

Review Article

Phytochemical Constituents, Biological Activities, Therapeutic Potentials and Nutritional Values of *Moringa oleifera* (Zogale): A Review

Adamu Idris Maizuwo^{1,*}, Aminu Sharif Hassan², Hassanah Momoh³,
Jabir Abdullahi Muhammad⁴

¹Department of Chemistry, School of Science Education, Sa'adatu Rimi College of Education Kumbotso, Kano, Nigeria

²Department of Physical and Health Education, School of Science Education, Sa'adatu Rimi College of Education Kumbotso, Kano, Nigeria

³Department of Pure and Industrial Chemistry, Bayero University Kano, Kano, Nigeria

⁴Department of Chemistry, Kano University of Science and Technology Wudil, Wudil, Nigeria

Email address:

adamuidris908@gmail.com (A. I. Maizuwo)

*Corresponding author

To cite this article:

Adamu Idris Maizuwo, Aminu Sharif Hassan, Hassanah Momoh, Jabir Abdullahi Muhammad. Phytochemical Constituents, Biological Activities, Therapeutic Potentials and Nutritional Values of *Moringa oleifera* (Zogale): A Review. *Journal of Drug Design and Medicinal Chemistry*. Vol. 3, No. 4, 2017, pp. 60-66. doi: 10.11648/j.jddmc.20170304.12

Received: June 20, 2017; **Accepted:** August 21, 2017; **Published:** October 28, 2017

Abstract: *Moringa oleifera* popularly known as Zogale in Northern Nigeria is one of the most widely distributed and cultivated plant species in the region. *Moringa oleifera* is a small or middle-sized tree, about 10m in height and is cultivated for different purposes such as vegetable, spice, medicine, for cooking and cosmetic oil. Different parts of this plant contain a profile of important minerals, and are a good source of protein, vitamins, β -carotene, amino acids and various phenolics. It was reported that *Moringa* trees are used to overcome malnutrition, especially in infants and nursing mothers, due to the presence of essential nutritional composition. *Moringa* leaves contain more vitamin A, calcium, iron, vitamin C, and potassium than carrots, milk, spinach, oranges and bananas respectively, and the protein quality of *Moringa* leaves is more than that of milk and eggs. An overview of phytochemical constituents present, biological activities, therapeutic potentials and their nutritional values are given in this paper.

Keywords: *Moringa oleifera*, Zogale, Phytochemical, Nutritional, Glucosinolate, β -Carotene

1. Introduction

Plants are the immediate companions of man. This originate from the story of the world creation as mentioned in the holy books. Man has been using plants for different purposes. The early man, used plants to treat diseases to make shelter and clothing plant extract contains phytochemical which includes alkaloid, flavonoids, steroids, glycosides and others which are responsible for the various biological activities e.g antimicrobial antioxidant, anticancer, ant diabetic and other activities [1].

The products derived from several herbs and plants, being a source of multifunctional curing agents and bioactive

compounds, are relatively considered safe for consumption. According to the Food and Agriculture Organization's (FAO) report, about 70–80% of the world's population, 25% of the synthesized drugs are manufactured from medicinal plants [2]. Increased demand for food to tackle hunger and malnutrition problems has been pertinent in developing countries over the last few decades. In Asian and African countries, the vast majority of the population suffers from malnutrition because of the deficiency of essential nutrients in foods. *M. oleifera* Lam. belongs to the family Moringaceae, commonly known as the 'drumstick' or 'horseradish' tree. It is an affordable and readily available source of major essential nutrients and nutraceuticals, and it has the potential to eradicate

malnutrition [3]. The *Moringa* is often considered as important famine food because of its high resistance to drought and arid conditions owing to their tuberous roots [4]. Almost each and every part of *Moringa* tree is useful for medicinal, functional food preparations, nutraceuticals, water purification, and biodiesel production; including roots, leaves, flowers, green pods, and seeds [5]. The immature pods, flowers, and foliage of this tree are used for culinary purposes in different parts of the world [6]. The foliage of *M. oleifera* has been established as a rich source of phenolics and glucosinolates, minerals [7], tocopherols [8], carotenoids [9], polyunsaturated fatty acids [10], ascorbic acid [5], and folate [9]. Moringa seed oil also known as “Ben oil” is used for the production of biodiesel, because of the high content of monounsaturated fatty acids in form of oleic acid [11, 12]. *Moringa* seed oil is a potential candidate for biodiesel production, as it meets all the main specifications of the biodiesel standards of US, Germany, and Europe [13]. Thus, it has great commercial and industrial importance. The low molecular weight cationic proteins, chitin binding protein isoforms, lectins, napins, mabinlins, and other seed proteins extracted from *M. oleifera* seeds are successfully characterized and used in domestic and industrial water purification, and hardness removal because of the potent antimicrobial and coagulant properties [14].

To our knowledge, no recent comprehensive reviews exist on water coagulation proteins and its coagulation and flocculation mechanism. Also, a significant amount of work has been conducted to explore the potential of MOME in biodiesel production. Thus, after reviewing the literature on nutritional, nutraceuticals, water purification and biodiesel potential uses of *M. Oleifera*, it is worthwhile to compile an updated and comprehensive review. Thus, the present study is focused on the bioactive composition, medicinal and biological properties, water coagulation proteins, and fatty acid methyl esters from different parts of *M. Oleifera*, to explore its sustainable uses in the domestic and industrial sectors. Additionally, future perspectives in these contexts are identified.

M. oleifera is the most widely cultivated plant species of a monogeneric family, the moringaceae which is native to the sub-Himalayan of India, Bangladesh and Pakistan [15, 16, 17, 18, 19], it is also widely distributed throughout Africa, Saudi Arabia, South east Asia the Caribbean Island, and south American [18, 20, 21]. In Philippines, Cambodia, Central and North America [22]. *M. oleifera* is known as drumstick in English [15, 16, 17, 18, 23, 24, 25, 26, 27], Zogale in Hausa [26, 27, 28], “Eweigbale” in Yoruba [26], Okweoyibo in Igbo [26]. *M. oleifera* is a small, fast growing evergreen or deciduous tree that usually grows up to 10-12m in height [16,18, 24, 25, 28]. It has an impressive range of medicinal uses with high nutritional value. Different parts of this plant contain a profile of important minerals, and are a good source of protein, vitamins, β -carotene, amino acids and various phenolics (Flavonoids, anthocyanins, proanthocyanidin and cinnamates) [29]. The whole part of *Moringa* tree are considered to possess medicinal properties and used in

different treatment of diseases or abnormalities such as, cardiac, circulatory stimulant, ascites, rheumatism, venomous bites [24], gastro-intestinal, inflammation, hepatorenal disorders and haematological disease [29].

Despite the advantages, *Moringa* plant contain harmful chemicals, alkaloids and other phytotoxin which have potentially nerve-paralysing properties and other adverse effects when consumed in high doses [21, 30]. “This compounds include moringine, moringinine, estrogene, pectinesterase, phenols including tannine [21]. Recently in Nigeria, *Moringa* has become an outstanding valuable nutrients, carbohydrate, proteins, lipids vitamin and essential minerals, that are highly beneficial to both humans and animals [21].

1.1. Botanical Description, Distribution and Production

Moringaceae is a single genus family of shrubs and trees, which comprise of 13 species, distributed in the Indian subcontinent (*M. oleifera* and *M. concanensis*), Kenya (*M. longituba* and *M. rivae*), northeastern and southwestern Africa (*M. stenopetala*), Arabia, and Madagascar (*M. drouhardii* and *M. hildebrandtii*) [4, 5]. *Moringa oleifera* Lam. is a tropical deciduous perennial dicotyledonous tree. The stem is brittle with a corky, whitish-gray bark, with drooping branches, pale green and bipinnate or more commonly tripinnate leaves (30–60 cm long) with opposite, ovate leaflets [31]. *M. Oleifera*, the native of the sub Himalayan mountains of northern India; is now cultivated for a variety of purposes in the whole tropical and subtropical regions of the world [32]. The distribution of *M. oleifera* in the world is outlined in Figure 1.1a. Similarly, different vegetative and reproductive parts of *M. oleifera* tree is shown in Figure 1b. [33] Recently reviewed the potential of the *M. oleifera* tree, emphasizing its nutritional applications for humans and industrial uses, and also described its propagation methods. It is propagated through cuttings (0.2–1.0 m long), with recommended tree to tree spacing of 1.2 and 5 m between rows (for pod yield), to obtain the desirable population of 1666 trees/ha. For foliage production, cuttings are planted with a close spacing to obtain 1 million trees/ha. Propagation through seeds is not recommended because of substantial genetic variation through cross-pollination [34]. The *Moringa* tree grows best in the temperature range of 25–35 C, under direct sunlight, at an altitude of 500 m, and in slightly acidic to alkaline soil (pH 5.0–9.0); although it can tolerate excess temperature, up to 48 C, frost in winter, altitude, and a wide variety of soil conditions. *M. oleifera* seeds can be planted just after maturity, as the seeds do not undergo dormancy while retaining viability up to 1 year. The tree starts bearing fruits at an age between six and 8 months, with a low fruit set in the initial one to 2 years, however, the yield increases in the subsequent years. The productivity of the Brazilian genotype was estimated as 45 tons of pods per hectare [35]. The oil yield of 258 kg/ha was recorded from the Indian cultivar grown in the subtropical northwestern region of Argentina, after 3 years of the plantation [36]. India is the largest producer of *M. oleifera* fruits (pods) with an annual production of 1.1–1.3 million tons from an area of 38,000 ha.

In India, the state of Andhra Pradesh is the major producer both area-wise (15665 ha) and in production, followed by Karnataka (10280 ha) and Tamil Nadu (7408 ha) [37].

1.2. Taxonomic Classification

a.	Kingdom	Plantae
b.	Sub-kingdom	Tracheobionta
c.	Super division	Spermatophyta
d.	Division	Magnoliophyta
e.	Class	Magnoliopsida
f.	Sub class	Dilleniidae
g.	Order	Capparales
h.	Family	Moringaceae
i.	Genus	Moringa
j.	Species	Oleifera [34]

2. Phytochemical Constituents

Different parts of the *M. oleifera* tree have been established as being good sources of unique glucosinolates, flavonoids and phenolic acids [32], carotenoids [9], tocopherols [38], polyunsaturated fatty acids [30], highly bio available minerals [9], and folate. Among glucosinolates, 4-O-(α -L-rhamnopyranosyloxy)-benzylglucosinolate (glucomoringin) is the most predominant in the stem, leaves, flowers, pods and seeds of *M. oleifera* [32]. Although in the roots, benzyl glucosinolate (glucotropaeolin) is the most

prominent. The highest content of glucosinolate is found in the leaves and seeds. The enzymatic catabolism of glucosinolates by the endogenous plant enzyme myrosinase produces isothiocyanates, nitriles, and thiocarbamates that are known for strong hypotensive (blood pressure lowering) and spasmolytic (muscle relaxant) effects [39]. Among flavonoids, flavonol glycosides (glucosides, rutosides, and malonyl glucosides) of quercetin [kaempferol] isorhamnetin are predominantly found in various parts of the tree, except in the roots and seeds. In the leaves, the amount of quercetin and kaempferol was found to be in the range of 0.07–1.26 and 0.05–0.67%, respectively. Also, among different varieties, the Indian varieties have shown a higher total content of quercetin and kaempferol, compared to the African indigenous samples [40]. The potent antioxidant activity *M. oleifera* is attributed to the high concentration of these polyphenols. Of late, seven major cultivars of *M. oleifera* from Pakistan have been characterized for their polyphenolic, nutrient, and antioxidant potential. The quercetin, apigenin, and kaempferol derivatives were recorded; the major flavonoids in the hydromethanolic extracts of the *Moringa* foliage, corresponded to 47.0, 20.9, and 30.0% of the total flavonoids (on an average), respectively. The varying concentrations of phenolics with the antioxidant capacity of the tested foliage established ‘Pakistan Black’ and ‘Techiman’ as the most nutritive cultivars, compared to the other major cultivars of *M. oleifera* from Pakistan [41].

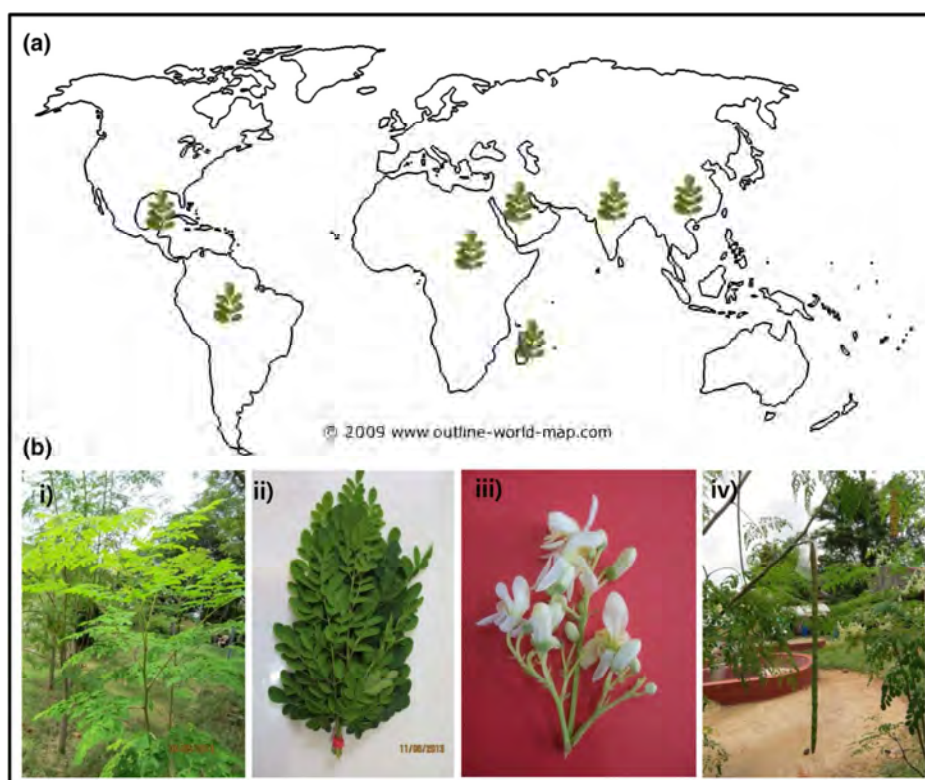


Figure 1. a The distribution of *Moringa oleifera* in the World. The image of world map was obtained from www.outline-world-map.com (Royalty free). b Different vegetative and reproductive parts of *M. oleifera* tree; i field grown tree, ii bundle of foliage, iii flowers, and iv fruit (pod).

5-Formyl-5,6,7,8-tetrahydrofolic acid (5-HCO-H₄folate; 502.1 lg/100 g DW), 5,6,7,8-tetrahydrofolic acid (H₄folate;

223.9 lg/100 g DW), 5-Methyl-5,6,7,8-tetrahydrofolic acid (5-CH₃-H₄folate; 144.9 lg/100 g DW), and 10-Formylfolic

acid (10-HCO-folic acid; 29.0 Ig/100 g DW) are the major forms of folates found in the foliage of *M. oleifera* [42]. Additionally, these forms are highly bio available in animals, compared to other folaterich foods, such as green leafy vegetables. Relative bioavailability, calculated as the response of *Moringa* folates compared to the response of synthetic folic acid in a rat model, was recorded as 81.9%. In the calculations of the recommended dietary allowances (RDA), only 50% of natural folate is assumed to be bio available. Thus, it is suggested that *M. oleifera*-based food can be used as a significant source of folate, because of significantly higher bioavailability in animals. Folate is the one of the most important water-soluble vitamins, plays an essential role in various cellular metabolisms, including oxidation and reduction of one-carbon units [43]. Folate deficiency causes severe chronic diseases and developmental disorders, including neural tube defects during pregnancy [44]. Thus, a folate-sufficient diet is strongly recommended during pregnancy to prevent the neural tube defects and other chronic dysfunctions.

The foliage, flowers, and immature pods (fruits) of various commercially grown Indian cultivars of *M. oleifera* have been characterized by the content of carotenoids [9]. All-E-lutein is the major carotenoid in foliage and immature pods (fruits), accounting for 53.6 and 52.0% of the total carotenoids, respectively. Other carotenoids, such as, all-E-luteoxanthin, 13-Z-lutein, all-E-zeaxanthin, and 15-Z-b-carotene have also been found in minor quantities. Among various tissues, the highest content of total carotenoids is recorded in leaves (44.30–80.48 mg/100 g FW), followed by immature pods (29.66 mg/100 g FW), and flowers (5.44 mg/100 g FW). Among the various Indian cultivars, the highest content of all-E-zeaxanthin, all-E-b-carotene, and total carotenoids was recorded in the Bhagya cultivar [9]. The *M. oleifera* leaves are a rich source of α -tocopherol (vitamin E), accounting for 17.3 mg/100 g FW in the cultivar. With evidence from various studies, the foliage of *M. oleifera* is established as a rich source of carotenoids and tocopherols. However, these vitamins are significantly degraded during dehydration and the other processes that occur in the *Moringa* foliage [38]. Thus, experiments have also been conducted to further enhance the content of these vitamins in the foliage of *M. oleifera* [8], and interestingly, foliar administration of biotic elicitors (carboxy-methyl chitosan and chitosan) and signaling molecules (methyl jasmonate and salicylic acid) has been found to be potentially beneficial for the enhancement of major carotenoids and α -tocopherol in the foliage of field grown *M. oleifera* trees.

The *M. oleifera* leaves are also established as a rich source of omega-3 and omega-6 polyunsaturated fatty acids, in the form of α -linolenic acid, and linoleic acid. Palmitic acid is recorded in the major saturated fatty acid, accounting for 16–18% of the total fatty acids in the *Moringa* leaves [10]. Immature pods and flowers are characterized by a higher content of total monounsaturated fatty acids and are low in polyunsaturated fatty acids compared to the leaves [10]. In contrast, the seeds and seed oil have a high content of oleic,

palmitoleic, stearic and arachidic acid and a lower content of linoleic, and linolenic acid [32]. This seed oil contains an identical fatty acid profile such as olive oil except for linoleic acid [45] [46]. To obtain the highest yield of oil from seeds, the solvent-assisted extraction using chloroform and methanol in the ratio of 3:1 at 100°C is seen to be most favorable. However, oil extracted with these solvents is not recommended for human consumption because of the residual amount of these toxic substances. Thus, hexane is routinely used in the extraction of oil from *Moringa* seeds, because of its efficiency and ease of recovery. The thermo gravimetric analysis (TGA) analysis revealed that the oil degrades at a temperature of about 425–450°C [47]. In terms of health effects, the *M. oleifera* leaves, immature pods, flowers, seeds, and seed oil have a low saturated fatty acid content and high monounsaturated fatty acids and polyunsaturated fatty acids content that can enhance the health benefits of *Moringa*-based foods.

Potassium (K), calcium (Ca), and magnesium (Mg) are the predominant minerals in the *M. oleifera* tissues. The highest content of K is found in the vegetative parts and immature pods, whereas, leaves and seeds are a rich source of Ca and Mg, respectively [32]. However, *M. oleifera* is also recorded as having a rich source of iron (Fe) (17.5 mg/100 g DW). In a bioavailability study conducted on a rat model, Fe from the *Moringa* leaf was found to be superior compared to ferric citrate, in overcoming iron deficiency [7].

Full-fat and defatted *M. oleifera* kernels are recorded as being rich in protein content and account for 36.18 and 62.76%, respectively. The concentrations of the other proximate constituents were found to be higher in defatted flour, compared to full-fat flour. Defatting also increased water absorption, fat absorption, foaming capacity, and foam stability of flour [48]. Reference [48] suggested that, the *M. oleifera* kernel flour could be used as a valuable source of protein in food product formulation. In the proximate studies from Brazil, the dehydrated leaf powder was recorded to contain 44.4% carbohydrate, 28.7% crude protein, 10.9% ash, 7.1% fat, 103.1 mg/100 g iron, and 3.0 mg/100 g calcium. Similarly, the protein profile showed 70.1% insoluble proteins, 3.5% glutelin, 3.1% albumin, 2.2% prolamin, and 0.3% globulins. Antinutritional compounds, such as, tannins (20.7 mg/g), trypsin inhibitor (1.45 TIU mg/g; Trypsin Inhibitor Units), nitrates (17 mg/g), and oxalic acids (10.5 mg/g) were also documented.

Oyeyinka and Oyeyinka [49], recently reviewed the possibilities of food fortification with *M. oleifera* leaf, seed, and flower powder to improve the nutritional value. Authors describe the fortification possibilities in various staple foods such as Amala (stiff dough), ogi (maize gruel), bread, biscuits, yogurt, and cheese for making soups. Authors described that although many of the reviewed studies reported improvement in the nutritional value of staple foods fortified with *M. oleifera*, none of the reports showed the in vivo or in vitro digestibility and availability of nutrients. Thus, the nutrient bioavailability and phytochemical contents of *M. oleifera*-fortified foods should be determined.

3. Biological Activity and Therapeutic Potential of *M. Oleifera*

The different parts of the *M. oleifera* tree, including roots, bark, leaves, flowers, fruits, and seeds are traditionally used in various therapeutic applications, including, abdominal tumors, hysteria (a psychological disorder), scurvy, paralysis, helminthic bladder, prostate problems, sores and other skin infections. The therapeutic potential and medicinal properties of *M. oleifera* are extensively reviewed [50, 51]. Stohs and Hartman [52] described the physiological and pharmacological activities of the leaves, seeds, bark, roots, sap, and flowers of *M. oleifera*.

The various safety studies conducted on animals are also reviewed by the authors and they have concluded that the *Moringa* foliage, flower, and fruit extracts offer a high degree of safety without any adverse effects on humans. The phytochemicals of *M. oleifera* have shown antidyslipidemic, anthelmintic, antihyperglycemic, anti-inflammatory, antimicrobial, antioxidant, antiproliferative, anti-ulcer, antiurolithiatic, and hepatoprotective properties. Potent antiproliferative and apoptotic properties of the *M. oleifera* leaf extract, rich in quercetin and kaempferol phenolics compounds, have been demonstrated using the human tumor (KB) cell line model. The *M. oleifera* leaf extract has shown significant morphological changes and decreased cell viability, with increased internucleosomal DNA fragmentation and ROS generation in the KB cells [53].

Chronic hyperglycemia is an indicator of diabetes mellitus, similarly, chronic dyslipidemia is a potential risk factor for cardiovascular disease (CVD). In animal studies, *Moringa* leaf water extract is found to control the fasting plasma glucose levels (FPG), postprandial blood glucose (PPPG), Blood glycated hemoglobin (HbA_{1c}), and increased glucose tolerance, studied by the oral glucose tolerance test (OGTT), in streptozotocin (STZ)-induced diabetic rats [58], and untreated diabetes mellitus patients [54]. The *Moringa* leaf water and methanol extract are also reported to have antidyslipidemic effects to lower the serum total cholesterol (TC), triacylglyceride (TG), very low-density lipoprotein (VLDL), low-density lipoprotein (LDL), and the atherogenic index, with increased high-density lipoprotein (HDL) in rats fed on a high-fat diet (HFD). A significant rise in the fecal excretion of cholesterol is observed in treated animals compared to the HFD control group [55]. Similar antidyslipidemic effects are also documented in hyperlipidemic patients (TC[180 mg/dL and TG[140 mg/dL), fed with leaf tablets (4.6 g/day) for 40–50 days [56].

The *M. oleifera* aqueous leaf extract down regulates a pro-inflammatory transcription factor (nuclear factor-kappa B; NF-kB) and increases the cytotoxic effect in apoptosis based chemotherapy, investigated in cultured human pancreatic cancer cells (Panc-1, p34, and COLO 357). The treatment of the extract (C0.75 mg/ml) induces a rise in the sub-G1 cell populations of the cell-cycle and reduces the expression of different subunits of NF-kB, namely, p65, p-IkBa, and IkBa. Also, the leaf extract synergistically enhances the cytotoxic effect of cisplatin on Panc-1 cells [57]. *M. oleifera* aqueous leaf extract containing

1.66% isothiocyanates [4-(α -L-rhamnosyloxy) and 4-(4⁰-O-acetyl- α -L-rhamnosyloxy)-benzyl isothiocyanate], and 3.82% total polyphenols, significantly decreases gene expression and production of inflammatory.

4. Nutritional Benefits

It was reported by [15] that, *Moringa* leaves are extremely nutritious and contain larger amounts of several nutrients than the common food often associated with these nutrients. The vitamin C, presence in *Moringa* fights a host of illness which include colds and flu vitamins A, act as a shield against eye disease, skin disease, heart ailments, diarrhea, and many other diseases; calcium builds strong bones and teeth and help prevent osteoporosis. According to [15, 16, 58] *Moringa* leaves contain more vitamin A than carrot, more calcium than milk, more iron than spinach, more Vitamin C than organs and more potassium than bananas; and that the protein quality of moringa leaves rivals that of milk and eggs. In fact the nutritional properties of *Moringa* are now so well-known seems to be little doubt of the substantial health benefit to be realized by consumption of *Moringa* leaf powder in situations where starvation is imminent [58]. A large number of reports on the nutritional qualities of *Moringa* now exist in both the scientific and the popular literature.

5. Conclusion

M. oleifera is the most widely cultivated plant species of a monogeneric family, the moringaceae. Different parts of this plant contain a profile of important minerals, and are a good source of protein, vitamins β -carotene, amino acids and various phenolics. *Moringa* trees are used to overcome malnutrition, especially in infants and nursing mothers due to the presence of essential nutritional composition. *Moringa* leaves contain more vitamin A, calcium, iron, vitamin C, and potassium than carrots, milk, spinach, oranges and bananas respectively, and the protein quality of *Moringa* leaves is more than that of milk and eggs.

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