Moringa oleifera: bioactive compounds and nutritional potential

Moringa oleifera: *compostos bioativos e potencialidade nutricional*

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A B S T R A C T

This work aims to review the nutritional properties of the *Moringa oleifera* tree, emphasizing its main constituents and nutritional applications for humans and animals. *Moringa oleifera* (Moringaceae) is a cosmopolitan tree that grows in many tropical countries showing uncountable folk uses due to its various nutritional and pharmacological applications. The young leaves, flowers and pods are common vegetables in the Asian diet. All parts of this plant are renewable sources of tocopherols (γ and α), phenolic compounds, ß-carotene, vitamin C and total proteins, including the essential sulfur amino acids, methionine and cysteine. The seed protein and fat contents are higher than those reported for important grain legumes and soybean varieties, respectively. Unsaturated fatty acids, especially oleic acid, carbohydrates and minerals are present in the seed in reasonable amounts. In general, there are low concentrations of antinutritional factors in the plant, although the seeds possess glucosinolates (65.5μmol/g dry matter), phytates (41g/kg) and hemagglutination activity while the leaves have appreciable amounts of saponins (80g/kg), besides low quantity of phytates (21g/kg) and tannins (12g/kg). Taking into consideration the excellent nutritional properties, the low toxicity of the seeds and the excellent ability of the plant to adapt to poor soils and dry climates, *Moringa oleifera* can be an alternative to some leguminous seeds as a source of high-quality protein, oil and antioxidant compounds and a way to treat water in rural areas where appropriate water resources are not available.

Indexing terms: Protease Inhibitors. *Moringa oleifera*. Nutritive value.

R E S U M O

O objetivo deste trabalho é fazer uma revisão sobre as propriedades nutricionais da planta Moringa oleifera*, enfatizando seus principais constituintes e suas aplicações nutricionais para o homem e os animais.* Moringa

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oleifera *é uma planta que cresce em muitos países tropicais, possuindo inúmeros usos populares devido às suas aplicações nutricionais e farmacológicas. Na Ásia, suas folhas, flores e vagens são geralmente consumidas como vegetais. Todas as suas partes são fontes renováveis de compostos fenólicos, tocoferóis (*γ *e*α*), ß-caroteno, vitamina C e proteínas totais, inclusive os aminoácidos essenciais sulfurados metionina e cisteína. Os conteúdos de proteínas e óleo nas sementes de Moringa oleifera são mais elevados que aqueles encontrados em legumes e em algumas variedades de soja, respectivamente. Ácidos graxos insaturados, principalmente o ácido oléico, carboidratos e minerais estão presentes nas sementes em quantidades razoáveis. No geral, a planta possui baixas concentrações de fatores antinutricionais, embora as sementes possuam glucosinolatos (65,5µmol/g), fitatos (41g/kg) e atividade hemaglutinante, enquanto as folhas têm apreciáveis quantidades de saponinas (80g/kg), além de fitatos (21g/kg) e taninos (12g/kg). Levando em consideração as excelentes propriedades nutricionais, a baixa toxicidade das sementes e a excelente habilidade da planta de se adaptar a solos pobres e a climas áridos, a* Moringa oleifera *pode ser uma alternativa ao consumo de sementes leguminosas, como fonte de proteínas de alta qualidade, de óleo e de compostos antioxidantes. Pode ser usada, ainda, como uma maneira de tratar água em áreas rurais onde recursos hídricos adequados não estão disponíveis.*

Termos de indexação: *Inibidores de proteases. Moringa oleifera. Valor nutritivo.*

INTRODUCTION

Moringa oleifera Lamarck (synonym: *Moringa pterygosperma* Gaertner) is a South Asian tree belonging to the Moringaceae family that grows near The Himalaya mountains, from Northwest Pakistan to North India[1]. The tree is deciduous, growing rapidly even in poor soils, well adapted to droughts and able to reach up to 15m in height, with a diameter of 20-40cm at chest height. It produces dry fruits, triangular in shape, making seed dispersion by the wind easier[2]. It has been introduced in many parts of the world, like Afghanistan, Bangladesh, Sri Lanka, Africa, West Asia and in the Americas, from Mexico to Peru, Caribbean Islands, Paraguay and Brazil[3-5].

The species *M. oleifera* is known worldwide by several popular names such as "resedá", "árbol de rábano", horseradish tree, drumstick tree, "ângela", "árbol de los espárragos", white-lily, "quiabo de quina" and many others[1,5].

Extracts from all parts of the plant show pharmacological properties, recognized by popular use and corroborated by the scientific community. Leaf extracts show hypocholesterolaemic[6], hypotensive, bradycardic[7] and anti-ulcerative activity[8]. The dry pods are adequate to use as a substratum for laboratory animal bedding[9]. The seeds show antimicrobial activity against fungi[10,11] and bacteria[10,12,13], antitumor[14], anti-inflammatory, antispasmodic, diuretic[15] and larvicidal activity against the mosquito that transmits dengue and yellow fever[16]. Gupta et al.[17] showed that the roots were able to depress the central nervous system, cause analgesia and potentiate the analgesic effect of morphine.

This article aims to review the nutritional properties of the *Moringa oleifera* tree, emphasizing its main constituents and nutritional applications for humans and animals.

Bioactive compounds

In Asia, the flowers of *M. oleifera* are mixed together with other foods since they are rich in Ca^{2+}, K^+, waxes, alkaloids, quercetin and kaempferol[1,18]. Quercetin and kaempferol are flavonoids, compounds with phenolic hydroxyl groups with antioxidant action that have potential therapeutic uses[19]. *In vitro* studies have shown that quercetin and other flavonoids strongly inhibit the production of both nitric oxide and tumor necrosis factor by Kupffer cells when stimulated by injury[20]. Flavonoids protect the cells against injury caused by X-rays, block the progression of the cell cycle and prostaglandin synthesis, inhibit mutations and prevent carcinogenesis in experimental animals[21].

A high content of γ-tocopherol has been found in practically the whole plant, ranging from 5.7µg/g (adult leaves) to 27.8µg/g (6 month-old leaves) of dry mass. Important variations have been encountered in α-tocopherol values which ranged from 95.9µg/g (green seeds) to 744.5µg/g (adult plant leaves)[22], differences probably explained by the variation between the age of the plants and their varied parts. Vitamin E is an antioxidant substance composed of tocopherols and α-tocopherol is the most active and abundant constituent. This vitamin helps halt lipid peroxidation chain reactions generated by free radicals from cellular and subcellular membranes, which are rich in polyunsaturated lipids[23]. These antioxidant substances metabolize peroxides before they can cause any injury to cell membranes, maintaining the intracellular redox status[24]. Violation of this status favors oxidative stress, resulting in pathologic manifestations, such as atherosclerosis and cancer.

The leaves are used worldwide as a nutritional supplement as it contains significant amounts of vitamins A, B and C, plus Ca^{2+}, Fe and proteins[1,25,26]. Traces of carotenoids, mainly, ß-carotene (401mg/kg of dry matter) and xanthins (neoxanthin 219mg/kg, violaxanthin 76.5mg/kg, zeaxanthin 19.4mg/kg) are also found[27]. In India and the Philippines, fresh leaves are used to preserve foods, probably due to the antioxidant substances[28]. Besides its well established role in collagen synthesis, which prevents gingival bleeding and skin ecchymosis, characteristics of scurvy, vitamin C can act as a scavenger of free radicals and indirectly regenerate vitamin E[23]. It is because of this synergism that both these vitamins have attracted interest as agents that can retard atherosclerosis by reducing low density lipoprotein (LDL) oxidation and thus limiting or even preventing injuries to vascular endothelial cells.

In Brazil, there have been efforts to divulge the plant as a rich source of vitamin A since the leaves contain approximately 23,000IU of this vitamin, much more than the traditional oily plants such as broccoli, carrot, kale, spinach and lettuce, which contain, respectively, 5,000, 3,700, 2,200, 1,900 and 1,000IU of vitamin A[29,30]. Vitamin A is important for normal vision in dim light, for the differentiation of mucus-secreting epithelium, preventing its keratinization[23] and for host resistance against infections[31].

In vivo radioprotective properties were demonstrated by methanolic extracts of dried leaves of *M. oleifera*, indicating that the leaves have a protective role against clastogenicity, evidently reducing chromosomal aberrations and micronuclei frequency in bone marrow cells[32].

Bharali et al.[14] showed that oral administration of a hydroalcoholic extract of *M. oleifera* green pods can increase liver levels of cytochrome b_5, cytochrome P_{450}, catalase and glutathione-peroxidase, reductase and S-transferase, enzymes involved in reactions of phases I and II that are responsible for the detoxification of xenobiotic substances, such as carcinogens and toxic plant compounds.

Epidemiologic studies have shown that population groups that consume high amounts of fruits and vegetables have a low risk of cancer. It has been postulated that carotenoids converted into vitamin A in the liver and intestines, vitamins C and E, sterols and selenium can have a relevant role in the primary chemoprevention of cancer by avoiding oxidative injury to DNA[21].

Nutritional potential

M. oleifera leaves have essential amino acids, including the sulfur-containing amino acids in higher levels[33] than those recommended by the Food and Agriculture Organization (FAO)[34], with patterns similar to those of soybean seeds.

Analyses of the proximate composition of *M. oleifera* seeds have showed high levels of lipids and proteins (Table 1), with minor variations[4,35]. These variations may be explained by different climatic conditions, time of the year and different soil types from which the seeds were collected[36]. Abdulkarim et al.[35] have described high levels of total proteins (383.0 standard deviation - SD=13.0g/kg dry matter), which turned out to be greater than important leguminous seeds with respect to human nutrition, whose dry seeds usually contain 18 to 25% of protein, nearly double the contents of cereals[36].

Table 1. Proximate composition of *Moringa oleifera* seeds. From Brazil (1998) and India (2005).

Components	g/kg			
	Dry matter [c]		Dry matter [d]	
	M	SD	M	SD
Total Protein[a]	332.5	11.6	383.0	13.0
Lipid	412.0	22.2	308.0	21.9
Carbohydrate[b]	211.2		165.0	
Ash	44.3	1.1	45.0	3.8

M: mean; SD: standard deviation; [a] N x 6.25; [b] Calculated by difference; [c] Oliveira et al.[4] ; [d] Abdulkarim et al.[35].

The seed lipid content (412.0 SD= 22.2g/kg dry matter) reported by Oliveira et al.[4] is greater than that of some soybean varieties (149-220g/kg meal)[37]. The major saturated fatty acids present in the seeds are palmitic, stearic, arachidic and benic acids. Oleic acid is the main unsaturated fatty acid (67.9-70.0%)[35], whose high concentration is desirable in terms of nutrition and stability during cooking and frying. Moreover, as a natural source of benic acid, the *M. oleifera* seed oil has been used as a solidifying agent in margarines and other foodstuffs containing solid and semi-solid fat, therefore eliminating hydrogenation processes[38]. A lot of attention has been dedicated to oleic acid-rich plant oils, since an association has been established between diets rich in trans-unsaturated and saturated fatty acids and increased risk of cardiovascular diseases caused by high blood cholesterol levels[39].

M. oleifera seed oil is highly resistant to oxidative rancification[40], which can explain its several industrial uses such as in the production of cosmetics, machinery lubricants, cooking oil and fuel for lamps, being quite appreciated in the perfume industry due to its high odor retention capacity[41].

Seed meal has high essential amino acid content, except for lysine (15.3g/kg protein), threonine (30.8g/kg) and valine (43.5g/kg)[4], which are present in lower levels than those recommended for 2 to 5-year-old children. The high methionine and cysteine (43.6g/kg protein) contents are close to those of human and cow milk and chicken eggs[34]. With respect to the needs of a growing rat, lysine is the first limiting amino acid followed by isoleucine and leucine[4]. This abundance of essential amino acids encourages using the seeds as an excellent food substitute for legumes, which are usually poor in sulfur-containing amino acids.

In relation to antinutritional factors, leaves have a low quantity of tannins (12g/kg dry matter), phytates (21g/kg) and absence of trypsin and amylase inhibitors, lectins, cyanogenic glucosides and glucosinolates. Pods and stem contain irrelevant amounts of tannins but saponins and alkaloids are present in amounts biologically important in leaves (80g/kg) and stem, respectively, although in levels considered nontoxic to ruminants[27,33]. Soliva et al.[42], using the Hohenheim gas test and the Rumen Simulation Technique, studied the effect on ruminal nitrogen turnover and fermentation of *M. oleifera* leaves in comparison with soybean and rapeseed meals. The high protein (230g/kg) content associated with high ruminal nitrogen degradability, good availability in the intestines and adequate levels of essential amino acids indicate the potential of *M. oleifera* leaves for ruminants fed tropical grasses, with about 95% of the total nitrogen in *Moringa* leaves being available either in the rumen or in the post rumen[33,42]. However, it is not known how these proteins arrive at the duodenum and how they would alter ruminant growth and milk composition.

In spite of being free of trypsin inhibitors and tannins, the seeds contain an acidic protein with hemagglutinating activity, glucosinolates (65.5µmol/g) and phytates (41g/kg)[4,16,33,43]. Phytate contents of the kernel samples were higher than those in the vegetative parts[27]. Phytates present to an extent of 1% to 6% reduce mineral bioavailability in monogastric animals[44], particularly, Zn^{2+} and Ca^{2+}. Lectins, on the other hand, are usually responsible for agglutinating cells, interacting with intestinal epithelium, interfering with nutrient digestion and absorption and reducing food efficiency[45].

The seed's bitter taste is generally attributed to alkaloids, saponins, cyanogenic glucosides and glucosinolates which are removed by treatment, suggesting that this taste would not limit the use of this material in animal diets. There is considerable genetic diversity between *M. oleifera* and *M. stenopetala*[2], for example, and the literature shows that there are many different varieties whose kernels taste from sweet to very bitter. Seeds of some varieties are consumed by humans after roasting and taste like peanuts[1]. The amount of available protein for animal absorption in the seeds (62%-69%) may be greater than that of wheat bran[33], which diminishes the nitrogen loss as ammonia.

The aqueous seed extract has been traditionally used to purify water in Africa and, in South Asian countries, as a natural coagulant since it has high levels of active cationic proteins with molecular mass between 6 and 16kDa and highly alkaline isoelectric points[3,13,46,47], with a coagulation efficiency similar to that of alumen in samples with high turbidimetry[13]. Studies have demonstrated low toxicity of this water extract, with a LD_{50} value of 512.8mg/kg body weight[16,48,49]. This LD_{50} value is considered to be only moderately toxic when compared with toxicological human standards[50]. In addition, it is known that the seeds are capable of reducing 99.9% of the bacteria suspended in water after a 1-to-2-hour treatment[12]. The seed powder suspension in concentrations of 30 to 200mg/L has been introduced into the Northeast Region of Brazil. Its cultivation has been stimulated in the vicinity of homes for its esthetic beauty, as a fence and to provide shade[51]. All these findings have promoted widespread application of the seeds as a coagulant all over the world, suggesting that the crude extract of. *M. oleifera* seeds can be an alternative for water treatment, especially in developing countries to reduce costs and expand water supplies in rural areas, although no large scale exploitation has yet been performed[3].

In the state of *Ceará* (Brazil), approximately 27,000km^2 out of a total area of 148,016km^2 are severely affected by desertification, common in the Northeastern Region of Brazil. Aiming to offer a simple and renewable solution for the deleterious effects of potable water shortage, programs have been created to distribute seeds to rural populations. These programs explore the soil characteristics of the region, improve the people's hygiene habits and quality of life, help reduce child mortality and collaborate with the sustainable development of the region. The population receives *Moringa* kits with instructions to purify water. The seeds are ground for better efficiency and three ground seeds are added per liter of water[51].

The roots are less consumed because they contain alkaloids (0.2% of the total)[1,17]. Nevertheless, they can be used after grinding as condiments with a hot flavor similar to that of horseradish, reason why *M. oleifera* is also known as the horseradish tree[52].

CONCLUSION

The relative lack of antinutritional components and the high protein, lipid and sulfur-containing amino acid contents encourage the use of *Moringa oleifera* as animal feed; it is an excellent source of proteins for monogastric animals. The antioxidant action of some compounds present in the plant, one of the most important physiological roles of food, can protect organisms against the deleterious effects of oxidation. Taking into consideration the relative lack of toxic compounds in the seed and its ability to clarify and purify muddy water, the popular dissemination of this plant could constitute an additional food source and an alternative to obtain clean drinking water where it is not available.

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COLLABORATORS

P.M.P. FERREIRA was reviewed and wrote the article. D.F. FARIAS helped search references and write the article. J.T.A. OLIVEIRA helped search references and organize the review. A.F.U. CARVALHO contributed by suggesting sources and correcting the final version. She also encouraged and accompanied the writing of this review.

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