferol-3-O-[β-glucosyl-(1→ 2)]-[α-rhamnosyl-(1→ 6)]-β-glucoside-7-O-α-rhamnoside, Kaempferide-3-O-(2′′ -O-galloylrhamnoside), Kaempferide-3-O-(2′′ -O-galloylrutinoside)- 7-O-α-rhamnoside, Kaempferol-3-O-[α-rhamnosyl-(1→2)]-[αrhamnosyl-(1→4)]β-glucoside-7- O-α-rhamnoside, 4-(α-L-rhamnopyranosyloxy) benzyl glucosinolate (glucomoringin), 4-[(2′ -O-acetyl-α-L-rhamnosyloxy) benzyl] Glucosinolate	anticancer, antidiabetic, antimicrobial, anti-inflammatory, antiviral, antileishmanial, Antihyperglycemic, Antihyperlipidemic, Hypocholesterolemic, Antifertility, Antihypertension, Antispasmodic	(Tumer et al., 2016; Rani et al., 2018)
	Quercetin-3-O-(X′′-malonyl) glucoside, quercetin-3-O-glucoside-7-O-rhamnoside, methyl-O-quercetin-malonylglucoside, apigenin-C-glucoside, apigenin-O-glucoside, s hexadecylferulate, 5-hydroxyferulic acid glucoside, diferuloyl-(5OH-feruloyl) spermidine, glucosinolates, dicoumaroyl putrescine, di(dihydrocaffeoyl)spermidine,	antioxidant activity, Anti-Inflammatory, Immunomodulatory, Hypoglycemic, hypolidipemic effects, Anticancer, anti-diabetes, cardiovascular disease, dyslipidemia	(Adeyemi & Elebiyo, 2014; Leone et al., 2015)
	4-(β-D-glucopyranosyl-1→4-α-L-rhamnopyranosyloxy)-benzyl isothiocyanate, Sitosterol, Lutein,	Cytotoxicity, Antioxidant, Apoptosis	(Maiyo et al., 2016)
	3-O-(6’ -O-oleoyl-β-D-glucopyranosyl)-β-sitosterol, 4-(4’ -O-acetyl-α-L-rhamnopyranosyloxy) benzyl isothiocyanate, 4-(α-L-rhamnopyranosyloxy) benzyl glucosinolate, ascorbic acid, isoquercetin, kaempferitrin, moringine, niazimicin, niaziminin A and B, niazirin, niazirinin, O-ethyl-4-(α-Lrhamnosyloxy) Benzylcarbamate, pterygospermin, quercetin, β-carotene, β-sitosterol, and β-sitosterol-3-O-β-Dglucopyranoside	Antioxidant, anticancer, antibacterial, antiinflammatory, antifungal, antipyretic, antiepileptic, anti-cancer, antitumor, anti-ulcer, diuretic, antihypertensive, antidiabetic, hepatoprotective	(Farooq et al., 2021; Padayachee & Baijnath, 2019)
	Quinic acid, Caffeic acid, Chlorogenic acid, Gallic acid, Coumaroylquinic acid, Apigenin-glucoside, Rutin, Quercetin-acetyl-glucoside, Quercetin-malonylhexoside, Isoquercetin, Kaempferol-acetylglucoside, Quercetin	Antioxidant, cytotoxicity, antiproliferative	(Vongsak et al., 2015; Nizioł-łukaszewska et al., 2020)

Tabel I. (Continued)

Part of plant	Phytochemistry content	Bioactivity	Ref
	Astragalin, 3-O-caffeoylquinic acid, Rutin, Caffeic acid	Antioxidant activity, Antihyperglycemic activity	(Tatiane Luiza Cadorin Oldoni et al., 2022)
	Apigenin-6,8-di-C-glucoside, Apigenin-8-C-glucoside, Apigenin-6-C-glucosid, Quercetin-3-O-(6"-O-acetyl) glucoside, Kaempferol-3-O-(6"-O-acetyl) glucoside, Isorhamnetin-3-O-glucosid	Antidiabetic, antioxidant, antiiflamatory	(Y. Yang et al., 2022)
	Quinic acid, Caffeic acid, Chlorogenic acid, Gallic acid, Coumaroylquinic acid, Kaempferol-3-O-rutinoside, Apigenin-glucoside, Rutin, Quercetin-acetyl-glucoside, Quercetin-malonylhexoside, Isoquercetin, Kaempferol-acetyl-glucoside, Quercetin	Antioxidant, Antidiabetic	(Nizioł-łukaszewska et al., 2020; Chigurupati et al., 2022)
Seeds	Myricetin, Quercetin-3-O-glucoside, 4-(α-L-rhamnopyranosyloxy) benzyl glucosinolate (glucomoringin), gallic acid, chlorogenic acid, ellagic acid, ferulic acid, kaempferol, quercetin, and vanillin	Anti-inflammatory activity, Antioxidant activity, Antitumor and anticancer activity,	(Padayachee & Baijnath, 2019)
	4(-L-rhamnosyloxy) phenyl acetonitrile, 4-(α-L-Rhamnosyloxy) benzyl isothiocyanate, Roridin E, 4-hydroxyphenylacetonitrile, 4-hydroxyphenyl-acetamide, Veridiflorol, 4-(α-l-rhamnopyranosyloxy)-benzylglucosinolate, 9-Octadecenoic acid, niazimicin, O-ethyl-4-(α-L-rhamnosyloxy) benzyl carbamate, niazirin, glycerol-1-(9-octadecanoate), 3-O-(6' -O oleoyl-β-D-glucopyranosyl)-β-sitosterol, β-sitosterol-3-O-β-D-glucopyranoside, and β-sitosterol	antimicrobial, anticancer, antidiabetic, antioxidant, antihypertensive, anti-inflammatory, cardioprotective	(Dzuvor et al., 2021)
	Catechol, Vanillic acid, Syringic acid, Vanillin, Benzoic acid, Naringenin	Antioxidant, Antibacterial, antifungal activities	(Barakat & Ghazal, 2016; Salem et al., 2021)
	4-(β-D-glucopyranosyl-1→4-α-L-rhamnopyranosyloxy)-benzyl isothiocyanate, Sitosterol, Lutein	antioxidant, cytotoxicity, apoptosis	(Maiyo et al., 2016)
	Marumoside A, Sitosterol 3-O-β-D-glucopyranoside	Anti-inflamatory	(N. Ma et al., 2018)

compounds in the form of 3-O-glycosides were the most dominant compounds obtained from Moringa oleifera leaves (Mbikay, 2012; Alegbeleye, 2018), Both quercetin and kaempferol have strong antioxidant properties. It has been experimentally demonstrated that the 3-O-glycoside form of quercetin, also known as isoquercitrin or isotrifolin, has hypotensive, antidyslipidemic, and anti-diabetic actions in the obese Zucker rat model of metabolic syndrome (Rivera et al., 2008). Similarly, studies of the antioxidant activity of water extracts, methanol extracts, and ethanol extracts on the stems, roots, and pods of Moringa oleifera, both in vitro and in vivo, showed strong antioxidant activity (Atawodi et al., 2010; Kumbhare et al., 2012; Satish et al., 2013; Gupta et al., 2012; Gull et al., 2016; Ramamurthy et al., 2022). The antioxidant potential of the plant makes it useful in the food and food preservation industry (Hodas et al., 2021; Indra et al., 2021; Peñalver et al., 2022). Meanwhile, Moringa oleifera flowers contain polyphenols of 18.34 - 19.49 (mg GAE/g dry matter) (Alhakmani et al., 2013; Madane et al., 2019). It can be employed

Tabel I. (Continued)

Part of plant	Phytochemistry content	Bioactivity	Ref
	1,3-bis-(4-(((2S, 3 R, 4 R, 5 R, 6S)-3,4,5-trihydroxy6-methyltetrahydro-2H-pyran-2-yl) oxy) benzyl) urea, Phenylmethanoid (4-hydroxyphenylethyl 4-O-β-D-glucopyranosyl-(1→3)-O-α-Lrhamnopyranoside), glucomoringin, p-hydroxybenzoic acid 4-O-β-D-glucopyranosyl-(1→3)-α-L-rhamnopyranoside, benzyl alcohol-β-vicianoside, uridine, adenosine, marumoside A, vitexin, 1-O-(4-hydroxymethylphenyl) α-L-rhamnopyranoside, 4-hydroxybenzaldehyde rhamnoside	Anti-inflammatory, Antiviral, antioxidant	(Xiong et al., 2020)
	O-ethyl4- (α -L-rhamnosyloxy) benzyl carbamate, 4 (α -Lrhamnosyloxy)-benzyl isothiocyanate, glycerol-1- (9 -octadecanoate), 3 -O- 6 -Ooleoyl- β -D-glucopyranosyl-b-sitosterol, and β -sitosterol- 3-X-O -β -D-glucopyranoside	cardiovascular, antioxidant, hypoglycemic, anti-tubercular	(Hussain et al., 2014)
	Moringa A, Phenylmethanoid (4-hydroxyphenylethyl 4-O-β-D-glucopyranosyl-(1→3)-O-α-Lrhamnopyranoside), glucomoringin, p-hydroxybenzoic acid 4-O-β-D-glucopyranosyl-(1→3)-α-L-rhamnopyranoside, benzyl alcohol-β-vicianoside, uridine, adenosine, marumoside A, vitexin, 1-O-(4-hydroxymethylphenyl) α-L-rhamnopyranoside, 4-hydroxybenzaldehyde rhamnoside	Anti-inflammatory, Antiviral, antioxidant	(Xiong et al., 2020)
Fruit	Gallic acid, chlorogenic acid, ellagic acid, ferulic acid, kaempferol, quercetin and vanillin	Anti-inflammatory activity, Antioxidant activity, Antitumor and anticancer activity,	(Padayachee & Baijnath, 2019)
Stem bark	Procyanidins		
	Quercetin-3-O-glucoside, 4-(β-D-glucopyranosyl-1→4-α-L-rhamnopyranosyloxy)-benzyl isothiocyanate, Sitosterol, Lutein,	antioxidant, cytotoxicity, apoptosis	(Maiyo et al., 2016)
	β-sitosterol	Anti-inflammatory	(Liao et al., 2018)

as a natural antioxidant molecule to inhibit the disease's onset and progression. According to (Alhakmani et al., 2013), *M. oleifera* flower extract can reduce inflammation, which supports the traditional use of flowers in Oman and other Asian nations.

Moringa oleifera seed powder significantly reduced the oxidative stress caused by arsenic and also stopped the accumulation of arsenic in blood and other soft tissues (Gupta et al., 2012). In a study involving 60 postmenopausal women, the level of malondialdehyde formed in serum as a result of lipid peroxidation was reduced when the subjects were administered *M. oleifera* leaf powder for three months. The plant's antioxidant capability was further demonstrated by the treatment's increased levels of superoxide dismutase, glutathione peroxidase, and ascorbic acid (Kushwaha et al., 2012).

A study conducted in vivo to measure the activities of superoxidase dismutase, catalase, and glutathione S-transferase in normal mice and

Table II. Uses of Moringa oleifera listed in Ayurvedic medicinal textbook (Pareek et al., 2023)

Name of Ayurvedic Text	Form of Plant Used	Treatment
Charaka Samhita (1000 BC- 4th Cent. AD)	Powder Decoction	Used for treatment of worms and headache, Ascites, edema Hiccough and asthma, deafness, tinnitus in the ear, worm manifestation
Ashtanga Hridaya (7th Cent. AD)	Oil	Ear ache, deafness, and tinnitus in the ear
Kashyapa Samhita (6–7th Cent AD)	Decoction Oil	Puerperal disorder, sleeplessness Edema
Sharangadhara Samhita (13 Cent. AD)	Decoction	Conjunctivitis
Yogaratnakara (17th Cent. A.D.)	Decoction	Enlargement of spleen, worm edema, Ascites, fever, abscess.

diabetic mice given water extract of *Moringa oleifera* leaves, showed a significant reduction in lipid peroxide levels. This shows that the extract has the potential as an antioxidant because the phenolic and flavonoid content contained in the extract is very high so that it can protect against damage in normal and diabetic test animals (Jaiswal et al., 2013).

The aqueous extract of *M. oleifera* leaves has been reported to have potential antioxidant activity in both in vitro and ex vivo systems. This has been proven by reducing cholesterol levels in rabbits fed a high-cholesterol diet, which shows that this extract has a higher therapeutic potential for preventing cardiovascular disease (Chumark et al., 2008). Likewise, (Jimoh, 2018) suggested that the chelation of copper and iron ions by Moringa leaves may be one of the mechanisms that explain the inhibitory effect on important enzymes related to the management/treatment of Type 2 diabetes mellitus (T2DM).

Antibacterial and antifungal activity

Water extract of *Moringa oleifera* leaf can inhibit *Staphylococcus aureus* bacteria, which are resistant to multi-antibiotics (linozidine, ofloxacin, chloramphenicol, gentamicin, ciprofloxacin, and vancomycin) which are associated with skin and soft tissue infections (Akinduti et al., 2022). The combination extract of *M. oleifera* leaf and silver Nanoparticles (AgNPs) produces a substance that has the potential to be an excellent antibacterial against pathogenic microorganisms such as *Escherichia coli* (ATCC-35218), *Klebsiella pneumoniae* (ATCC-700603), *Staphylococcus aureus* (ATCC-25923), and *Bacillus subtilis* (ATCC-27853) (Mohammed et al., 2022). The acetone extract Moringa seed had maximum antibacterial activity against *E. coli* (ATCC 2592) and *E. coli* (clinical isolate) compared to methanol and water extract. Further, for *Shigella dysenteriae* (clinical isolate) and *Salmonella typhii* (clinical isolate), the acetone extract has shown a maximum and significant variation compared to the other extracts (Delelegn et al., 2018).

In another study, it was reported that five peptide sequences had been isolated from *Moringa oleifera* seeds, effectively inhibiting Gram-positive and Gram-negative bacteria. One of the peptide sequences that was successfully isolated was MOp3. This new sequence isolated from Moringa seeds is more effective against Gram-positive bacteria. This is due to the ability of MOp3 to induce irreversible damage to the cell membrane of *S. aureus* and could bind tightly to DHFR and DNA gyrase through hydrogen bonding and hydrophobic interaction. (X. Wang et al., 2023). Reports also the peptide sequence Mop3 can significantly inhibit the growth of *S. aureus* bacteria in pasteurized milk, so it can be used as a new natural antibacterial agent to control the growth of *S. aureus* bacteria in dairy products (Sun et al., 2023). Meanwhile, ethyl acetate extract of *M. oleifera* stem bark has the strongest potential to inhibit the growth of *S. aureus, C. freundii, B. megaterium*, and *P. fluorescens* bacteria (Zaffer et al., 2014). Likewise, the extract of Moringa root bark most strongly inhibits the growth *of Escherichia coli, Staphylococcus aureus, Salmonella gallinarum*, and *Pseudomonas aeruginosa* bacteria (Dewangan et al., 2010), (Elgamily et al., 2016). The results of clinical trials on 30 patients (adults, uncomplicated UTI, and BPH patients) who were given a decoction of Moringa bark proved effective in treating most of the main symptoms of urinary tract infections. This drug also helps in eradicating urinary tract pathogens such as *E. coli*, which causes UTI (Maurya & Singh, 2014).

Moringa oleifera flower pod extract, tested for its activity against the growth of bacteria found in food, showed the most potent ability to inhibit the growth of Gram-positive and Gram-negative pathogenic bacteria found in food (Gull et al., 2016). Other research, such as that conducted by (Shaji & Suji, 2023), shows that chloroform extract of Moringa flowers has the potential as a food preservative to prevent food spoilage caused by the growth of *Staphylococcus aureus* and *Pseudomonas aeruginosa* bacteria. The Hydroxyapatite (HAp) compound synthesized from flower extract (Hydroxyapatite nanorod MOFE: HAp), which is a tannin compound, has more significant antibacterial activity against Gram-positive bacteria (*Bacillus subtilis, Monococcus luteus*, and *Staphylococcus aureus*) compared with Gram-negative bacteria (*Klebsiella pneumoniae, Pseudomonas aeruginosa*, and *Salmonella paratyphi*). In addition, it has anti-fungal activity against common pathogenic fungi (*Candida albicans, Aspergillus nige*r, and *Aspergillus fumigatus*) (Kalaiselvi et al., 2019).

Antiviral activity

Moringa oleifera has been used for years for traditional, medicinal, and industrial uses. The parts of the plant are eaten as a vegetable and are added to a regular diet to combat several diseases. The Moringa leaves have been found as food to combat malnutrition. *M. oleifera* acts as an antiviral, diuretic, antipyretic, anti-inflammatory, anticancer, and antibacterial plant. The immune-modulatory effects of the Moringa plant could serve as protection or prevention from future infections (Fajri, 2021). According to other studies, administering moringa supplements to HIV patients had positive results. The study's findings demonstrated that CD4 cell counts in patients who took a moringa supplement increased throughout a three-month treatment period, with a notable decrease in the population of subjects with low CD4 counts (500 cells/l). The favorable improvement in CD4 count was reduced in those who got HAART alone, demonstrating the immuno-beneficial effect of moringa (Gambo et al., 2021; Aprioku et al., 2022). A study by Penduka in 2017 showed that MO was well tolerated by HIV patients when combined with nevirapine. The CYP3A4 enzyme, which breaks down nevirapine, is inhibited by MO. When given in combination with MO, nevirapine's safety profile did not change (Penduka et al., 2017). The MO tree extracts have also demonstrated inhibitory efficacy, particularly against HIV-1, Herpes Simplex Virus (HSV), and Hepatitis B Virus (HBV), which harms the liver by causing inflammation, cirrhosis, and liver cancer (Biswas et al., 2020). In addition, through molecular docking, ADMET, and dynamics studies, the ligands Rutin and Isorhamnetin-3-O-rutinoside from Moringa oleifera have been discovered to exhibit an inhibitory effect against the target Main protease (Mpro) of SARS-CoV-2. Overall, the findings show that chemicals found in *Moringa oleifera* have the potential to be effective anti-COVID-19 medication candidates. Additionally, this discovery brings up the possibility of evaluating these two successful medicines against COVID-19 in vitro and in vivo (Sivani et al., 2021). Similar research has demonstrated that the leaves of *M. oleifera* have significant antiviral action against one of the deadliest animal diseases, foot and mouth disease (FMD) (Younus et al., 2016).

Moringa A, Glucomoringin, and Vitexin isolated from *Moringa oleifera* seeds are reported can decrease RBC hemolysis and plaque formation in H1N1-infected cells, suggesting that it has strong antiviral action against H1N1 in RAW264.7 cells. Additionally, the MA improves cell survival and shields cells from the cytopathic damage caused by H1N1. The results of several treatment studies demonstrated that MA's primary anti-H1N1 action is probably a result of its activity against the advanced stages of infection (Xiong et al., 2021). *Moringa Oleifera* leaf extract given to Hubbard chickens may be helpful in the protection against Newcastle virus when used in combination with the vaccine (Tolba et al., 2022).

Antidiabetic & Anti-obesity activity

Type 2 Diabetes Mellitus (T2DM), one of the most common metabolic diseases in the world, is primarily caused by the combination of two basic factors: reduced insulin production by pancreatic beta-cells and impaired insulin sensitivity in tissues. For insulin to completely fulfill the metabolic demand, the molecular processes involved in its synthesis, release, and tissue response must be tightly regulated. Therefore, anomalies in any of the systems involved may be the source of a metabolic imbalance that leads to the development of T2DM (Galicia-garcia et al., 2020). Free radicals and oxidative stress are important mediators of insulin resistance and glucotoxicity-induced beta cell malfunction and death in type 2 diabetes (T2D), as well as autoimmune beta cell destruction in type 1 diabetes (T1D). In T2D, oxidative stress also promotes beta cell de-/trans-differentiatiossn by causing the loss of transcription factors necessary for beta cell growth, maturity, and regeneration. This lowers the functionality of beta cells (Maria et al., 2018; Dinic et al., 2022). The *M. oleifera* aqueous leaves extract minimizes hyperglycemia in STZ-induced diabetes and guards cells against ROS-mediated damage, according to histological, histochemical, morhometric, and ultrastructural tests (Yassa & Tohamy, 2014; Y. Yang et al., 2022). The *M. oleifera* extract (DHE)-treated diabetic mice showed significantly lower glucose levels than the diabetic control group. This is because the phenolic compounds in *M. oleifera* extract can serve as insulin secretagogues to maintain glucose homeostasis when hyperglycemia occurs by targeting pancreatic β-cells (Tuorkey, 2016; Oldoni et al., 2021). The phenolic and flavonoid compounds found in the ethanol extract of *Moringa oleifera* leaf were proven in vitro and in silico to have antidiabetic potential by inhibiting human pancreatic α-amylase (HPA) (Chigurupati et al., 2022). According to other research, *Moringa oleifera* leaf extracts are more effective at inhibiting the enzymes α-glucosidase and α-amylase than the widely used drug acarbose, which is a potent inhibitor of both. According to reports, consuming acarbose may have several adverse effects. For instance, it causes diarrhea by excessively blocking the digestive tract's amylase enzyme, which can lead to inappropriate bacterial digestion of carbohydrate meals in the colon and unpleasant digestive disorders (Nakhaee & Sanjari, 2013; Mahmouda et al., 2022).

Glucosidase inhibition tests to see the anti-diabetic effects of *M. oleifera* leaves and roots have recently been carried out by (Tshabalala et al., 2020) According to them, *M. oleifera* leaves have better antidiabetic action than the main and lateral roots, which have EC50 values of 40.7 ± 5.2 (EC50) μg/ml, 870.1 ± 12.0 and 560, respectively. 7 ± 7.4 μg/ml. Furthermore, researchers claim that the antioxidants vitamin C, ascorbic acid, and have comparable anti-diabetic effects.

Moringa oleifera not only does it have antidiabetic properties, but it has been also reported to have anti-obesity properties (Nahar et al., 2016). In particular, administering methanol extract from Moringa oleifera leaves to obese mice fed a high-fat diet was proven to reduce body weight, total cholesterol, triglycerides, organ body weight, and blood glucose levels (Bais et al., 2014). The same study revealed that *M. oleifera* can help people maintain their weight by preventing them from gaining weight. Furthermore, administration of *M. oleifera* leaf petroleum ether extract reduced lipid accumulation in mice fed a high-fat diet; this was accomplished by inhibiting adipogenesis and promoting lipolysis. The same study demonstrated that the extract can increase the expression of a lipolysis-related protein in 3T3-L1 adipocytes while decreasing the expression of proteins involved with adipogenesis (Xie et al., 2018). In another study conducted by Metwally et al., (2017) on obese rats fed with *M. oleifera* extract, it was found that leptin and resistin responses were reduced, adiponectin gene expression was increased, and body weight decreased. The researchers concluded that M. oleifera's anti-obesity and antidiabetic effects affect the adipokines generated by visceral adipose tissue.

Anti-inflammatory activity

Inflammation is a suitable defense mechanism against tissue damage caused by trauma, harmful chemicals, ischemia, antigen-antibody interactions, infectious agent factors, and denaturation of proteins (Lintang et al., 2019), (Yani & Fatahillah, 2022). Usually, cellular and molecular processes and interactions effectively reduce the risk of harm or infection during acute inflammatory reactions. The acute inflammation is reduced and tissue homeostasis is restored as a result of this mitigating process. However, uncontrolled acute inflammation can lead to a variety of chronic inflammatory disorders and eventually become a chronic inflammatory diseases (Zhou et al., 2016), (L. Chen et al., 2018). Various parts of *M. oleifera* have been shown to possess anti-inflammatory properties, for example, the leaves (Xu et al., 2019; Sugiharto et al., 2022), roots (Rathore & Das, 2022; Tanga, 2022), stem bark

According to (Fard et al., 2015), the primary stimulus for inflammation is a microbial stimulus such as lipopolysaccharide (LPS), which is found on the membrane of gram-negative bacteria. LPS is an endotoxin that contributes to macrophage activation. The presence of Toll-like receptor 4 (TLR4) on the cell membrane of white blood cells (macrophages) enables TLR4 to recognize the LPS on the bacterium. The damage caused by the presence of a bioactive extract derived from *M. oleifera* is facilitated through the TLR4-NFκB (nuclear factor kappa-light-chain-enhancer of activated B-cells) signaling pathway. This pathway efficiently inhibits the activity of cyclooxygenase-2 (COX-2) and isoform nitric oxide synthases (iNOS). As per the researcher's assertion, the leaf extract additionally inhibits the synthesis of pro-inflammatory cytokines (e.g., interleukin-1β, interleukin-6), and tumor necrosis factor-alpha (TNF-α), in macrophages that have been stimulated with lipopolysaccharide (LPS). Other research conducted by (Sugiharto et al., 2022), shows application of *M. oleifera* leaf extract as a pretreatment for intestinal organoids resulted in a notable decrease in TNF-α-induced injury and aberrant proliferation. The DSS-induced injury in the colons of mice that were pretreated with the extract was considerably reduced. Additionally, there was a significant decrease in the expression of inflammatory cytokines and the depletion of goblet cells.

Microbial stimuli such as lipopolysaccharide (LPS), an endotoxin, play a role in activating macrophages, which are found on the membranes of gram-negative bacteria, and are the initial trigger for inflammation. Toll-like receptor 4 (TLR4), which is found on the cell membrane of white blood cells (macrophages) is used to identify LPS in bacteria. If there is a bioactive extract from M. oleifera, then the damage will occur. mediated by the TLR4-NFκB (nuclear factor kappa light chain enhancer of activated B cells) signaling pathway, which effectively suppresses nitric oxide isoform synthase (iNOS) and cyclooxygenase-2 (COX-2). The leaf extract, according to researchers, also reduces the production of proinflammatory cytokines in macrophages stimulated by lipopolysaccharide (LPS), including tumor necrosis factor-alpha (TNF-α), interleukin-1β (IL-1β), and interleukin-6 (IL-6) (Fard et al., 2015).

Another study, Assessment of the anti-inflammatory activities of the Moringa leaf extract in Periodontitis cases through IL-6 cytokine analysis, carried out by (Sugiharto et al., 2022), measured differences in the reduction of IL-6 levels in the Wistar group given Moringa extract with the control group given distilled water irrigation. The results showed that the Wistar group given Moringa extract showed a higher average reduction in IL-6 levels compared to the control group. This corresponds with studies by (Xu et al., 2019), which examined the antioxidant and anti-inflammatory properties of *M. oleifera* leaves, seeds, and stems and found that the anti-inflammatory activity was demonstrated by a reduction in nitric oxide (NO) levels in RAW264.7 macrophage cells. This is because Moringa contains several chemical compounds that are responsible for pharmacological effects, one of which is flavonoid compounds. Flavonoids are polyphenolic compounds that are found in many plants. The main flavonoids found in Moringa leaves, including quercetin, kaempferol glucoside, and malonic flavonoids, show anti-inflammatory activity by inhibiting NO production in LPS-stimulated macrophages (Coppin et al., 2013). Flavonoids are a group of phenolics that have a mechanism similar to non-steroidal anti-inflammatory drugs. Flavonoids can inhibit the activity of pro-inflammatory mediators other than COX (Izzi et al., 2012).

In other research, *Moringa oleifera*seeds have also been proven to treat colitis, a disease that occurs due to inflammation of the large intestine (Crohn's disease and ulcerative colitis) (Minaiyan et al., 2014). Meanwhile, (Jaja-chimedza et al., 2017), validate and biochemically characterize an isothiocyanate-enriched moringa seed extract (MSE), and assess how well MSE-containing moringa isothiocyanate-1 (MIC-1) reduces inflammation in comparison to a turmeric extract that has been enriched with curcuminoid (CTE). The results showed that rats given Moringa seed extract could reduce carrageenan-induced rat paw edema (33% at 500 mg/kg MIC-1) comparable to aspirin (27% at 300 mg/kg), whereas CTE did not have any significant effect. In addition, MIC-1 also showed more significant effectiveness in reducing the expression of the pro-inflammatory cytokine genes IL-1β and IL-6 compared to curcumin at all concentrations test.

Anticancer activity

Cancer is the second biggest cause of mortality globally, accounting for 8.8 million deaths in 2015. Cancer accounts for one out of every six deaths worldwide (A. K. Singh, Bishayee, et al., 2018). Lung, breast, stomach, prostate, colorectal, and skin cancer are the most frequent types of cancer. In recent years, there have been breakthroughs in successful cancer treatment; nonetheless, there is a need for even better therapies since present approaches have unpleasant side effects, may be poisonous, or meet resistance (Singh et al., 2018; Kou et al., 2018). Consequently, it is necessary to investigate natural remedies, which typically have few or no adverse effects.

*Moringa oleifera*Lam. is widely regarded as a remarkable plant due to its many components, including leaves, bark, and fruit, which have shown potent anticancer properties in breast, colorectal, oral, pancreatic, hepatic carcinoma, and melanoma cancer (Berkovich et al., 2013; Al-Amari et al., 2015; Jung et al., 2015). The anti-cancer properties of Moringa leaves (ML), Moringa leaves nanoparticles (MLn), Moringa root core (MRc), and Moringa root outer (MRo) extracts have been observed in various cancer cell lines, including liver HepG2, colon HCT 116 and Caco-2, and breast MCF7. These extracts have been found to inhibit cell proliferation and induce apoptosis-mediated cell death. Notably, the MRc extract demonstrated a minimal cytotoxic effect on the healthy BHK-21 cell line, suggesting its potential as a selective anti-cancer agent. Furthermore, the application of MLn/ML and Rc/Ro extracts resulted in a notable decrease in cell viability and a significant increase in apoptosis when compared to the control group (Abd-rabou et al., 2017). *Moringa oleifera*leaf extracts inhibit c-myc expression in AsPC 1 cells. On the other hand, the p53 gene is a tumor suppressor gene that works as a genome protector, but its down-regulation causes apoptosis, and the leaf extracts reduced p53 gene expression in all cell lines examined. Apoptotic genes showed heterogeneous expression, suggesting that the mechanisms of apoptosis varied amongst these cell lines. Mta-1, BRCA1, and Ki-67 genes are all downregulated by *M. oleifera* leaf extracts, suggesting that the mechanism that leads to apoptosis was accompanied by considerable downregulation of these genes (Pappas et al., 2021). Whereas, MoFTI (*M. oleifera* floral trypsin inhibitor) was found in *M. oleifera* flowers and demonstrated potent anticancer effects in vivo against sarcoma 180 cells (Leite et al., 2020). M. oliefera fruit cooked shows chemopreventive properties, reducing the development and multiplicity of tumors in the rat colon that are carcinogenic caused by azoxymethane and dextran sodium sulfate. Inhibition of tumor cell growth is caused by the presence of bioactive components such as niazimicin and glucomorimgin (Budda et al., 2011). However, (Jung, 2014) found that cold water extracts of *M. oleifera* exhibited more anticancer activity than hot water extracts, probably due to heat inactivation of several bioactive compounds in the leaves. Furthermore, *M. oleifera* cold water leaf extract has been proven to be efficient against malignant cells in mice's lungs and liver. Other research conducted by (Madi et al., 2016) examined the antiproliferative activities of a hot water extract from the MO leaf in A549 lung cancer cells. The extract elicited an elevation in reactive oxygen species, resulting in the activation of p53, caspases, and subsequent cleavage of PARP-1. Consequently, the cancer cell line underwent apoptosis. Furthermore, it was shown that the crude aqueous extract of hot water also exhibited antiproliferative activities in A549 lung cancer and SNO esophageal cancer cells.

The study conducted by : (Gismondi et al., 2013) showed that the given of a leaf extract derived from *M. oleifera* resulted in a 22% cell death and inhibited the growth of B16F10 murine melanoma cells. The researchers detected a proportion of 21.1% of nuclei undergoing apoptosis in the sub-G1 region, along with cell cycle arrest in the G2/M phase. Simultaneously, there was a notable elevation in the levels of p53 protein inside the cellular environment, a protein renowned for its role in suppressing tumorigenesis. Furthermore, it was shown that MO leaves downregulated the NFκB pathway by reducing the expression levels of IκBα, pIκBα, and p65 proteins. The combination of this substance with cisplatin resulted in a synergistic induction of cytotoxicity in pancreatic cancer cells. Furthermore, it has been shown to have efficacy against breast cancer cells (Vergara-jimenez et al., 2017). Besides that, *Moringa oleifera*leaves and bark have potent anticancer properties at cancer cell lines HCT-8 and MDA-MB-231, it exhibited antiproliferative properties. However, the seed extract did not poten. Cell cycle arrest in the G2/M phase was followed by apoptosis. Bioactive substances such as D-allose, hexadecanoic acid ethyl ester, eugenol, and isopropyl isothiocyanate were implicated in the anticancer action. This is especially significant since the bioactive substances that were found included long-chain hydrocarbons, aromatic rings, and a sugar moiety. Consequently, MO has the prospect of the discovery of new drugs (Al-asmari et al., 2015).

Nutritional ingredients of *M. oleifera*

The non-governmental organizations, including the Educational Concerns for Hunger Organization, Church World Service, and Trees for Life, have adopted the slogan "Natural nutrition for the tropics" to promote the use of many plant species groupings, including M. oleifera, as viable food sources (Brilhante et al., 2017). Numerous studies have disclosed that the leaves of *M. oleifera* contain an exceptionally high concentration of proteins (20–35% by dried weight). In addition, the nutritional profile of leaves is well-balanced, containing all the essential amino acids and an unusually high level of alpha-linoleic acid among unsaturated fatty acids (Y. Liu et al., 2018). In addition to high levels of protein, amino acids, and unsaturated fatty acids, Moringa leaves also contain significant amounts of other nutrients. Vitamin A, vitamin B (including folic acid, pyridoxine, and nicotinic acid), vitamin C, vitamin D, and vitamin E are only some of the many vitamins found in abundance in *M. oleifera* (Kashyap et al., 2022). In addition, this plant is known to possess a composition of 16-19 amino acids, encompassing the 10 essential amino acids, specifically threonine, tyrosine, methionine, valine, phenylalanine, isoleucine, leucine, histidine, lysine, and tryptophan. *M. oleifera* exhibits much higher levels of lysine, leucine, histidine, glutamic acid, valine, isoleucine, alanine, phenylalanine, and arginine compared to other woody plant species (Falowo et al., 2018; Su & Chen, 2020). Moringa leaf also has a significant quantity of iron, zinc, calcium, potassium, and several other essential minerals (Gopalakrishnan et al., 2016). Apart from that, this plant is also rich in vitamins, including vitamin A, vitamin B (including folic acid, pyridoxine, and nicotinic acid), vitamin C, vitamin D, and vitamin E (Kashyap et al., 2022; Yanuartono et al., 2022).

Conclusion and future perspectives

This review summarizes research on *M. oleifera* plants from various countries around the world, including extraction methods, phytochemical content, biological activity, traditional uses, and nutritional content. The presence of flavonoids, steroids, alkaloids, terpenes, glycosides, and fatty acids is responsible for the pharmacological effects of the *M. oleifera* plant. In addition, the presence of compounds such as carotenoids, vitamins, and macronutrients increases the potential of this plant as a food source for the treatment of disease. Various pharmacological studies show that the Moringa plant has activity as antibacterial, antifungal, antioxidant, anti-inflammatory, anti-diabetic, anti-cancer, etc.. In recent times, a lot of preclinical research has been carried out on the potential of this plant. However, various studies carried out in the last few decades have focused more on the potential of Moringa leaves as a source of medicinal ingredients. Therefore, it is proposed to explore the phytochemical content of Moringa seeds, which can be used as food that, if consumed every day, has the potential to prevent and treat disease in humans so that it can be used as a functional food source.

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