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Nutritional and Phytochemical Composition of *Moringa oleifera* Lam and its Potential Use as Nutraceutical Plant: A Review

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Abstract: *Moringa oleifera* Lam. is a plant that is known for its nutritional value and particularly for its protein quantity and quality. Due to its nutrient constitution, *M. oleifera* is used in several regions to treat malnutrition, especially in children. Moreover, *M. oleifera* contains phytochemical compounds that have important biological activities. Several previous studies confirmed that extracts or compounds isolated from *M. oleifera* have antioxidant, anti-carcinogenic, anti-diabetic, anti-inflammatory and anti-hypertensive properties, as well as the ability to protect against hepatic damage. This review discusses the characteristics and potential benefits of *M. oleifera* nutrients and phytochemicals.

Key words: *Moringa oleifera* Lam, phytochemicals, nutrients, biological activity

INTRODUCTION

Many plants have important nutritional and medicinal properties. *Moringa oleifera* Lam is a plant that belongs to the family *Moringaceae* that contains a single genus "*Moringa*" with thirteen species (Morton, 1991). Among these, the *M. oleifera* Lam tree is the most common. *M. oleifera* Lam originated in the Agra and Oudh provinces located in the Himalayan Mountains (Dhakar *et al*., 2011). This tree is high in nutrients and phytochemical compounds (Ashfaq *et al*., 2012). The nutrient concentration of *M. oleifera* leaves is notable, as they contain all the essential amino acids, including arginine and histidine, which are important for infant development, as well as high concentrations of vitamins and minerals (Tree for life, 2005; Teixeira *et al*., 2014). *M. oleifera* seeds also have nutritional value, particularly with respect to the lipid profile, which has a high percentage of oleic acid (Abdulkarim *et al*., 2005). Some social organizations and rural areas use *M. oleifera* to treat malnutrition, especially in children and nursing mothers. Meanwhile, studies by Fahey (2005) and Ashfaq *et al*. (2012) yielded important results that support the use of *M. oleifera* as supplement or complementary food. *M. oleifera* contains many phytochemicals that have known activities, most notably antioxidant capacity. This review will discuss the nutrients and phytochemicals present in *M. oleifera*, as well as the studies that have evaluated the potential uses of this plant. We will also make critical assessments of earlier findings that will help define future research and applications of *M. oleifera*.

Chemical composition and nutritional value: *M. oleifera* contains more than 90 important nutrients that have synergic effects and high bioavailability (Simonsohn, 2012). Protein is the most prominent nutrient (25% of dry matter) in all *M. oleifera* parts, while the lipid content is higher in seeds (30% of dry matter) and lower in the fruit, leaves and pods (Lalas and Tsaknis, 2002a; Banerji *et al*., 2003; Abdulkarim *et al*., 2005; Anwar *et al*., 2005; Rashid *et al*., 2008). Meanwhile, dietary fiber is an important component of *M. oleifera* fruit, leaves and pods (~20% of dry matter). Table 1 shows the approximate compositions of different *M. oleifera* tissues.

M. oleifera leaves contain all essential amino acids (Tree for Life, 2005; Ashfaq *et al*., 2012) (Table 2) and important biological proteins, including globulin, albumin, glutein and prolamin (Tree for Life, 2005; Teixeira *et al*., 2014). The lipid content of *M. oleifera* seeds consists of saturated palmitic, stearic, arachidic and behenic fatty acids (Banerji *et al*., 2003; Abdulkarim *et al*., 2005), while oleic acid is the major unsaturated fatty acid (65.7 to 85%) (Lalas and Tsaknis, 2002a; Banerji *et al*., 2003; Anwar *et al*., 2005; Rashid *et al*., 2008). This high percentage of oleic acid in *M. oleifera* seed oil not only enhances its nutritional value, but also its usefulness for other industrial applications. Indeed, Abdulkarim *et al*. (2007) evaluated the cooking and frying stability of different oils and found that *M. oleifera* oil is more stable at high temperature than regular oils. Other lipids found in the *Moringa* seed oils are α-tocopherol, β-sitosterol and stigmasterol (Lalas and Tsaknis, 2002a; Abdulkarim *et al*., 2005). Meanwhile, *M. oleifera* leaves have palmitic and heneicosanoic acid as the most prevalent saturated fatty acids and α-linolenic is the most common unsaturated fatty acid (Moyo *et al*., 2011). *M. oleifera* leaves have higher concentrations of vitamin A, vitamin C, calcium, potassium and iron relative to

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other foods that also have these nutrients (Table 3). Variations in the micronutrient concentration in dry leaves can be related to the processes used to obtain this product (time, temperature) and the characteristics of the plant (e.g., origin, agronomic culture, weather).

Phytochemicals: Currently there is a demand for foods that contain active substances that yield positive benefits for health. Phytochemicals represent one such active substance. Several studies have analyzed various *M. oleifera* tissues to determine which parts or extracts have the highest concentrations of phytochemicals, with phenols and the tannins being the most studied (Table 4). Leaves showed the highest amount of variation, which can depend of the type of extraction solvent and method, as well as the native characteristics of the plant. Vongsak *et al.* (2013) demonstrated that different methods of extraction affected the total content of phenolic and flavonoid compounds and that maceration and extraction with 70% ethanol was the most effective. Furthermore, Kasolo *et al.* (2010) showed that water rather than ether or ethanol as a solvent extracted all the phytochemicals tested. Iqbal and Bhanger *et al.* (2006) also showed that the agroclimatic location and season affected the phenol and flavonoid content, which was inversely related to environmental temperature.

The principal phytochemicals present in different *M. oleifera* tissues include: (I) leaf powder: tannins, saponins, alkaloids, phenols, flavonoids and glycosides (Mensah *et al.*, 2012); (ii) flowers: tannins, steroids, flavonoids, alkaloids, glycoside, quercetin and terpenoids (Alhakmani *et al.*, 2013); (iii) seeds: gallic acid, catechin, epicatechin, ferulic acid, vanillin, caffeic acid, protocatechuic acid, cinnamic acid, quercetin phytosterol, glycosides and phenols (Hukkeri *et al.*, 2006; Singh *et al.*, 2013); (iv) roots: procyanidin, aurantiamide acetate, 3-dibenzyl urea, quercetin glycoside, quercetin rhamnoglucoside and chlorogenic acid (Sashidhara *et al.*, 2009; Atawodi *et al.*, 2010) and (v) stem bark: procyanidin, sterols, triterpenoids, glycosides, tannins, alkaloids (moringine and moringinine), β-sitosterol, β-sitostenone and octacosanoic acid (Anwar *et al.*, 2007; Atawodi *et al.*, 2010; Kumbhare *et al.*, 2012). In general, glycosides are one of the most commonly isolated and studied compounds in *M. oleifera* (Table 5).

Biological activity

Antioxidant activity: Although phytochemicals have many uses, the most important is their antioxidant capacity. Several studies showed that petroleum ether, chloroform and/or methanol extracts of leaves, flowers, fruits, seed oil, seed flour and stem and root bark of *M. oleifera* exhibited strong *in vitro* and *in vivo* antioxidant activity (Lalas and Tsaknis, 2002b; Kumar and Pari, 2003; Iqbal and Bhanger, 2006; Chumark *et al.*, 2008;

Table 1: Composition of *Moringa oleifera* Lam tissues (%)

Part of the plant	Moisture	Ash	Protein	Fat	Carbohydrate	Fiber	Reference	Type
Fruit	89.9	ND	20.7	ND	ND	27.0	Foid *et al.* (2001)	Dry matter
	75	ND	6.7	1.7	13.4	0.9	Price (1985)	Fresh leaves
	7.5	ND	27.1	2.3	38.2	19.2	Price (1985)	Leaf powder
	ND	10	43.5	1.4	ND	ND	Makkar and Becker (1996)	Extracted leaves (dry matter)
	ND	11.5	25.1	5.1	ND	ND	Makkar and Becker (1996)	Unextracted leaves (dry matter)
Leaves	81.3	ND	25.1-29	ND	ND	19.1	Foid *et al.* (2001)	Fresh leaves (dry matter)
	ND	8.4	25.0	10.6	ND	28.5	Richter *et al.* (2003)	Dry matter
	76.5	7.1	27.5	2.2	43.9	19.3	Oduro *et al.* (2008)	Dry matter
	ND	ND	26.3	4.7	ND	ND	Simonsohn (2012)	Leaf powder
	9.0	10.9	28.7	7.1	44.36	ND	Borges *et al.* (2014)	Leaf flour
	9.5	7.6	30.3	6.5	ND	19.9	Moyo *et al.* (2011)	Dry leaf
Pods	86.9	ND	2.5	0.1	3.7	4.8	Price (1985)	Fresh poods
	7.0	4.4	33.3	41.2	21.1	ND	Oliveira *et al.* (1999)	Dry matter
Seeds	5.7	6.6	29.4	40.4	ND	7.2	Anwar and Bhanger (2003)	Dry seeds
	ND	4.4-4.5	33.2-38.3	30.8-41.2	16.5-21.1	ND	Ferreira *et al.* (2008)	Dry matter

ND: Not determined

Table 2: Amino acid composition of *Moringa oleifera* Lam

Amino acid	Seeds (g/kg protein)	Fresh leaves (mg/100 g leaves)	Dried Leaf (mg/100 g dried leaf)
Essential			
Arg	45.3[4]	406.6[6]	1564[1], 1250[2], 1780[3], 1200[5], 1325[6]
Hist	22.9[4]	149.8[6]	750[1], 615[2], 716[3], 600[5], 613[6]
Ile	32.5[4]	299.6[6]	1130[1], 1500[2], 1777[3], 900[5], 825[6]
Leu	67.5[4]	492.2[6]	2184[1], 1995[2], 1960[3], 1800[4], 1950[5]
Lys	15.3[4]	342.4[6]	1406[1], 1300[2], 1100[5], 1325[6]
Met	23.6[4]	117.7[6]	497[1], 348[2], 297[3]350[6]
Phe	39.7[4]	310.3[6]	1551[1], 1390[2], 1640[3], 1388[4]
Thr	30.8[4]	117.7[6]	1170[1], 1,255[2], 800[4], 1357[3], 1188[6]
Trp	16.3[4]	107[6]	5271, 486[3], 700[4], 425[6]
Val	43.5[4]	374.5[6]	1426[1], 1413[3], 1100[4], 1063[6]
Non-essential			
Ala	69.1[4]	ND	18371, 3033[3]
Asp	50.5[4]	ND	2216[1], 1430[3]
Cys	20.1[4]	ND	339[1], 10[3], 122.2[2]
Glu	209.5[4]	ND	2565[1], 2530[3]
Gly	108.9[4]	ND	1373[1], 1533[3]
Pro	45[4]	ND	1363[1], 1203[3]
Ser	43.6[4]	ND	1034[1], 1087[3]
Tyr	15.9[4]	ND	9.71[1], 2650[3]

[1]Makkar and Becker, (1996); [2]Mensah *et al*. (2012); [3]Moyo *et al*. (2011); [4]Oliveira *et al*. (1999); [5]Richter *et al*. (2003); [6]Tree of life, (2005); ND. Not determined

Table 3: Mineral composition per 100 g *Moringa oleifera*

	Fresh leaves	Dry leaves	Lamina	Petboiole	Fruits	Pod	Seed shell
Minerals							
Calcium (mg)	440[6,7]	2293.1[2], 2003[7], 2009.8[5], 3650[4],1530[3]	382.7[1]	373.4[1]	30[6]	237.7[1],156.3[2]	263.5[1]
Copper (mg)	1.1[6],0.7[7]	0.9[2], 0.6[7],0.8[4], 0.6[3]	4.4[1]	3.5[1]	3.1[6]	3.5[1], 2.7[2]	1.3[1]
Iron (mg)	7[6], 0.85[7]	2.05[2], 28.2[7], 28.3[5],49[4],126.2[3]	7.8[1]	14.4[1]	5.3[6]	4.4[1], 15.5[2]	44.8[1]
Magnesium (mg)	24[6], 42[7]	1050[6], 368[7], 10.0[2], 500[95], 255[91]	80.5[1]	83.0[1]	24[6]	83.4[1], 9.6[2]	78.4[1]
Phosphorus (mg)	70[6, 7]	204[7], 123.7[2], 300[95], 158[91]	ND	ND	110[6]	194.3[2]	ND
Potassium (mg)	259[6, 7]	20616, 1324[7], 2098.2[2], 1500[4], 170[3]	ND	ND	259[6]	2097.2[2]	ND
Sodium (mg)		272.1[2], 164[4]	ND	ND	ND	210.5[21]	ND
Sulphur (mg)	137[6]	630[6], 925[3]	ND	ND	137[6]	ND	ND
Zinc (mg)	0.16[7]	2.9[6], 3.3[7], 3.1[4],3.3[3]	ND	1.8[5]	ND	ND	ND
Vitamins							
Vitamin A mg*	6.78[7]	18.9[2], 18.5[7]	ND	ND	1.1[6]	ND	ND
Vitamin B2 (mg)	0.05[2,7]	20.5[7]	ND	ND	0.07[6]	ND	ND
Vitamin B3 (mg)	0.8[2,7]	8.2[7]	ND	ND	0.2[6]	ND	ND
Vitamin B7 (mg)	423[7]	ND	ND	ND	423[6]	ND	ND
Vitamin B12 (mg)	0.06[2,3]	2.64[7]	ND	ND	0.05[6]	ND	ND
Vitamin C (mg)	220[2,7]	17.3[7]	ND	ND	120[6]	ND	ND
Vitamin E (mg)	ND	77[5]	ND	ND	ND	ND	ND

*vitamin A is carotene content for fresh leaves and beta-carotene content for dried leaves.
[1]Anjorin *et al*. (2010); [2]Aslam *et al*. (2005); [3]Mensah *et al*. (2012); [4]Moyo *et al*. (2011); [5]Oduro *et al*. (2008); [6]Ramachachandra *et al*. (1980); [7]Tree of Life (2005).
[+]In some studies that evaluated parts of the tree of different origin only choose one result of one type of sample. ND. Not determined

Singh *et al*., 2009; Sreelatha and Padma, 2009; Verma *et al*., 2009; Atawodi *et al*., 2010; Kumbhare *et al*., 2012; Alhakmani *et al*., 2013; Jaiswal *et al*., 2013; Singh *et al*., 2013; Vongsak *et al*., 2013). Moreover, agroclimatic conditions (Siddhuraju and Becker, 2003; Iqbal and Bhanger, 2006), plant tissue type (Singh *et al*., 2009) and leaf development stage (Sreelatha and Padma, 2009), as well as the method of extraction (Siddhuraju and Becker, 2003; Vongsak *et al*., 2013) can all affect the antioxidant activity and these factors should be taken into account in order to optimize the antioxidant capacity of supplements derived from *M. oleifera*.

Anti-cancer/tumor effects: The effect of aqueous extracts of *M. oleifera* leaves on the human pancreatic cancer cell line Panc-1 was investigated in a study by Berkovich *et al*. (2013). *M. oleifera* extracts either alone ($\geq$0.75 mg/mL) or together with cisplatin significantly reduced the viability of Panc-1 cells. Furthermore, treatment of human lung cancer cells with cold aqueous extracts of *M. oleifera* leaves (10 to 200 µg/mL) induced apoptosis and also reduced the proliferation and invasion of the cancer cells as well as the level of internal reactive oxygen species (Jung, 2014). Similar results were obtained by Sreelatha *et al*. (2011) in the human tumor cell line KB.

Table 4: Total phenolic and flavonoid content in *Moringa oleifera*

Source	Characteristic	Total phenols (mgGAE/g extract)	Total flavonoids (mgQE/g extract)	Reference
Flower	Ethanol extract of dried powder flowers	19.3	ND	Alhakmani *et al*. (2013)
Fruit	Aqueous extract of dried powder fruit	72.8	8.8	Singh *et al*. (2009)
	Aqueous extract of dried powder leaf	105	31.3	Singh *et al*. (2009)
	Aqueous extract of fresh leaf	36.0-45.8	15.0-27.0	Sreelatha and Padma (2009)
	Aqueous extract of fresh leaf	120	40.5	Jaiswal *et al*. (2013)
	Aqueous extract of freeze-dried powder leaf	53-74	33-108*	Siddhuraju and Becker (2003)
	Dried powder leaf	2.5-53.5	2-25.1	Vongsak *et al*. (2013)
Leaf	Ethanol extract of freeze-dried powder leaf	81-110	59-101*	Siddhuraju and Becker (2003)
	Ethanol extract of dried powder leaf	23-132.3***	9-62**	Vongsak *et al*. (2013)
	Freeze-dried leaf	29-43	21-44.3*	Siddhuraju and Becker (2003)
	Methanol extract of freeze-dried powder leaf	89-123	59-140*	Siddhuraju and Becker (2003)
	Methanolic extract of dried leaf	83-135	69.3-125	Iqbal and Bhanger *et al*. (2006)
Seed	Aqueous extract of dried powder seeds	45.8	9.9	Singh *et al*. (2009)
	Methanol Extract of seed flour	41.73	2.3	Singh *et al*. (2013)
	Seed oil	40.2	18.2*	Ogbunugafor *et al*. (2011)

GAE, garlic acid equivalent, QE, quercetin equivalent.
*RE, rutin equivalent (RE), **IQE, isoquercetin equivalent, ***CAE chlorogenic acid equivalent

Table 5: Glycosides present in *Moringa oleifera*

Tissue	Bark	Fruit	Leaf	Root	Seed	Stem
3-O-(6'-O-oleoyl-β-D-glucopyranosyl)-β-sitosterol					X	
4-(2'-O-acetyl-α-L-rhamnosyloxy)benzyl) isothiocyanate		X				
4-(3'-O-acetyl-α-L-rhamnosyloxy)benzyl) isothiocyanate		X				
4-(4'-O-acetyl-α-L-rhamnosyloxy)benzyl) isothiocyanate			X			
4-(α (-L-rhamnopyranosyloxy)-benzylglucosinolate			X	X	X	X
4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate monoacetyl-Isomer I			X			X
4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate monoacetyl-Isomer II			X			
4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate monoacetyl-Isomer III			X			X
4(α-L-rhamnosyloxy.-benzyl) isothiocyanate					X	
4'-O-acetyl-α-L-rhamnoside			X			
4-O-(3'-O-α-D-glucopyranosyl)-caffeoyl quinic acid			X			
4-O-(4'-O-α-D-glucopyranosyl)-caffeoyl quinic acid			X			
benzyl-glucosinolate				X		X
Glycerol-1-(9-octadecanote)					X	
Kaempferide 3-O-(2".3'-diacetylglucoside)			X			
Kaempferide 3-O.(2"-O-galloyrutinoside)-7-O-αrhamnoside			X			
Kaempferol 3-O-[β-glucosyl-(1_2)]-[α-rhamnosyl-(1_6)]-β-glucoside-7-O-α-rhamnoside			X			
Kaempferol 3-O-[α-rhamnosyl-(1_2)]-[α-rhamnosyl-(1_4)]-β-glucoside-7-O-α-rhamnoside			X			
N-benzyl, S-ethyl thioformate				X		
Niazimicin			X		X	
Niaziminin A+B			X			
Niazinin A			X		X	
Niazinin B			X		X	
O-ethyl-4-(α-L-rhamnosyloxy)benzyl) carbamate			X		X	
O-methyl-4-(4'-O-acetyl-α-L-rhamnosyloxy)benzyl) carbamate			X			
Quercetin glycoside				X		
Quercetin rhamnoglycoside				X		
S-methyl-N-(4-[(α-L-rhamnosyloxy) benzyl]-thiocarbamate		X				
Thiocarbamates			X			
β-sitosterol					X	X
β-sitosterol-3-O-β-D-glucopyranoside					X	

Anwar *et al*. (1994); Anwar *et al*. (2007); Atawodi *et al*. (2010); Bennett *et al*. (2003); Cheenprancha *et al*. (2010); Faizi *et al*. (1994); Faizi *et al*. (1995); Faizi *et al*. (1998); Guevara *et al*. (1999); Kashiwada *et al*. (2012); Nikkon *et al*. (2003); Onyango *et al*. (2007)

An evaluation of the effect of *M. oleifera* root extracts on different tumor cells lines by Costa-Lotufo *et al*. (2005) showed good toxicity of the extracts towards CEM and B-16 tumor cells lines, with an IC_{50} of 12.7 and 28.8 µg/mL, respectively.

Bioactive compounds isolated from *M. oleifera* seeds, including [4(α-L-rhamnosyloxy-benzyl) isothiocyanate, niazimicin, niazirin, 3-O-(6'-O-oleoyl-β-D-glucopyranosyl) -β-sitosterol and β-sitosterol-3-O-β-D-glucopyranoside showed activity against Epstein-Barr virus-early antigen activation in Raji cells induced with the tumor promoter 12-O-tetradecanoyl-phorbol-13-acetate. Of all the isolated compounds, niazimicin had the most powerful effect. Moreover, treatment of mouse skin with 850

nmol/mL niazimicin for 20 weeks significantly decreased carcinogenesis by reducing the percentage of mice bearing papillomas and the average number of papillomas per mouse (Guevara *et al*., 1999). Similar results were shown using a hydroalcoholic extract of *M. oleifera* drumsticks to treat mice at 5 mg/kg body weight (Bharali *et al*., 2003). All of these studies suggest that *M. oleifera* extracts and the compounds isolated from them have chemo-protective activity that may be related to their ability to reduce levels of reactive oxygen species.

Anti-diabetic action of *M. oleifera*: Powder made from *M. oleifera* leaves given to rats that serve as a model of type 2 diabetes was associated with decreased blood glucose levels that could be attributable to the quercetin-3-glucoside and fiber content of the extract (Ndong *et al*., 2007). A similar study with diabetic rats that were treated with a methanolic extract of *M. oleifera* pods showed a significant reduction in serum glucose and nitric oxide, an increase in serum insulin and protein levels and a reversion of histoarchitectural damage of the pancreas β-cells (Gupta *et al*., 2012). Moreover, aqueous extracts of leaves administered to sub-, mild- and severely diabetic rats promoted decreases in blood glucose levels and lipid peroxide contents and increased the activities of superoxide dismutase, catalase and glutathione-S-transferase (Jaiswal *et al*., 2009; Jaiswal *et al*., 2013).

On the other hand, human studies performed at the Hospital of Acharya Nagarjuna University and Diabetic wherein type 2 diabetes patients were treated with *M. oleifera* leaf powder (8 g/day) for 40 days showed a significant reduction in fasting blood glucose, post-prandial blood glucose and blood lipid levels of the subjects (Kumari, 2010). Although additional studies are needed to determine whether this anti-diabetic effect is dose-dependent and reproducible, *M. oleifera* extracts and compounds isolated from *M. oleifera* leaves could be an economical approach for mitigating the effects of type 2 diabetes.

Anti-inflammatory action of *M. oleifera*: Compounds in *M. oleifera* also appear to anti-inflammatory effects. Alcoholic extracts of *M. oleifera* seeds at a dose of 200 and 400 mg/kg body weight produced a 77% reduction in carrageenan-induced edema in rat paws (Mehta and Agrawal, 2008). Mahajan *et al*. (2007) used n-butanol extracts of *M. oleifera* seeds (100 mg/kg body weight) to examine anti-inflammatory effects toward ovalbumin-induced airway inflammation in guinea pigs and observed a protective effect against acetylcholine-induced bronchoconstriction and airway inflammation.

M. oleifera pod extracts also had an anti-inflammatory activity in lipopolysaccharide-induced murine RAW2647 macrophages as evidenced by elevated levels of cytokine proteins that suppressed inflammatory mechanisms (Muangnoi *et al*., 2012). Compounds isolated from *M. oleifera* using aurantiamide acetate, 1,3-dibenzyl urea and (4-[(2'-O-acetyl-α-L-rhamnosyloxy) benzyl] isothiocyanate also showed anti-inflammatory effects by significantly inhibiting TNF-α and IL-2 and IL-2, respectively (Sashidhara *et al*., 2009). These results suggest that the anti-inflammatory activity of *M. oleifera* is associated with the inhibition or reduction of cytokine production.

Protective effect of *M. oleifera* against hyperlipidemia and liver damage: The hypolipidemic activity of *M. oleifera* has been analyzed in different *in vivo* models.

Mehta *et al*. (2003) fed hypercholesterolaemic rabbits *M. oleifera* fruit powder (200 mg/kg/day p.o) and a standard diet for 120 days and found that the animals showed decreased lipid levels in liver, heart and aorta tissue and an accompanying increase in the excretion of fecal cholesterol. Similar results were obtained by Jain *et al*. (2010), who fed hyperlipidemic rats a methanolic extract of *M. oleifera* (150, 300 and 600 mg/kg/day p.o) in combination with a hyperlipidemic diet. In rabbits fed powdered *M. oleifera* leaf extract (0.1g/ kg/day p.o.), Chumark *et al*. (2008) found reduced cholesterol levels (50%) and atherosclerotic plaque formation (86%).

Other researchers investigated the effects of a high fat diet coupled with *M. oleifera* treatment. Ghasi *et al*. (2000) discovered that administration of a crude *M. oleifera* leaf extract (1 mg/g body weight) to rats decreased cholesterol levels in serum as well as liver and kidney tissues relative to rats that consumed only the high-fat diet, while a study by Das *et al*. (2012) used a related model in mice with a similar extract (150 mg/kg/day) and found fewer alterations to liver lobular architecture compared to the control group. These results suggest that the possible mechanisms of *M. oleifera* action are related to the antioxidant activity of the extracts and the induction of hepatic enzymes that are involved in oxidative stress responses.

Prevention of hepatic damage by *M. oleifera*: *In vitro* experiments demonstrated that aqueous extracts of *M. oleifera* leaves (500 mg/g tissue) applied to liver slices treated with carbon tetrachloride increased the activities of antioxidant enzymes and the glutathione content while decreasing the levels of thiobarbituric acid-reactive substances and lipid peroxide (Sreelatha and Padma, 2010). Also, when rats with induced liver fibrosis were treated with a *M. oleifera* seed extract (1 g/kg), there was a reduction in liver damage as well as liver fibrosis symptoms. This extract reduced the elevations in hepatic hydroxyproline content, myeloperoxidase activity, the number of smooth muscle α-actin positive cells and the accumulation of collagens I and III in liver (Hamza, 2010). Similar results were obtained in rats that were

treated with *M. oleifera* seed oil (0.2 and 0.4 mL/rat), which lowered levels of liver marker enzymes and elevated malondialdehyde, as well as non-protein-sulfhydryl and total protein contents in liver tissue (Al-Said *et al*., 2012).

Pari and Kumar (2002) employed ethanolic *M. oleifera* leaf extracts and Fakurazi *et al.* (2008b) used aqueous *M. oleifera* leaf extracts to treat rats with hepatic injuries and both observed a significant reduction in the level of alanine aminotransferase, aspartate aminotransferase and alkaline phosphatase relative to control animals. The hepatoprotective activity of these extracts was similar to that of silymarin, a common hepatoprotective drug (Pari and Kumar, 2002; Kumar and Pari, 2003; Fakurazi *et al*., 2008a) and thus *M. oleifera* may be a good alternative for treating hepatic damage. The putative hepatoprotective mechanism of these extracts may again be related to their antioxidant properties and their anti-inflammatory effects, as well as to their ability to attenuate activation of hepatic stellate cells (Hamza, 2010).

Toxicity: Finally, the growing interest in the nutritive and medicinal uses of *M. oleifera* prompted an evaluation of the possible toxic effects of this plant. Akinlolu *et al.* (2014) observed that adult rats treated with methanolic *M. oleifera* extracts (250, 500 and 750 mg/kg) showed increased levels of alanine and aspartate transaminases, as well as serum urea, relative to control animals. The elevated levels of these compounds could be possible indicators of liver and/or kidney damage. In contrast, Karadi *et al.* (2006) treated rats with urolithiasis with aqueous and alcoholic extracts of *M. oleifera* root wood (200 mg/kg) and observed a reduction in urinary oxalate and kidney stone formation (Karadi *et al*., 2006). Some studies showed that consumption of *M. oleifera* leaves did not result in adverse histopathological effects or affect blood metabolite concentrations, liver glycogen levels and lipid storage, or plasma activity of aspartate transaminase and alkaline phosphatase (Zvinorova *et al*., 2015). Similarly, Adedapo *et al.* (2009) suggested that administration of *M. oleifera* leaves is relatively safe, as evidenced by the lack of effects produced following the delivery of 2,000 mg/kg p.o. to rats.

Conclusion: *M. oleifera* is rich in nutrients and phytochemical compounds that confer on this plant important medicinal properties that could be useful for treating certain chronic diseases. The use of *M. oleifera* as a nutraceutical plant is now supported not only by traditional knowledge, but also by scientific evidence. However, future investigations concerning the biological activity of *M. oleifera* as well as analysis of the potential side effects associated with regular consumption of this plant are needed.

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