

REVIEW

Potential of *Moringa oleifera* seeds and leaves as functional food ingredients for human health promotion

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Summary

Moringa (Moringa oleifera Lam.) is a tropical and subtropical shrub used for horticultural, food and folk medicinal purposes. It has a prospect of use in meeting human nutritional needs and in health promotion. The interest in the application of *Moringa oleifera* as a functional food or source of nutraceuticals is an indication of the versatility of the plant and its various medicinal properties and use in the temperate and semi-temperate regions. *Moringa* seeds and leaves are the most utilized parts, containing bioactive compounds that can regulate osmotic adjustment, enzymatic and hormonal activities and various metabolic pathways. Studies showed that they possess the capacity to intervene in human diseases including diabetes, obesity, inflammation, cancer, hypertension and microbial infections. Their biological effects, especially in chronic diseases, are discussed in this review, focusing on the active phytochemicals and mechanisms of action. Further research is needed to identify the physiological targets, specific molecular mechanisms and bioaccessibility/bioavailability of the active components in *moringa* seeds and leaves. Most importantly, thorough human trials are strongly needed to validate efficacy and risk of toxicity, in order to facilitate their development and incorporation into foods as health-promoting agents.

Keywords

Moringa oleifera; functional food; natural health product; phytochemical; biological activity

With the increasing rate of health-compromising diseases, coupled with the shortcomings of synthetic drug therapies, alternative sources of health-promoting agents are actively sought after. Plants have proven to be a repository of diverse classes of compounds with strong positive effects on physiological processes and general well-being. Among these plants is *Moringa oleifera* Lam., a highly valued plant, a member of the Moraceae family, whose therapeutic and prophylactic properties were first acknowledged in folk medicine. *Moringa* originates from the sub-Himalayan parts of North India, but is now widely cultivated in many parts of the tropical and sub-tropical re-

gions of the world [1]. It can grow on marginal soils, under humid/hot and dry tropical conditions [2]. The plant bears many indigenous names such as drumstick tree, horseradish tree, benzolive tree, kelor tree or malungay, in different areas where it is cultivated [3]. *Moringa* extracts have been employed in the traditional treatment and prevention of numerous ailments such as diabetes, hypertension, skin infections, anaemia, asthma, cholera, indigestion and anxiety [4]. In fact, the plant has gained such popularity to be referred to as “Miracle tree”, “Tree of life”, or “Mothers’ best friend” (due to its ability to enhance breast milk production) [4, 5]. Besides their medicinal prop-

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erties, moringa parts, including the leaves, seeds, bark, stem, roots, flowers and pods, possess exceptional nutritional quality and, therefore, are used in many countries for malnutrition remediation [6]. For instance, the leaves are rich in zinc, manganese, selenium, boron, potassium, calcium, iron, essential amino and fatty acids, vitamins C and E, and β -carotene [5, 7].

In the past few decades, a wide scientific evidence supporting the traditionally-acclaimed

health benefits of moringa has emerged, in addition to identification of many active constituents (compounds in Tab. 1 and Fig. 1). The fact that these studies involved researchers from different fields and geographical regions of the world indicates a considerable interest in the use of *M. oleifera* for its perceived health benefits. It also demonstrates the potential of this plant to thrive on the market of functional foods. Like other plants, several factors, including genotype,

Tab. 1. Bioactive phytochemicals in the seeds and leaves extracts of *Moringa oleifera*.

Plant part	Compound	Content [g·kg ⁻¹]	Reference
Ethanollic leaves extract	Niaziridin	0.15	SHANKER et al. [8]
Aqueous extract of defatted seeds	4-(α -L-Rhamnosyloxy)-benzyl isothiocyanate	3.6	EILERT et al. [9]
Aqueous extract of defatted seeds with 0.1% ascorbic acid at pH 6.8		8.9	
Ethanollic leaves extract	Niazirin	36	FAIZI et al. [10]
	Niazirinin	22	
	Niaziminin A	23	
	Niaziminin B	6.2	
	Niazinin A	19	
	Niazinin B	21	
	4-(4-O-Acetyl- α -L-rhamnosyloxy)-benzyl isothiocyanate	10	
Ethanollic leaves extract	O-Ethyl-4-(α -L-rhamnosyloxy)-benzyl carbamate	1.25	GUEVARA et al. [11]
	Niazimicin	0.42	
	Niazirin	1.67	
	Glycerol-1-(9-octadecanoate)- β -sitosterol	8.9	
	3-O-(6'-O-Oleoyl- β -D-glucopyranosyl)- β -sitosterol	5.42	
	β -Sitosterol-3-O- β -D-glucopyranoside	2.5	
Methanolic seeds and leaves extracts	4-(α -L-Rhamnosyloxy)-benzyl glucosinolate	202 ^a ; 59.4 ^b	BENNETT et al. [12]
	Quercetin-3-O-glucoside	0.21 ^b	
	Quercetin-3-O-(6''-malonyl) glucoside	0.25 ^b	
	Kaempferol-3-O-glucoside	0.08 ^b	
	Kaempferol-3-O-(6''-malonyl) glucoside	0.08 ^b	
	3-Caffeolyquinic acid	8.9 ^b	
	5-Caffeolyquinic acid	1.1 ^b	
Aqueous seeds and leaves extracts	Ascorbic acid	0.62 ^a ; 0.91 ^b	SINGH et al. [13]
	Gallic acid	0.11 ^a ; 1.03 ^b	
	Quercetin	0.81 ^b	
	3-Caffeolyquinic acid	0.49 ^b	
	Ferulic acid	0.13 ^b	
	Vanillin	0.14 ^b	
	Ellagic acid	0.19 ^b	
	Kaempferol	0.1 ^a ; 0.2 ^b	

Lowercase letters in superscript denote the plant part where the compound was identified (a – seeds, b – leaves).

environmental and cultural practices, can affect the amount of moringa bioactive components and their bioactivity [14]. However, irrespective of these factors, moringa plant extracts influence a broad spectrum of human health conditions, producing beneficial effects such as anti-inflammatory, antidiabetic, hypocholesterolemic, antioxidant, hepatoprotective, anticancer, antimicrobial and antihypertensive activities [15]. The effects of moringa leaves and seeds, particularly in chronic diseases, are reviewed, with a focus on the active phytochemicals and their molecular mechanisms. Important considerations for global appreciation and commercialization as functional food ingredients for health promotion are also discussed.

BIOLOGICAL ACTIVITIES

Anti-inflammatory activity

Chronic diseases are usually characterized by aberrant inflammatory response, which, when attenuated, can reduce disease severity. In lipopolysaccharide (LPS)-activated RAW macrophages, treatment with moringa leaves-derived isothiocyanates (ITCs), compounds 4-(α -l-rhamnosyloxy)-benzyl isothiocyanate and 4-(4-*O*-acetyl- α -l-rhamnosyloxy)-benzyl isothiocyanate in Fig. 1) downregulated the mRNA levels of inducible nitric oxide synthase (iNOS) and interleukin-1 β (IL-1 β), and reduced nitric oxide (NO) production. However, these effects were more pronounced in the whole leaves extract, indicating a collective action by ITCs and possibly other contained active compounds [16]. Conversely, tumour necrosis factor (TNF)- α mRNA expression was largely unaffected, but the protein level was significantly decreased, which suggests that the molecular targets of the active constituents may lie within the translational or posttranslational pathways. Studies showed the anti-inflammatory property of moringa tissues to be more related to ITCs. In fact, they competed favourably with popular and extensively studied anti-inflammatory ITCs, such as sulforaphane and benzyl isothiocyanates from crucifers, in the suppression of iNOS and cyclooxygenase-2 (COX-2) mRNA expression, NO production as well as inhibition of nuclear factor kappa-light-chain-enhancer of activated B cells (NF- κ B) as well as mitogen-activated protein kinase (MAPK) signalling pathways in RAW 264.7 mouse macrophages [17]. A recent comparative study found that moringa seed ITC (compound 4-(α -l-rhamnosyloxy)-benzyl isothiocyanate) had stronger in vitro and in vivo anti-inflammatory

effects than turmeric-derived curcumin, which is known for its strong anti-inflammatory activity [18]. Moringa ITCs are formed by myrosinase action on the corresponding constituent glucosinolates, and are more potent anti-inflammatory compounds than their precursors [19]. They can be enriched in an extract by the addition of ascorbic acid, which functions as a coenzyme [9]. Moreover, their structures contain rhamnose, which is a unique feature that was thought to impart strong thermal and storage stability, unlike their volatile and less stable counterparts [20] and, therefore, makes them preferable for incorporation into functional food products.

Furthermore, the seeds extract of moringa was reported to exert a synergistic inhibition of TNF- α , NO and IL-1 β production compared to isolated lectin proteins (cMol and WSMol) and these effects, including 71% decrease in leukocyte migration and consequent myeloperoxidase activity, were reproduced at a greater strength in a mice model of carrageenan-induced pleurisy [21]. Treatment with moringa seed extract and the derived β -sitosterol also modulated inflammatory responses in animal models of asthma and arthritis, marked by decreased TNF- α , IL-4, IL-6 protein levels, histamine and neutrophils in the bronchoalveolar lavaged fluid [22–24]. Pro-inflammatory mediators such as TNF- α , NO, interleukins, COX-2 and transcription factors are important targets of conventional anti-inflammatory drugs, thus making moringa leaves and seeds promising candidates for food-based intervention in alleviating chronic inflammatory diseases.

Antioxidative activity

Plants intrinsically possess antioxidative property, which is associated with contained compounds such as polyphenolics, ascorbic acid, tocopherol and β -carotene, whose dietary intake can reduce the risk of cardiovascular diseases and cancer, amongst other diseases [25]. While several studies demonstrated the antioxidative activity of moringa leaves and seeds in various systems, phenolic compounds such as chlorogenic acid, quercetin (or its glycoside), gallic acid, rutin and kaempferol were consistently reported as the key antioxidants [13, 20, 26, 27]. For instance, the total phenolic content (*TPC*) of the methanolic leaves extract was strongly correlated with oxygen radical-scavenging activity (*ORAC*) [20]. Moreover, no significant difference in *ORAC* was observed between the extract and its derivative, which had lower *TPC* but was richer in rutin, chlorogenic acid and quercetin malonyl-glucoside, denoting strong antioxidative capacity [20]. Similarly, the leaves ex-

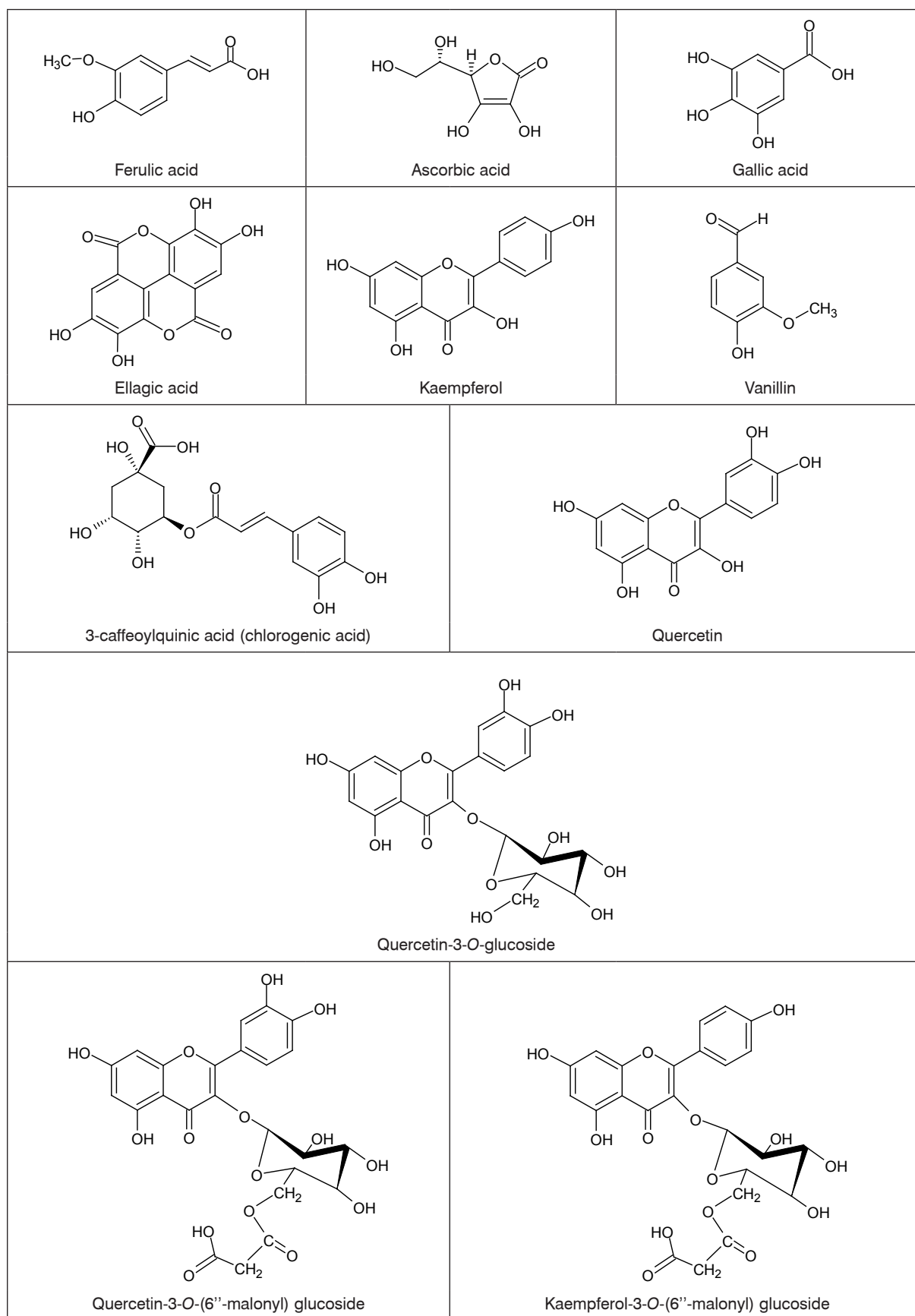


Fig. 1. Structures of the reported bioactive phytochemicals in *Moringa oleifera* seeds and leaves extracts.

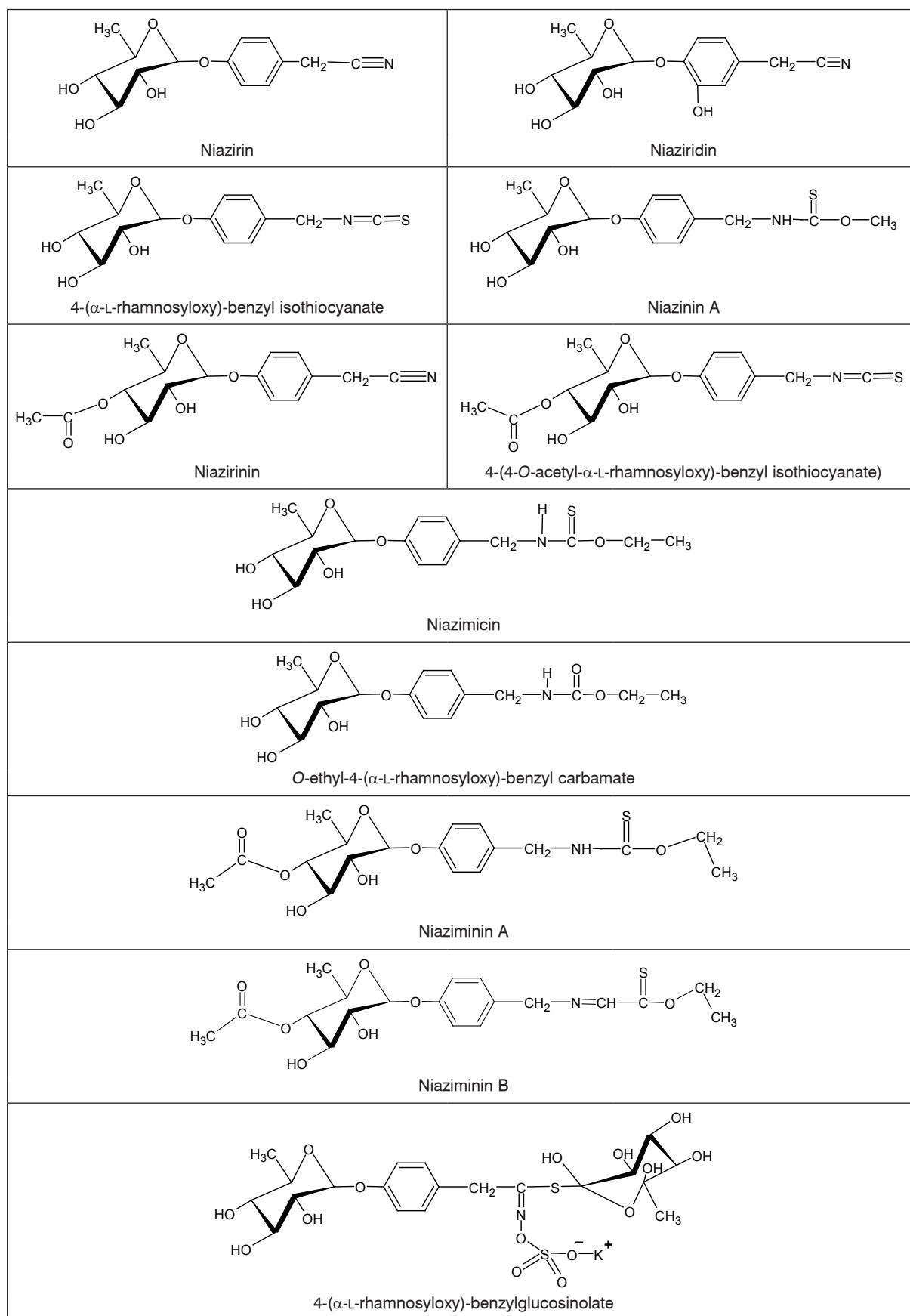


Fig. 1. continued

tract induced nicotinamide adenine dinucleotide phosphate (NADPH) quinone oxidoreductase 1 (NQO1) activity in Hepa1c1c7 mouse hepatoma cells, which is a functional characteristic of ITCs (compounds 4-(α -l-rhamnosyloxy)-benzyl isothiocyanate and 4-(4-*O*-acetyl- α -l-rhamnosyloxy)-benzyl isothiocyanate) [20]. NQO1 is a phase II xenobiotic metabolizing enzyme that catalyses the two-electron reduction of quinones and their derivatives, thereby preventing free radical production and oxidative stress to tissues [28].

The solvent used in extraction plays an important role in the antioxidative activity (notably radical scavenging) of moringa extracts. Leaves extract obtained with methanol had significantly higher 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical-scavenging activity (half maximal effective concentration, EC_{50} , of $1.60 \text{ mg}\cdot\text{ml}^{-1}$) than that extracted with dichloromethane (EC_{50} of $2.31 \text{ mg}\cdot\text{ml}^{-1}$) [29]. Similarly, the half maximal inhibitory concentration (IC_{50}) values for 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid (ABTS, $11.73 \text{ }\mu\text{g}\cdot\text{ml}^{-1}$) and DPPH ($49.30 \text{ }\mu\text{g}\cdot\text{ml}^{-1}$) radical-scavenging activities of another methanolic leaves extract were 6–22 times lower than those of dichloromethane, ethyl acetate and hexane extracts [30]. Solvent polarity can affect the solubility of antioxidative compounds, which can result in both quantitative and qualitative variations in the extracts. These findings demonstrate the suitability of highly polar solvents for extracting stronger and higher amounts of free radical scavengers from moringa tissues. Moreover, other studies suggested that flavonoids and phenolic acids can be optimally enriched in the leaves extracts by maceration and ultrasound-assisted extraction technique using aqueous mixtures of strong polar solvents such as methanol or ethanol [31, 32].

The antioxidative activities of *M. oleifera* also include cellular protection against metal-induced toxicity, which can activate the release of reactive oxygen species, leading to tissue damage. Simultaneous oral administration of moringa seed powder ($250 \text{ mg}\cdot\text{kg}^{-1}$ and $500 \text{ mg}\cdot\text{kg}^{-1}$) in male Swiss mice mitigated the deleterious effects of arsenic toxicity, marked by 42–57% reduction in free radical production in tissues and 50% preservation of endogenous antioxidants, including glutathione [33]. Arsenic chelation and consequent decrease in its uptake by tissues was suggested as a possible mechanism. However, even with the unclear molecular mechanism(s), moringa seed proteins are rich in cysteine residues [34], which can participate in thiol-disulfide exchange leading to glutathione (GSH) regeneration from its oxidized form [35]. Therefore, the antioxidative activity of the

extract can be due to synergistic mechanisms, but these need to be elucidated. Pre-treatment and co-administration of moringa leaves extract reduced intracellular cadmium uptake and accumulation in *Saccharomyces cerevisiae* by downregulating a low-affinity iron transporter, Fe(II) permease (Fet4p), which also participates in cadmium transport [36]. Whether the active constituent(s) in the extract interacted directly with the transporter or intercepted its expression is still not known, but the downregulation was accompanied by an untargeted depletion of intracellular iron. This could have beneficial effects by attenuating iron-mediated free radical production, or pose detrimental effects by decreasing iron bioavailability.

Antidiabetic activity

Moringa extracts have been extensively used for controlling diabetes in traditional medicine, as it is believed to regulate blood sugar level [37]. Several studies demonstrated remarkable decrease in both fasting blood glucose (FBG) and postprandial blood glucose (PPBG) as well as oxidative stress markers, when moringa leaves extracts ($55\text{--}250 \text{ mg}\cdot\text{kg}^{-1}$ body weight) were administered to chemically or diet-induced diabetic rats [37–40]. Inhibition of carbohydrate digestive enzymes and consequent prevention of postprandial blood glucose spike were reported as one of the ways by which moringa plant extracts can promote glucose homeostasis. For instance, an aqueous moringa leaves extract inhibited intestinal sucrase and maltase activity, with IC_{50} values of $0.98 \text{ mg}\cdot\text{ml}^{-1}$ and $>5 \text{ mg}\cdot\text{ml}^{-1}$, respectively [41]. Moreover, concurrent administration of the leaves extract to saccharose-fed diabetic rats strongly suppressed gastrointestinal digestion of the disaccharide, and reduced the absorption and blood concentration of glucose [42]. The antidiabetic property of moringa leaves and seeds is usually linked to the plant secondary metabolites, but the proteins also possess substantial blood glucose-regulatory functions in diabetic mice through unidentified mechanisms not involving stimulation of insulin secretion [43]. However, it should be noted that the protein, when orally administered, is subject to gastrointestinal proteolysis and degradation of the sequence(s), leading to complete loss of the antidiabetic potency. The effect of moringa leaves extract on insulin secretion is rather inconclusive, as some studies found negligible or zero effect [42–44] while others reported significant increase in secretion [45, 46].

Moringa leaves can suppress hepatic gluconeogenesis by inhibiting the expression of key gluconeogenic enzymes, such as glucose-6-phosphatase

and pyruvate carboxylase [47], and this is partly mediated by ITCs [48]. The ability of moringa leaves and seeds to restore retinal and renal histological structures, antioxidative activities of glutathione, glutathione peroxidase, superoxide dismutase and catalase, as well as to downregulate the protein levels of the pro-inflammatory cytokines (TNF- α , IL-1 and IL-6) and angiogenic factors (vascular endothelial growth factors and protein kinase C), demonstrates their potential to improve diabetic retinopathy and nephropathy complications [49–51].

The glycemic control potential of moringa leaves has been evaluated in humans. In one study, 55 type 2 diabetes mellitus (T2DM) patients (FBG ≥ 140 mg·dl⁻¹), who were not receiving treatments, were placed on a standard meal supplemented with 8 g of moringa leaves powder for 40 days [52]. While FBG and PPBG remained the same in the control group, the experimental group had 28% and 25% reduction in FBG and PPBG levels, respectively, over the study duration [52]. Similarly, PPBG and glycosylated hemoglobin (HbA1c) levels of 60 T2DM patients were decreased by 55% and 0.4%, respectively, upon administration of dehydrated moringa leaves tablets twice daily for 3 months [53]. Intake of moringa tea, prepared with the leaves powder prior to glucose load, also significantly decreased PPBG level by about 20% in 15 normoglycemic male subjects [54]. Moreover, a study conducted with 10 healthy subjects, which each consumed up to 4 g of moringa leaves powder, demonstrated an increase in insulin secretion but with no significant difference in blood glucose level [46]. There is a dearth of information on the active constituent(s) of moringa that mediated glucose homeostasis in the human subjects, although animal studies reported that chlorogenic acid, kaempferol-3-*O*-glucoside, quercetin (or its 3- β -D-glucoside), rutin and moringinine constitute the principal glycemic controlling agents in moringa leaves extract [55, 56].

Anticancer activity

Several studies have examined the anticancer effect of moringa leaves and seeds in different kinds of cancer cell lines. Treatment with the leaves and seed extracts suppressed proliferation, arrested cell cycle at the G2/M phase, induced apoptotic pathway via caspase-3 activation and subsequent cleavage of poly (ADP) ribose polymerase (PARP-1), and deactivated important tumour-promoting signalling pathways such as NF- κ B and Janus kinase/signal transducers and activators of transcription (JAK/STAT) pathways [11, 29, 57–62]. The anticancer property

was linked to some moringa compounds including 4-(α -L-rhamnosyloxy)benzyl isothiocyanate (and its acetylated form), niazimicin, β -sitosterol-3-*O*- β -D-glucopyranoside, quercetin, moringinine, eugenol, D-allose, isopropyl isothiocyanate and hexadecanoic acid (Fig. 1) [11, 56, 59]. However, the physiological targets of these compounds as well as molecular interactions that led to their anticancer activities still need to be clearly elucidated. The presence of an acetoxy group at the 4'-position in niaziminin was observed as a structural requirement for the inhibition of 12-*O*-tetradecanoyl-phorbol-13-acetate-induced activation of Epstein-Barr virus in Raji cells [63]. Treatment with moringa seeds lectin (cMol) reduced the viability of B16-F10 murine melanoma cells, with no toxicity to normal cells, increased mitochondrial reactive oxygen species, and stimulated the activation of apoptotic caspases-3,8,9 [64]. Quercetin-3-*O*-glucoside and 4-(β -D-glucopyranosyl-1 \rightarrow 4- α -L-rhamnopyranosyloxy)benzyl isothiocyanate demonstrated significant cytotoxic effects in liver hepatocellular carcinoma (HepG2) and colon carcinoma (Caco-2) cell lines, with marginal toxicity to non-cancerous human embryonic kidney cell lines (HEK293) [65]. Despite the prospects, it should be noted that bioavailability of the moringa compounds needs to be established prior to exploring their in vivo anticancer roles in human subjects.

Antihypertensive activity

Moringa has also shown potential for use in regulating elevated blood pressure. For instance, the administration of 5–10 mg·kg⁻¹ of moringa leaves extract to normotensive Wistar rats reduced systolic, diastolic and mean arterial blood pressures by 34–40%, and niazimicin, niaziminin A and B, and niazinin A (Fig. 1) were proposed to be the major active components [10, 66–68]. These compounds are rare naturally occurring thiocarbamates and are concentrated in moringa leaves. Recently, ATTAKPA et al. [69] showed that feeding a diet rich in moringa leaves extract (200–600 mg·kg⁻¹ body weight) to spontaneously hypertensive rats (SHR) decreased the blood pressure and also modulated T-cell immune response and intracellular calcium signalling. The effects were induced by suppressing IL-2 and increasing basal calcium ion concentration, respectively, with the highest activity observed for the diet formulated with 400 mg·kg⁻¹ of the extract [69]. Conversely, oral administration of the seeds powder to SHR had no measurable effect on blood pressure, but reverted hypertension-induced cardiac hypertrophy and fibrosis as well as increased the expres-

sion of peroxisome proliferator-activated receptor (PPAR)- α and PPAR- γ , which trigger fatty acid oxidation leading to decrease in triglyceride level in the cardiac left ventricle [70]. Moringa seeds extract was also shown to modulate vascular oxidative stress and inflammation in SHR, marked by inactivation of NF- κ B, downregulation of NADPH oxidase and iNOS expression, as well as upregulation of superoxide dismutase (SOD) [71]. Regulation of blood pressure is one of the therapeutic properties of *M. oleifera* leaves and seeds that is prominent among traditional users. However, the scientific literature on this topic is limited and the antihypertensive mechanism(s) of the active components is largely unexplored. Furthermore, the effects of moringa extracts and components on the physiological renin-angiotensin system pathway, which is the primary blood pressure regulation system, have yet to be investigated.

Hepatoprotective activity

The leaves and seed extracts of *M. oleifera* have also demonstrated liver function-promoting activities by offering protection against liver toxicity and cellular damage. Pre-administration of rats with moringa leaves and seeds extract (200–800 mg·kg⁻¹) was found to revert drug-induced elevation of important liver damage markers, including alanine transaminase, aspartate transaminase, alkaline phosphatases, myeloperoxidase and bilubrin [27, 72–77]. The hepatoprotective effect of the extracts is comparable to standard drugs such as Silymarin, and hence *M. oleifera* can be considered for use as a natural alternative to synthetic drugs for preventing hepatotoxicity during chemotherapy. The hepatoprotective effects of moringa extracts are partly mediated by their activities against oxidative stress, with significant contribution from their constituent chlorogenic acid and quercetin [56, 73, 75]. Another possible underlying mechanism for future studies is drug-herb interaction, which can result in a reduced negative effect of drugs to the liver.

Lipid-lowering activity

Moringa leaves and seeds have shown promising lipid-regulatory effect and modification of the risk of developing metabolic syndrome and cardiovascular diseases. Substantial decrease in serum cholesterol, low-density lipoproteins and triglycerides, as well as formation of atherosclerotic plaque were observed in hyperlipidemic animal models treated with the leaves or seeds extracts [78–82]. β -Sitosterol is one of the active moringa phytochemicals and, like other plant sterols, it has a strong association with reduced risk of develop-

ing cardiovascular diseases. The leaves extracts were shown to aid in the improvement of obesity-induced insulin resistance through the stimulation of insulin-dependent Akt pathway, increased expression of glucose transporter (GLUT4), metabolic hormones (such as adiponectin) and transcription factors (such as PPAR α), and down-regulated hepatic lipogenic sterol regulatory element-binding protein (SREBP)-1 levels [83–85]. Binding of bile acids and salts, such as taurocholate, taurodeoxycholate and glycodeoxycholate, was also reported to be a potential mechanism by which moringa leaves extract can promote cholesterol catabolism and homeostasis [41]. This activity is expected to enhance the enterohepatic circulation and excretion of bile acids and salts, and upregulated catabolism of endogenous cholesterol in the hepatocytes. The lipid-lowering effect of moringa leaves extracts was examined in hyperlipidemic subjects with total cholesterol and triglyceride concentration of >180 mg·dl⁻¹ and >140 mg·dl⁻¹, respectively. Daily consumption of dehydrated leaves (4.6 g) resulted in 1.6% reduction in total cholesterol level and 6.3% rise in high density cholesterol [86]. Similarly, the cholesterol, low density lipoprotein and triglyceride levels decreased by 14 %, 29 % and 14 %, respectively, in individuals with type 2 diabetes, after the consumption of 8 g of the leaves extracts [52]. However, the hypolipidemic activity of the leaves extracts could not be fully extended from small animal models to humans as it appeared to be more pronounced in animal models than in hyperlipidemic humans.

Antimicrobial activity

Studies strongly supported the traditional use of moringa in treating microbial infections. Aqueous moringa seeds extract and fresh leaves juice inhibited the growth of bacteria *Pseudomonas aeruginosa* and *Staphylococcus aureus* [87]. The compound 4-(α -L-rhamnosyloxy)-benzyl isothiocyanate was reported to be the active antimicrobial component present in an aqueous extract of the seeds [9]. Moreover, antimicrobial activities of aqueous and chloroform extracts of moringa leaves were investigated against bacteria *Escherichia coli*, *Salmonella typhi* and *Pseudomonas aeruginosa*. The chloroform extracts yielded positive inhibition results whereas the aqueous extract inhibited the growth of only the first two bacteria [88]. Phytochemical analysis revealed the presence of secondary metabolites such as alkaloids, tannins, flavonoids and saponins [88], but none of these compounds were particularly noted to be responsible for the antimicrobial activity. Moringa seeds-derived essential oils also

exhibited antifungal effect against dermatophytes such as *Trichophyton* spp. [89]. In another study, the ethanolic moringa leaves extract, among others (acetone and aqueous extracts), demonstrated the highest antibacterial activity that was comparable to those of known antimicrobials including clotrimazole, ciprofloxacin, and chloramphenicol [90]. In addition to phytochemicals and essential oil, NETO et al. [91] found that a protein (Mo-CBP₂) derived from moringa seeds inhibited the growth of different *Candida* species, with IC₅₀ of 9.45–37.9 $\mu\text{mol}\cdot\text{l}^{-1}$, and also disrupted the cell membrane integrity, leading to increased permeability, through its chitin-binding property. These findings support the potential of the moringa extracts for use as antimicrobial agents against *Candida* spp., and possibly other pathogenic and food spoilage microorganisms.

FUTURE RESEARCH CONSIDERATIONS

M. oleifera leaves and seeds are currently marketed based on their nutritional value, and not primarily for their bioactive properties. One major impediment to the development of marketable health products from moringa is the lack of clear-cut evidence of their effectiveness in human subjects, especially in preventing and managing chronic diseases. The current therapeutic usage of moringa is driven by traditional claims, and mostly limited to some indigenous populations. There is ample pre-clinical evidence to propel further rigorous human studies. Moreover, moringa leaves and seeds extracts are relatively safer than the other plant parts such as the bark and roots [92], but this cannot be ascertained without critical toxicity evaluations in clinical settings. There is scarcity of information regarding the bioavailability of the bioactive constituents in moringa, which can be influenced by a number of factors. For instance, dietary polyphenolic components are usually bound to sugar molecules, which can hinder intestinal absorption [93]. This is especially true for rhamnose-bound glycosides, which have to be hydrolysed by gut microbiota and are less readily absorbed [94]. Moreover, the active compounds can be involved in complex matrix interactions within the moringa extracts, which may result in decreased bioaccessibility and bioavailability [95]. Elucidating the bioavailability of the active compounds in moringa will help in determination of the intake amounts required to produce the desired physiological effects. Furthermore, the health-promoting effects of moringa leaves and seeds can be optimized for targeted health pro-

motion, if the biological targets of the active components and their specific molecular mechanisms of action are known. Finally, moringa leaves and seeds hold strong promise for diet-based disease intervention, but more studies are needed to develop this potential.

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