Chapter

# African *Moringa stenopetala* Plant: An Emerging Source of Novel Ingredients for Plant-Based Foods

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## Abstract

*Moringa stenopetala* is a multi-purpose tropical plant native to East Africa. The plant is exceptionally rich in nutrients and health-promoting bioactive compounds. It is among the top plants that could potentially feed the world and alleviate nutritional deficiencies. *Moringa stenopetala* is a versatile plant because its various parts, including leaves, seeds, flowers, pods, bark, and roots are useful to humans. Especially, the leaves and seeds are high in protein with all the essential amino acids. Based on the FAO database, *M. stenopetala* seed protein with its essential amino acid content stands highest among all commercial plant protein sources. Though it is a high-value plant and extensively used for food and traditional medicine by the local people in its native place, it is underutilized elsewhere. This chapter reviews recent research efforts that aim to unlock the potential of the plant as a source of ingredients for food, cosmetic and nutraceutical industries.

**Keywords:** bioactive compounds, *Moringa stenopetala*, oil, plant-based food, protein

## 1. Introduction

The growing awareness of the effects of food on human health and the environment has warranted a need to look for alternative food sources. This has promoted a steady increase in demand for plant-based diets [1], which can be attributed to increasing vegan, vegetarian, and flexitarian populations as well as increasing intolerance to animal proteins. Ethical concerns about animal abuse, the nutritional benefits of plant-based diets and the ever-increasing investments in the plant protein sector are all factors contributing to the growth of plant-based foods [2, 3].

The plant-based food market is expected to grow at a compound annual growth rate (CAGR) of 12.4% in 2022 to reach $95.52 billion by 2029 [2]. The growth rate for the U.S. plant-based food market was more than doubled in 2020 as sales surged 27% to $7 billion, according to the Plant Based Foods Association (PBFA) and Good Food Institute (GFI). To meet the increasing demand, there is a need to adopt

climate-resilient food production system with higher yields of improved functional food ingredients. The versatile tropical plant species Moringa with uses for its various parts, particularly the leaves and seeds, holds immense potential for use as ingredients in plant-based food and therapeutic applications.

Moringa belongs to the monogeneric Moringaceae family [4]. The genus consists of about 14 species, including the well-known species, *Moringa oleifera*, which is native to the Indian sub-continent, and *Moringa stenopetala*, also known as African Moringa, which is endemic to East Africa [5]. The leaves and green pods of Moringa are rich in both macro and micro-nutrients and are eaten as a staple vegetable, especially in the Indian sub-continent and Africa [6].

Moringa is one of the world's most useful tropical trees and often nick-named a 'multi-purpose tree' [7, 8]. It is a resilient and highly drought-tolerant tree growing on marginalized land and almost all parts of the plant are useful [9]. The leaves, seeds, pods, flowers, and roots are excellent sources of nutrients and bioactive compounds [10, 11], especially dietary fiber, proteins, minerals, vitamins, and phytochemicals that offer great nutritional and therapeutic benefits [5, 12–14].

Moringa is listed among the top plants that could help feed the world and alleviate nutritional deficiencies and is often considered as a superfood [7, 8]. It holds much promise to serve as a source of valuable bioactive compounds for food, pharmaceutical and cosmetic applications [5]. Moringa seed hulls (often considered a waste) are used to develop high performance carbonaceous adsorbents and biological coagulants for water and wastewater treatment and removal of hazardous contaminants, which enhances environmental health [15–17].

Unlike *M. oleifera* for which there are robust scientific studies on its chemistry, food, and therapeutic uses [12, 13], only a few similar scientific studies have been conducted on *M. stenopetala* [18].

*M. stenopetala* is used as a staple food and traditional medicine by the local people in its native place in East Africa. It grows on the homesteads of small-holder farmers and is tightly linked to the livelihood of local communities in the region (**Figure 1**). The plant is exceptionally rich in nutrients and health-boosting bioactive compounds and could potentially alleviate nutritional deficiencies. The leaves and seeds are high in protein content and contain all the essential amino acids. Recent studies in Canada revealed that *M. stenopetala* seed protein with its essential amino acid content is the highest among all the commercial plant protein sources based on the FAO database (personal communication).


**Figure 1.**
*Moringa stenopetala in Konso, Southern Ethiopia.*

Though the plant holds much promise as a source of ingredients for nutrient-and mineral-rich plant-based diets, it is less known to the outside world and rarely utilized in food product formulations. Thus, this chapter reviews recent research interests that aim to uncover potential uses of *M. stenopetala* ingredients for plant-based food and therapeutic applications.

## 2. Origin, ecology, and production of *M. stenopetala*

*M. stenopetala* is native to east Africa, with diversity spanning Ethiopia, Kenya, and Central Somalia [19]. In Ethiopia, the distribution of the species is mostly concentrated in specific zones in the south [20–23]. The presence of *M. stenopetala* has also been reported in the northern part of the country, specifically in Alamata district of southern Tigray, where it is promoted as an agroforestry tree species [24].

*M. stenopetala* grows in Ethiopia from 390 to 2200 meters above sea level (mas) in the southern Rift Valley, including the arid and semi-arid regions between 1000 and 1800 mas [23, 25]. *M. stenopetala* grows well in areas receiving annual rainfall and temperature that ranges from 250 to 1500 mm and 25°C to 35°C, respectively. According to a summary of the national herbarium's vouchers, the habitat where the genus occurs in Ethiopia consists of rocky riverbanks, dry scrub land, Acacia-Commiphora woodland, watercourses with some evergreens, open Acacia Commiphora bush land on gray alluvial soil, and cultivated lands in and around villages.

*M. stenopetala* is intercropped with food crops in moderately dry regions of southern Ethiopia and used as a farm tree (home gardens) to support the livelihoods of the high population present in the region. It is among the most useful trees planted and managed by rural people in the dry areas of Ethiopia [7, 26]. With proper agronomic practices, *M. stenopetala* has the potential for large-scale commercial farming. It was reported that a single tree of *M. stenopetala* could support a large family for several years [21, 27]. Thus, *M. stenopetala* is a promising plant to adopt for a climate-resilient food production system that could have a significant impact on alleviating food insecurity and serve as a source of ingredients in food and therapeutic applications.

## 3. Nutrient and bioactive composition of various parts of *M. stenopetala*

The nutrient, bioactive compounds, vitamin, and mineral composition of various parts of the plant, particularly the leaves and seeds, are presented in this section. The trending potential of the use of *M. stenopetala* ingredients in plant-food formulations is also highlighted. The nutritional and bioactive composition of *M. stenopetala* is presented and compared with that of *M. oleifera*, for which a wealth of information on its chemistry, nutrient and bioactive profiles and therapeutic potential is available [12, 13].

Moringa leaves, seeds, flowers, roots, and green pods are rich in macro and micronutrients. The leaves of *M. stenopetala* are popular as a staple vegetable in eastern Africa as is *M. oleifera* in the Indian subcontinent [21, 28, 29]. Dried Moringa leaf powder that is kept under dark conditions preserves the nutritional potency of the leaves for a long period of time [30, 31]. Dried leaves are utilized for the preparation of Moringa herbal tea and other non-alcoholic beverages that have significant health benefits [18].

### 3.1 Dietary composition of the leaf

Findings from various studies revealed that *M. stenopetala* and *M. oleifera* are rich in nutrients, minerals, vitamins, and bioactive compounds [32]. *M. stenopetala* dried leaf has a high protein content of about 28% (**Figure 2**). The protein from the leaves of *M. stenopetala* is complete and contains all the essential amino acids at levels equal to or higher than those found in soybean seeds [32, 33]. Similarly, recent research conducted in Canada found that *M. stenopetala* leaf has high protein content and contains all the essential amino acids (personal communication).

*M. stenopetala* leaf contains 28 and 160 mg/100 g of vitamin C and beta carotene, respectively [21]. Some studies have also reported the presence of other vitamins in higher amounts [21, 32]. Among many green leafy vegetables, Moringa was found to be a rich source of ß-carotene (vitamin A) and other micronutrients [34].

Leaf extracts of *M. stenopetala* have good amounts of phenolic and flavonoid compounds that have high antioxidant activities [35, 36]. Habtemariam and Varghese [18] have also reported the presence of a high amount of rutin, a bioflavonoid antioxidant that could be extracted from *M. stenopetala*'s dried leaves.

Previously published papers demonstrated that the minerals found in Moringa leaves are diverse and abundant. *M. stenopetala* leaves had 3363 mg/100 g of potassium, which was 3.96 times higher than in banana fruit (933 mg/100 g) [37]. Banana fruit is one of the foods recommended as a source of potassium and calcium [38]. *M. stenopetala* dried leaf is rich in calcium, potassium, magnesium, iron, phosphorus, and zinc but characterized by its low content of sodium [37]. *M. stenopetala* is nutrient-rich but low-calorie food and is an ideal part of a diet designed for body weight management.

### 3.2 Composition of *M. stenopetala* seed

Different research results have reported protein (28–43%) and oil (33–41%) levels from *M. stenopetala* seeds. *M. stenopetala* seeds are a great source of protein, high-quality edible oil, and numerous other beneficial compounds [12]. Studies have shown high protein content and considerable levels of essential amino acids in

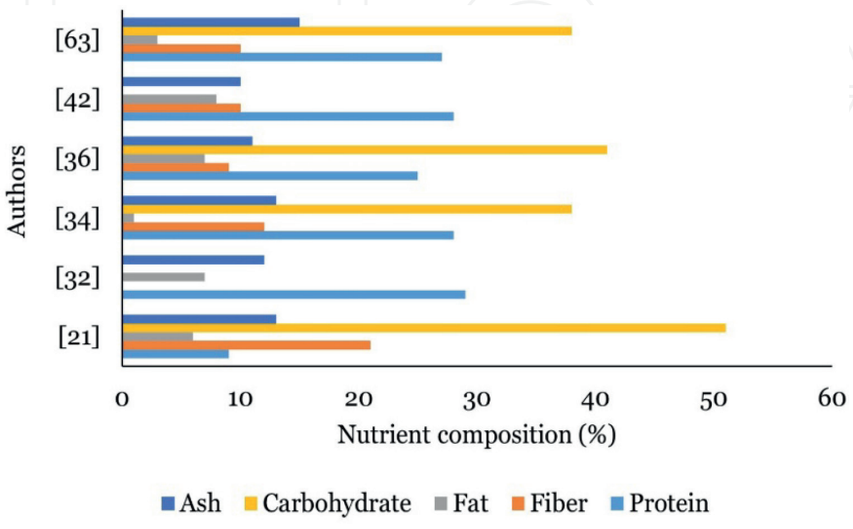


**Figure 2.**
*Nutrient composition (%) of* Moringa stenopetala *dried leaves (adapted from authors indicated on the above chart).*

Moringa seeds [12]. Results of different studies on the amino acids exhibited high qualities of the seed protein [39, 40]. Various studies have shown that the protein from Moringa seeds contains all nine essential amino acids, making it one of the best sources of plant-based proteins [12, 41, 42].

The amino acid composition of Moringa seed was compared to the hen's egg used as the reference by the FAO [43], and assessed the protein quality using the individual amino acid score. The results of this study showed that Moringa seed proteins have higher amounts of total amino acids and fewer amounts of total essential amino acids than hen's egg protein, revealing the potential use of Moringa seed protein in food applications.

According to the report, 45% of *M. stenopetala* seed is oil, with 78% of the fatty acid composition being monounsaturated (of which 76% is oleic) and 22% is saturated fatty acids [22]. *M. stenopetala* seed oil has an average value of oil density (0.919 kg/cm$^3$), specific gravity (0.918 g/cm$^3$), peroxide value (11.52 millieq $O_2$/kg), viscosity (19 mPa.s), acid value (3.74 mg KOH/g) and ester value (177.2 mg KOH/g) [44, 45]. According to Vaknin and Mishal [46], the saturated fatty acids present in Moringa oil include palmitic acid, stearic acid, arachidic acid, and behenic acid. The unique fatty acid and bioactive components, combined with distinct physiochemical properties, make *M. stenopetala* oil an ideal ingredient for food, pharmaceutical, cosmeceutical, and therapeutic applications [43, 47].

### 3.3 Pods and other parts

*Moringa stenopetala*'s flower, pod, and roots have received much less attention and are less known than the leaves and seeds. The protein, fiber, and ash contents of the pods of *M. stenopetala* and *M. oleifera* were 18 and 17%, 37 and 36%, and 12 and 10%, respectively [48]. The authors have also reported the mineral contents of pods of *M. stenopetala* and *M. oleifera* (**Figure 3**) with the further remark that the flowers, pods, and roots of Moringa contain appreciable concentrations of minerals and nutrients. Therefore, *M. stenopetala* enhances dietary diversification and thus has a significant impact on mitigating hunger in developing countries.

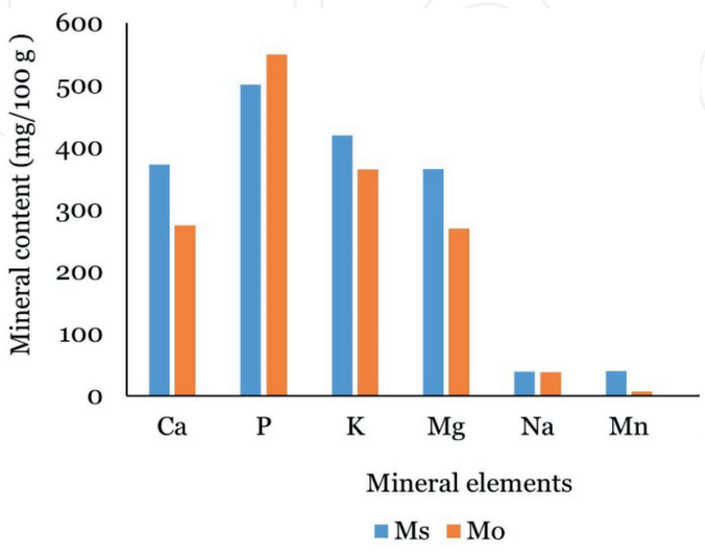


**Figure 3.**
*Mineral contents of pods of* M. stenopetala *(Ms) and M. oleifera (Mo) [48].*

## 4. Health benefits of *Moringa stenopetala* diet

The health benefits of *M. oleifera* are well documented in recent research reports [12, 13]. Though we have a dearth of information, some studies have also shown the nutritional and health benefits of *M. stenopetala*. Different parts of the plant are traditionally used to treat hypertension, diabetes, malaria, common cold, asthma, wounds, retained placenta, and stomach-ache [49, 50]. The leaf extracts of *M. stenopetala* have shown antihypertensive effects and antidiabetic activity [51, 52]. Furthermore, hepato- and kidney protective effects of Moringa leaf extracts were also reported [53]. This might be due to the presence of protective action against lipid peroxidation and reactive oxygen species of the plant's extract, which can be attributed to the presence of phenolic and flavonoid compounds [18, 54]. *M. stenopetala* leaf extract also has a high content of rutin, a powerful bioflavonoid [18]. These compounds exhibit higher antioxidant activity and are claimed to be responsible for several beneficial biological activities.

Diabetes mellitus is a complex metabolic disease that is a major global public health concern. Diabetes is increasing at an alarming rate all over the world and its prevention will necessitate measures to promote a healthy dietary pattern. Studies revealed that *M. stenopetala* leaf extract has the potential to reduce blood glucose levels effectively [55, 56]. Serum glucose level was also decreased significantly after 6 weeks of treatment of mice with *M. stenopetala* leaf extract [57]. In addition, microencapsulated products developed from *M. stenopetala* leaf extracts have shown a significant effect on diabetes [52]. The leaf of *M. stenopetala* also has a high dietary fiber [21], which may help in the prevention and management of diabetes. Furthermore, the phenolic compounds, vitamin E and tannins, present in *M. stenopetala*, can also help to reduce the risk of diabetes by managing blood glucose levels.

*M. stenopetala* leaf extract showed an antihypertensive activity as it was found from the result of vasodilator and urinary excretion increment [52]. The decreased blood pressure, extracellular fluid volume, and cardiac output occurred due to diuretics, which increase the urinary sodium excretion, thereby reducing the plasma volume that controls hypertension [58]. *M. stenopetala* leaf extract has shown significant diuretic activity [51, 52], consequently it has the potential to act as an antihypertensive agent.

The relaxation of the smooth muscle of blood vessels (vasodilation) favors normal blood pressure. However, if this blood vessel is contracted, relaxation is required using nitric oxide [59]. It was found that *M. stenopetala* leaf extract has a high relaxation (99.13%) against potassium chloride induced contraction of the guinea pig thoracic aorta at a concentration of 40 mg/mL [52]. Oral administration of the aqueous extract of *M. stenopetala* leaves led to significant reductions in systolic blood pressure, diastolic blood pressure and mean arterial blood pressure [16].

It is claimed that *M. stenopetala* has anti-carcinogenic activities due to the presence of glucosinolate compounds [60]. In addition, *M. stenopetala* leaf extract contains polyphenols and flavonoids that give a synergistic effect to anti-carcinogenic activities [54, 60].

## 5. Trends of *Moringa stenopetala* use in food and nutraceutical applications

*M. stenopetala* is emerging as a trending source of novel ingredients in the food, pharmaceutical and skin care industries. The dried leaves are used to formulate health-boosting herbal tea, the dried leaf powder is a source of nutrient-dense

**Figure 4.**
*Commercialized herbal tea, leaf protein powder, seed oil and moisturizing facial cream developed from* M. stenopetala *leaves and seeds through research and development project in Canada (Photo credit: BioTEI Inc.).*

ingredient for food applications, and the seed oil is used by the food and skin care industries (**Figure 4**). After the oil is extracted from the seed, it leaves a protein-rich press cake as a secondary extraction product.

The seeds of *M. stenopetala* are good sources of edible oil and flocculent agents for water purification as well as biofuel [49]. It was found that the protein content of *M. stenopetala* seed was higher than the protein content of other oilseeds and pulses [45]. This shows that *M. stenopetala* seeds can be utilized as a potential protein source to combat malnutrition in developing countries and as an ingredient for food applications in general. *M. stenopetala* seed oil yield reaches about 44% [61], which can be considered as a major source of oil that could be used for cooking, salad dressing, and cosmetics applications. Moringa oil is also known as ben oil and has been reported to have physical and chemical properties comparable to olive oil with a high concentration of tocopherols and oleic fatty acid [61]. Thus, this oil has better oxidative stability, which can be used in the food industry for longer storage and high-temperature frying. Furthermore, *M. stenopetala* seed oil has excellent absorbing properties on the skin which makes it a vital ingredient for the cosmetic industry. Moringa oil also has anti-aging properties due to its key bio-agents that could maintain moisture and promote the mechanical elasticity and flexibility of the skin [62]. These findings indicate that *M. stenopetala* seed oil is an ideal candidate for the pharmaceutical and cosmetics industries manifesting its untapped multifaceted business potential.

### 5.1 Food fortification

*M. stenopetala* enhances dietary diversification and thus has a significant impact on mitigating hunger in developing countries. The leaves are consumed as cabbage and the dried powder is used as a dietary supplement for proteins, calcium, iron, phosphorous as well as vitamins [63, 64]. The essential amino acids concentration of *M. stenopetala* leaves is comparable with that of defatted soybean seed meal [63]. The author has also reported the metabolizable energy, organic matter digestibility, and short chain fatty acids contents. *M. stenopetala* is a rich source of micronutrients that are commonly deficient in cereal-based diets. The concentrations of essential minerals in *M. stenopetala* leaf are very high [7], indicating its superiority to other staple foods grown in Ethiopia (**Table 1**). Moreover, cooking improved the digestibility of protein

| Crop | Concentration (mg/kg dw) | | | | | |
|---|---|---|---|---|---|---|
| | Ca | Cu | Fe | Mg | Se | Zn |
| *M. stenopetala* leaves | 19,400 | 4.71 | 117 | 6070 | 1.12 | 21.0 |
| Maize grain | 55.1 | 0.943 | 28.2 | 918 | 0.182 | 20.4 |
| Enset | 2190 | 1.3 | 71.3 | 260 | 0.060 | 34.2 |
| Sorghum grain | 176 | 1.74 | 51.5 | 1350 | 0.097 | 16.1 |
| Beans | 1500 | 9.41 | 88.5 | 88.5 | 0.150 | 24.9 |

*Data adapted from Kumssa et al. [7].*

**Table 1.**
*Medial elemental concentrations in* M. stenopetala *leaves and other food sources grown in Ethiopia.*

by 20.7 and 7.8% in leaves and pods, respectively; the same trend was observed for the total carbohydrates [64]. These authors have also confirmed the importance of cooking the leaves and pods of *M. stenopetala* for the reduction of tannins (a known anti-nutritional factor) by 27 and 45%, respectively.

The essential amino acids concentration of *M. stenopetala* leaves is comparable with soybean seed meal content [63]. The author has also reported the metabolizable energy, organic matter digestibility, and short-chain fatty acids contents. The leaves of *M. stenopetala* leaves have also relatively high phenolic and flavonoid compounds [18] indicating their antioxidant properties with a health-promoting effect on consumers [54]. Plant-derived bioactive components such as phenolic compounds inhibit the formation of free radicals, thereby preventing the formation of hydroperoxides. However, these bioactive components are lost during food processing using the conventional thermal approach. As a result, fortification is necessary to restore these bioactive components to the final food products, this makes Moringa an incredible ingredient in food fortification.

### 5.2 Functional and nutraceutical applications

The presence of phenolic and flavonoid compounds helps to prevent oxidative damage. Currently, synthetic antioxidants are reported to be associated with carcinogenic effects; as a result, consumers' interest in natural antioxidant sources is increasing. Nutraceutical, functional foods and pharmaceutical product development have created opportunities for these emerging ingredients derived from Moringa. Functional and nutraceutical products development from *M. stenopetala* extract is a promising strategy to maximize the utilization and industrialization of this underutilized but highly versatile plant. Due to its richness in proteins [63], β-carotene, other bioactive compounds, and antioxidant properties [54] and a high selenium concentration, this plant has untapped potential in human health enhancement [7]. Hence, *M. stenopetala* has the potential to be used as a key ingredient in functional foods and nutraceutical product development.

Environmental variables, storage conditions, and thermal processing, all contribute to the easy degradation of nutritional and bioactive components in *M. stenopetala*. Therefore, it is important to find alternative methods to maintain and improve the stability of these compounds. Product development from *M. stenopetala* is also important to improve the storage stability of the harvested plant parts. Spray-drying

microencapsulation of *M. stenopetala* leaf extract using a mixture of maltodextrin and pectin as a coating material is more efficient for the food and pharmaceutical industries than other processes [65]. A microencapsulated product developed from *M. stenopetala* leaf extract showed significant antidiabetic and antihypertensive effects. According to the findings, the percentage of urinary excretion was increased with the increment of the dose of the microencapsulated bioactive product developed from *M. stenopetala* leaf extract [52]. This shows that microencapsulated products have significant diuretic activity. Thus, this microencapsulated product may be used to minimize the abnormal accumulation of fluid in the human/animal body which in turn helps to manage hypertension.

### 5.3 Antimicrobial properties

Endemic plants, like *M. stenopetala*, are good sources of new antimicrobial compounds that might be effective against microorganisms resistant to commonly prescribed antimicrobials. The leaves/seeds extract from *M. stenopetala* have shown antimicrobial properties. According to Mekonnen and Dräger [60], *M. stenopetala* seed oil extract inhibited the growth of some pathogenic microorganisms such as *Staphylococcus aureus*, *Salmonella typhi*, *Shigella* spp. and *Candida albicans.* Similarly, leaf extracts of *M. stenopetala* using a mixture of methanol and chloroform have significant inhibitory activity against *Klebsiella pneumoniae* and *Bacillus cereus* [66]. Thus, it is important to develop antimicrobial products from *M. stenopetala* as an alternative bio-preservative to improve the shelf stability of some perishable food products.

### 5.4 Other industrial applications of *Moringa stenopetala* by-products

The seed husk and defatted seed press cake of *M. stenopetala* could be used to develop valuable bio-products (e.g., activated carbons and biological coagulants) that could be utilized in water and wastewater treatment applications that considerably promote a circular economy to enhance environmentally safe clean technology.

## 6. Conclusion

The African endemic Moringa tree, *M. stenopetala* is well regarded as a beneficial botanical with exceptionally high nutritional and health benefits to humans and thus nicknamed 'the multipurpose tree'. It is highly drought-tolerant and suitable for climate-resilient sustainable food production. Almost all parts of the plant (leaves, flowers, pods, seeds and hulls) have uses in the food, cosmetic and pharmaceutical industries due to their high contents of nutritional and essential bioactive components. Moringa seed oil has a good fatty acid profile suitable for food and cosmetic applications while the press cake (by-product of oil extraction) is rich in protein with good amino acid profile, and dietary fiber, making it a good raw material for protein extraction for the plant-based food industry. The leaves are dried to produce herbal tea, but they can also be ground into nutrient-dense ingredients for the development and fortification of various food products including smoothies, bars, and chips. The hulls can be used to produce activated carbon for water and wastewater treatment. Moringa is a multi-functional plant that is good for human nutrition, environmental health, and plays a pivotal role in economic sustainability of the population. However,

more research is required to realize the full potential of *M. stenopetala* through the development of extraction technologies for seed protein and its hydrolysates and fractionated peptides. Research on development of food, cosmetic and nutraceutical products with Moringa ingredients will allow consumers to fully benefit from the nutritional and bioactive components of this African "miracle" tree.

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