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Review

The Potential of Some *Moringa* Species for Seed Oil Production †

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Abstract: There is an increasingly demand for alternative vegetable oils sources. Over the last decade there has been fast growing interest in *Moringa oleifera* Lam., particularly due to its high seed oil yield (30–40%), while other Moringa species with similar potentialities are reducing their representativeness worldwide. This review reinforces the interesting composition of *Moringa* oil, rich in oleic acid and highly resistant to oxidation, for industrial purposes, and shows that other *Moringa* species could also be exploited for similar purposes. In particular, *Moringa peregrina* (Forssk.) Fiori has an interesting oil yield and higher resistance to pest and diseases, and *Moringa stenopetala* (Bak. f.) Cuf. is highlighted for its increased resistance to adverse climate conditions, of potential interest in a climate change scenario. Exploring adapted varieties or producing interspecies hybrids can create added value to these less explored species, while renewing attention to endangered species. Moringa seed oil can be extracted by conventional methods or using physical methods (pressing), creating diverse products from a compositional perspective, able to serve both the biodiesel and food industries.

Keywords: *Moringa* species; cultivation; diversification; morphology; production; climate; pests and diseases; seed oil content; oleic acid

1. Introduction

The *Moringa* genus comprises fast-growing plants, widely distributed along tropical and subtropical climates [1]. Among its 13 species, *Moringa oleifera* Lam. is the one receiving more attention worldwide, being among the most economically important tree crops, especially in developing countries. Several factors contribute for this widespread interest, including its easy cultivation in a variable range of climatic and geographical conditions, its high production yields, the multipurpose uses of all its vegetative structures (leaves, flowers, immature pods, seeds, etc.), with nutritional relevance for humans and animals, a traditional use for medicinal purposes, in agroforestry systems and for water purification [2–6]. Its seeds are rich in oil, used for cosmetic and perfume production since ancient times, as lubricants in machinery and, more recently, for biodiesel production [7–9]. *M. oleifera* oil has oleic acid as its main fatty acid, similarly to olive oil, with a great potential to become a promising commercial source of edible oil for the food industry [7]. *Moringa peregrina* (Forssk.) Fiori has also an important position, especially in the Arab peninsula and northern Africa [10], but is essentially a wild species and its commercial value has not been considered widely [11]. *Moringa stenopetala* (Bak. f.) Cuf. has also not received much attention until now despite being recognized as one of the most drought-resistant species [12], while many other species are in danger of extinction, including *M. arborea* Verdc., *M. Borziana* Mattei, *M. longituba* Engl., *M. rivae* Chiov., and *M. ruspoliana* Engl. [13].

The need for a comparison of all *Moringa* species, aiming to ascertain their potential as oils sources for food and biodiesel purposes, has motivated us to bridge the information available in this field. In this regard, the objective of the present review is to report similarities and differences between *Moringa* species in general, focusing the ones with higher economic feasibility, particularly for oil production. Therefore, after a brief revision on geographical distribution, morphological characteristics and cultivation methods, available data on *Moringa* species seed yields, oil content and composition are compared, aiming to highlight for the feasibility of using other species than *M. oleifera* for oil production purposes.

2. Origin, Geographical Distribution and Diversity of *Moringa* Species

Moringa, the sole genus of the *Moringa* ceae family, order Brassicales, includes 13 known species [1]. All species are indigenous to Africa and Asia, as detailed in Table 1, despite being now cultivated in all continents [1,6,7,13].

The most economically valuable species, *M. oleifera*, is native to the dry tropical areas in north-western India, in the south of the Himalayas, and is now the most widely cultivated, spread and naturalized *Moringa* species around the world [6,14]. It has been introduced and adapted in more than 60 different countries worldwide, including the Philippines, Mexico, Caribbean Islands, Argentina, Brazil, Algeria, among many others [15–22]. Still, *M. oleifera* represents only 7% of the genus gene pool, with the remaining diversity being underexplored [23–28]. Other multipurpose species of potential economic importance include *M. Stenopetala*, and *M. peregrina* and, to a lesser extent, *M. concanensis* Nimmo and *M. drouhardii* Jum. (Table 1). Unfortunately, the genetic diversity of *M. arborea*, *M. borziana*, *M. longituba*, *M. peregrina*, *M. rivae*, *M. ruspoliana*, and *M. stenopetala* is endangered [13,25], with *M. arborea* being listed in the 2006 International Union for Conservation of Nature (IUCN) Red List of Threatened species [27]. *M. hildebrandtii* Engl. is extinct in the wild, but still surviving in a huge numbers of traditional horticultural uses in Madagascar [28]. Therefore, the preservation of the *Moringa* species is of a great importance for biodiversity, ethno-botanical, dietary, nutritional, pharmacological, medicinal and socio-economical perspectives.

Table 1. *Moringa* species origin, distribution, preservation status and major uses [1,14–28].

Species	Native To	Actual Distribution	Preservation	Major Use
M. arborea Verdc.	Africa (Kenya)	Kenya	vulnerable	medicinal
M. borziana Mattei	Africa (Somalia)	Kenya, Somalia	endangered	few studies
M. concanensis Nimmo	Asia (India)	India, Pakistan, Bangladesh		multipurpose
M. drouhardii Jum.	Africa (Madagascar)	Madagascar		multipurpose
M. hildebrandtii Engl.	Africa (Madagascar)	Madagascar	endangered	few studies
M. longituba Engl.	Africa (Ethiopia)	Kenya, Ethiopia, Somalia	endangered	medicinal
M. oleifera Lam.	Asia (India)	subtropical regions worldwide		multipurpose
M. ovalifolia Dinter & Berger	Africa (Namibia, Angola)	Namibia, Angola		ornamental
M. peregrine (Forssk.) Fiori	Africa (Horn of Africa, Egypt)	Red sea, Arabia, northwest Africa	endangered	multipurpose
M. pygmaea Verdc.	Africa (Somalia)	Somalia		medicinal (few studies)
M. rivae Chiov.	Africa (Kenya and Ethiopia)	Kenya, Ethiopia	endangered	medicinal (few studies)
M. ruspoliana Engl.	Africa (Ethiopia)	Kenya, Ethiopia, Somalia		medicinal
M. stenopetala (Bak. f.) Cuf.	Africa (Kenya and Ethiopia)	Ethiopia, Kenya, Somalia	endangered	multipurpose

3. Morphological Characteristics

Although with only 13 species, the *Moringa* genus is one of the most phenotypically and morphologically diverse group of the angiosperms, ranging in size from tiny herbs to massive trees [1]. This great variability is probably due to the various ecological and environmental conditions in which the species are grown and naturalized [29]. *Moringa* species are mainly divided into three different classes according to their size and shape: the "slender trees" group includes *M. peregrina*, *M. concanensis* and *M. oleifera*; the "bottle trees" group comprises *M. drouhardii*, *M. hildebrandtii*, *M. stenopetala* and *M. ovalifolia*; and the "tuberous shrubs" group is composed of *M. arborea*, *M. borziana*, *M. rivae*, *M. ruspoliana*, *M. longituba* Engl. and *M. pygmaea* Verdc. [1].

M. oleifera (Table 2) is a relatively fast-growing tree which can achieve more than 10 m tall and is supplemented by a crown in the shape of an umbrella [14]. Its leaves are small and pale green in color; the flowers are fragrant, white or creamy white; immature pods are pendulous, green and tender, and turn dark and solid at maturity, the bark is whitish and corky [30]. Among the best studied species, accurate data can also be found for *M. peregrina* and *M. stenopetala*, the ones of most potential based on present knowledge. *M. peregrina* (Table 2) can reach 3 to 10 m height after only 10 months from seeds' planting. It has grayish-green bark; long leaves; bisexual yellowish white to pink, showy, fragrant flowers; the fruits are elongate capsules, with a beak, glabrous and slightly narrowed between the seeds [23,24]. *M. stenopetala* (Table 2) is a 6 to 12 m tall tree with a diameter of 60 cm and a smooth bark; its pods are elongated, reddish with grayish blooms and twisted when the fruit is fresh [23]; its seeds are triangular, containing an oval shaped whitish grey kernel [31].

Table 2. Some quantitative and qualitative characteristics of the three most known *Moringa* species [12,14,23,24,30–35].

Parameter	*M. oleifera*	*M. peregrina.*	*M. stenopetala*
Tree Height (m)	6–12	6–15	6–11
Trunk Diameter (cm)	20–45	170–190	60
Branch Length (cm)	30–75	250	25–67
Leaf Length (cm)	25–52	22–75	33–50
Leaflet Length (mm)	15–25	6–8	13–24
N° Leaflets/Leaf	9.7–13.3	7.0–10.3	
Flower Length (cm)	25–52	22–75	33–50
Pod Length (cm)	20–60	37	20–40
N° Seeds/Pods	12–18	11–14	9–11
Seed Length (cm)	0.9–1.6	1.2	2.5–3.5
N° of Wings	3	Not found	3
Flowers	Fragrant, yellowish-white	Fragrant, creamy-white	White
Fruit	Pod-like capsule	Elongate capsule	3-valve elongated capsule
Pod Color	Light green	Woody	Reddish
Pod Type	Simple dry dehiscent legume	Simple dry dehiscent legume	Simple dry dehiscent legume
Seed Shape	Ovate	Globus to ovate	Elliptical
Seed Color	Dark brown	Brown	Creamy
Wing Form	Papery	Not found	Papery
Wing Color	Whitish	Not found	Creamy

Several studies have been focused on the morphological and molecular differences among the most economically and commercially important species. El-Kheir et al. [12] investigated the morphological differences among three known *Moringa* species during the flowering season, namely *M. oleifera*, *M. peregrina* and *M. stenopetala*, and reported a significant range of variation between *M. peregrina* and the two other species, which are nearly similar in respect to quantitative and qualitative parameters namely the leaf, leaflet, branch and pod (Table 2). Pod types were similar in the three species despite their different color and seeds shape but the leaves' characteristics are sufficient to distinguish these two species: *M. oleifera* has larger tripinnate leaves while *M. peregrina* is characterized with bipinnate and smaller leaves [32]. Despite the reduced information on *M. concanensis* to enable its parallel comparison in Table 2, this species is smaller is height and distinguishable by its flowers with yellow petals with red or pink veins, and 3 angles white or pale yellow seeds [33].

All *Moringa* trees bear long pods (fruits) in variable numbers, containing up to 20 seeds each [11]. The number of pods per *M. oleifera* tree differs between accessions, ranging from 10 to 62, with different seed weights (between 25.5 g and 37.3 g for 100 seeds) but with reduced productivity over years [16,34]. *M. oleifera* tree produces more flowers per tree than *M. peregrina* and, therefore, sets higher number of pods and seeds per tree and in a more consistent and homogeneous way with plant maturity [35]. On the other hand, *M. peregrina* plant produces bigger seeds and appears to be less vulnerable to diseases than *M. oleifera* [36]. However, effective seed productivity is dependent not only upon the species/varieties, but also on cultivation techniques, soil and climate, as discussed below.

4. Cultivation and Climatic Requirements

M. oleifera is the unique species for which cultivation practices have been developed and reported in the literature [27,37]. Cultivation and propagation information on the other *Moringa* species are very restricted [38]. Therefore, in the absence of cultivation practices of other species, and with the growing demands by local populations, wild-harvest and over-browsing is decimating natural tree resources [27].

Moringa is widely known as the "Never Die" plant because of its large-scale adaptability to climate, soil and other environmental variations [39]. *M. oleifera* grows in almost all types of soils, except stiff, heavy clays, and it does not tolerate stagnant water or frequent flooding [38]. It grows well in sandy or loamy soils with a slightly acidic to highly alkaline pH, a rainfall range of 250–3000 mm and a temperature range of 25–35 °C [40]. Soil compositions was found to have no significant influence on the growth character of *M. oleifera* including the number of the leaves, stem diameter and plant height [41], although it affects seed weight [42].

Direct seeding is the most adopted method because of its high germination rate and formation of deep, stout taproot with a wide-spreading system of thick, tuberous lateral roots [33]. The percentage of *M. oleifera* seeds' germination is generally high, ranging from 60% to 100% [35]. Steinitz et al. [27], while examining the possibility of initiating micro-cloning in vitro of seedlings, found comparable germination rate for *M. oleifera*, *M. stenopetala*, and *M. peregrine*, of 77%, 72% and 69%, respectively. Cultivation by cuttings and transplantation are also used, but the plants do not develop taproots, making them more sensitive to drought and wind. Still, propagation by cuttings seems to be preferred by some farmers, since it promises a quick flowering and fruiting rates, and gives the best quality fruits [4,22]. Still, transplanting young plants requires utmost care as the tap roots are tender [33,43].

Cultivation methods should be also adapted to the major crop purpose, for seed or leaf production [44]. Seeds production requires a low density plantation (2.5 × 2.5 m or 3 × 3 m), while for leaf production it can vary from intensive (spacing from 10 × 10 cm to 20 × 20 cm), semi-intensive (spacing 50 × 50 cm), or integrated into an agroforestry system (spacing distance of 2–4 m) [45,46]. Intercropping with other staple food crops, like cassava, maize and sorghum, is very frequent in south Ethiopia and Kenya: *Moringa* leaves shed on the soil serve as green manure to increase soil fertility and to maximize crop yield [46]. Pruning increases branching and vegetative growth, being adequate to maximize leaf production, but the number of pods per plant decreases, despite showing no significant effect on seed weight [45].

Moringa seeds are usually sown during the rainy season and can germinate and grow without any irrigation. Still, for commercial purposes, *Moringa* seedlings are usually watered twice a day during three months, and irrigation through a drip system is recommended, in order to maintain leaf and seed production during the dry season [2,46]. Also, watering regimes had a significant effect on some growth parameters; the plants watered twice a day gave higher number of leaves and increased seeds weight and oil yield [42]. Ferreira da Costa et al. [47] investigated the cultivation of *M. oleifera* under low temperature conditions and observed a slow initial growth rate (in autumn/winter season), with high mortality. Accordingly, extreme frost or freeze conditions are not recommended for *Moringa* cultivation [19,47].

Plantations of *M. peregrina* have also been assessed as quite promising, with reasonably rapid and an easy cultivation [48]. The juvenility of *M. peregrina* trees was significantly extended compared to *M. oleifera*, with trees blooming twice a year, during summer and autumn, and with a bloom level of individual trees significantly more uniform with years of cultivation. Summer bloom of *M. peregrina* produced mature pods during autumn of the same year while autumn bloom produces a significantly lower number of pods that remained immature throughout the winter and matured during the spring of the following year. However, the average temperature increase in the last decades is causing several climate alterations, as in the Sinai Peninsula, where extended droughts periods, followed by extreme rainfalls, concentrate all the precipitation over only a few days. This is affecting particularly *M. peregrina* in this region, with a population decline of over 15% in from 2009 to 2015 [25], sustaining its susceptibility to harsh climates and the need to give attention to this species.

Cultivation of adequate *Moringa* species can contribute to minimize desertification under changing climatic conditions and improve the environmental condition of arid countries [12,19], in addition to its inspiring ability to sequester the level of atmospheric carbon dioxide, 20 times higher than that of general vegetation [49]. Therefore, the encouragement of its planting and development is suitable and beneficial from an environmental point of view, to combat desertification and climate changes mitigation in arid and semi-arid areas. Nevertheless, the lack of awareness in regards to this crop made its development for commercial purposes restricted and uncommon. India is the sole country where *Moringa* is developed as an export crop [19,50]. For commercial purposes, large-scale and semi-intensive plantations of *Moringa* are advised and widely pursued [43] but smallholder commercial production areas (ranging from 16 to 1200 ha) are also adapted [45].

5. Pests and Diseases

Generally, *Moringa* is usually resistant to most serious pathogenic pests and diseases in its native or introduced forms [19,51], without suffering greatly from insect attacks or diseases [45]. However, some exceptions may occur under certain practices and climatic conditions, especially under new environments as it faces new ecological interactions. Over the last few years, pests, diseases and parasitic plants affecting *Moringa* crops have been the keen target of scientific researchers in the field, partly to maintain the survey of plantations and the high yields production of the tree parts (leaves, pods, seeds, etc.) and to prevent consumers' health hazards [46,51].

Insect pests associated with *M. oleifera* can be categorized as defoliators, sap feeders, and bark, pod and seed borers, together with some non-insect pests [52,53]. Insect larva (e.g., *Noordablitealis*, *Eupterote mollifera*, *Euproctis pasteopa* [53], *Ulopeza phaeothoracica* [54]) mostly fed on the leaves, causing reduced leaf biomass production and damaged leaves are improper for human consumption. Seeds, when punctured by larva, became unviable for seedling and other uses. Mridha and Barakah (2015) [55] reported several pathogenic fungi in pods sold in Saudi Arabian markets. Parasitic plants growing on *M. oleifera* (e.g., Mistletoe *Phoradendron quadrangulare* (Viscaceae) in Mexico [56], *Dendrophthoe falcata* [57]) were also listed as a problem by farmers [46,56].

M. stenopetala seems to be more resistant to insect pests than the other family species [31]. Nevertheless, it is vulnerable to a caterpillar called seexxe [58]. On the same line, Vaknin and Mishal [36] reported *M. oleifera* trees to be the most susceptible to a fungal disease attacking specifically their root system, while all *M. peregrina* trees remained unaffected. Moreover, non-insect pests like spider mites are reported to infect *M. rivae*, *M. concanensis* and *M. oleifera* leaves [53,59], while *M. peregrina* and *M. borziana* have not shown any mites troubles [53], demonstrating that some *Moringa* species are more exposed than others to pests and diseases attacks. Although pests and diseases are not a major warning for *Moringa* cultivation, some measures and practices should be followed to avoid any economic losses, in accordance to the problem faced.

6. Seed Oil Content and Composition

Seed weight and kernel percentage are highly variable between species. Table 3 resumes published data, showing that *M. oleifera* and *M. concanensis* have the highest kernel yield per seed, but the latter has very small seeds. On the other hand, *M. drouhardii* and *M. hildebrandtii* have seeds almost tenfold heavier than *M. oleifera*, with a kernel proportion still superior to 50%.

Table 3. Seed characteristics of some *Moringa* species.

Species	Whole Seed Weight (g)	Kernel Proportion (%)	Oil Content (%)	References
M. concanensis	0.1	70–81	37.6–40.1	[33]
M. drouhardii	3.1	53.2	22.7	[38]
M. hildebrandtii	3.9	53.7	48.2	[38]
M. oleifera	0.3	75	28.5–59.8	[15,16,38,60]
M. peregrina	0.7	58.6	33.3–55.7	[11,48,60,61]
M. stenopetala	0.6–1.1	64.2–79.7	31.0–45.0	[31,38,62–64]

Generally, all *Moringa* species are rich in oil. However, variations in oil contents are perceived from literature (Table 3). Except for *M. drouhardii,* all species have interesting oil contents, particularly *M. oleifera* and *M. stenopetala*. These variations are related to factors influencing oil content such as cultivars, environmental and geographical conditions, as previously discussed.

Within *M. oleifera*, breeding efforts have been focused on the development or preservation of adapted varieties with high yields of edible and fleshy green fruits (pods), due to their nutritional potential, and also high seed oil yield, but most reports are within the 30% to 40% range (Table 4). For effective yield, however, field productivity has also to be taken into account, particularly the number of seeds per hectare, strongly associated with cultivation practices. All combined, the early *Moringa* variety Periyakalum-1 (PKM-1) from India has an interesting productivity per tree, higher than others from African origin, and consistent between geographical zones, being interesting for the development of improved *M. oleifera* varieties adapted to sub-tropical environments [15,16].

Table 4. Some *M. oleifera* varieties cultivated worldwide and reported oil yields.

Variety Name	Origin/Cultivation	Seed Oil Content (%)	References
Jaffna	India	39	[65,66]
Mbololo	Kenya	35.7	[67]
Periyakalum-1 (PKM-1)	India/Argentina, South America	33.9–40.8	[15,16,68]
Unamed African variety	Argentina	33.3–40.7	[15]
Unnamed	Pakistan	30.4–40.9	[41,69,70]
Unnamed	Nigeria	33–37	[71,72]
Unnamed	Congo-Brazaville	39.3–40.0	[73,74]
Unnamed (wild)	Malawi	41.4	[75]
Unnamed	Malaysia	31	[76]
Unnamed	Bangladesh	37.5–40.2	[77]
Unnamed	Brazil	39.0	[8]
Unnamed	Algeria	27.0–37.4	[18]
Supergenius	Cuba	31.6	[78]

Vaknin and Mishal. [36] proposed the development of *M. oleifera* × *M. peregrina* interspecies hybrids to ensure new efficient *Moringa* genotypes producing elevated fruits yields, as in *M. oleifera*, and bigger seeds yielding higher levels oil and less affected by diseases, as in *M. peregrina*.

As regards *Moringa* oil composition in fatty acids (Table 5), a clear dominance of mono-unsaturated fatty acids is highlighted, mainly composed by oleic, palmitoleic and eicosenoic acids. Saturated fatty acids are reduced, with palmitic, arachidic and behenic acids being the most representative ones, and only traces of polyunsaturated fatty acids [37,48,60–63,78]. In *M. oleifera* seed oil, oleic acid ranged from 66.5% to 81.7%, in *M. peregrina* from 71.1% to 77.8% and in *M. stenopetala* is within the 63% to 76% range (Table 5), highly similar. *Moringa* species are characterized by a high levels of behenic acids, with *M. oleifera* being the richest species (2.9–8.13%) against 2.7–7.8% in *M. peregrina* and 5.6–6.1% in *M. stenopetala* [36,60,63,79]. These high behenic acid amounts are responsible for *M. oleifera* generic name "Ben-oil tree" [36]. *Moringa* oils have usually low free fatty acid content (2%), making neutralization unnecessary. However, due to the presence of high amounts of phospholipids there is usually a need for degumming [61,79].

Table 5. Seed oil main components of the most known *Moringa* species [11,18,36,38,48,60–63,67,70,76,80–83].

Parameter (g/100 g)	*M. oleifera*	*M. peregrina*	*M. stenopetala*	*M. concanensis*
Palmitic Acid	5.3–10.5	5.4–12.4	6.0–6.2	9.7–11.0
Palmitoleic Acid	0.4–5.7	0.5–3.7	1.0–1.3	0.0–2.4
Stearic Acid	2.9–11.9	3.5–7.0	4.0–7.1	3.6
Oleic Acid	66.5–81.7	65.4–80.0	63.0–76.4	67.3–83.8
Linoleic Acid	0.3–1.0	0.3–0.7	0.0–0.7	0.8–1.8
Linolenic Acid	0.01–0.2	0.01–0.2	0.1–0.2	
Arachidic Acid	1.7–5.5	2.1–4.4	2.3–3.8	3.3–3.6
Eicosenoic Acid	0.1–3.2	0.1–2.4	0.8–2.0	1.7–1.8
Behenic Acid	2.9–8.1	2.4–7.8	5.3–6.1	7.0–7.6
Erucic Acid	0.02–0.2	0.01–0.1	0.6	
Tetracosanoic Acid	0.4–1.8	0.5–1.5		
Hexacosanoic Acid	0.0–1.2		1.4–1.6	
Sterols (g/100 g oil)	0.25–0.56	0.21	0.10–0.58	
Vitamin E (mg/100 g)	9.0–28.7	20.0–26.9	20.2–22.4	11.5
Oxidative Stability (h, at 110 °C)	8–60	8–30	12–36	9–11

From a health point of view, the oil is also rich is phytosterols, consistently between 0.2 and 0.6 g/100 g oil, being rich in β-sitosterol, stigmasterol, campesterol and Δ5-avenalsterol [71]. The vitamin E amounts are variable, probably depending on extractive conditions and preservation of the oil, but are consistently dominated by α-tocopherol, relevant for human health (Table 5). Altogether, this composition is responsible for its high resistance to oxidation (Table 5), described as being higher than that of olive oil [64]. The potential nutritional quality of *M. oleifera* oil was further evaluated on both crude and degummed oil, on 28-day to 49-day feeding experiments with Fisher rats, using soybean, corn and olive oils as references [84,85]. Results showed similar food efficiency with other oils, with no differences between crude and degummed oil, and without visible alteration of with adequate biological quality for both crude and degummed oils.

7. Oil Extraction and Applications

The amounts of seed oil reported in the literature, as reviewed above (Tables 3 and 4), are quantified under laboratory conditions, making use of organic solvents. Therefore, they give a measure of the maximum oil potential but not the true yield under field extractive conditions. There are currently several options for the industrial extraction of oil from *Moringa* seeds. Similar to other vegetable oils, conventional solvent extraction with hexane or petroleum ether is the classical approach [64,79], recovering around 90% of the lipids. Several attempts to decrease its environmental impact, using greener solvents, as ethanol [85], or supercritical fluids [86,87] are being reported. Extraction efficiency can also be enhanced with the combined use of ultrasound or microwave treatments, with 95% extraction efficiently in the latter [88]. All these approaches have been implemented mostly in *M. oleifera* seeds. No data on other methods than organic solvent extraction under laboratory conditions were found for other *Moringa* species, but their effectiveness is not expected to be highly variable.

Mechanical pressing has been classically used by local producers. However, these techniques have gained high importance in modern vegetable oil industry, imposed by their natural richness in bioactive compounds, increasingly pursued by consumers, and lower environmental impact. However, the yields under cold extraction are usually low, corresponding to about 60% of the extractive efficiency obtained with hexane [67,76]. Several parameters can be optimized to maximize recovery, including the seeds' size, moisture content, applied pressure, and temperature [89]. Aqueous enzymatic extraction has also been approached with positive outcomes, with up to 70% oil recovery [90,91], with easier phase separation efficiency when kernels are previously submitted to high pressure treatments, an increasingly common technique in the food industry [92]. One report on cold extraction of *M. stenopetala* seeds, variety Marigat, gave 35.7% of oil [64], which corresponds to an efficiency superior to 79%.

Seed remains after oil extraction have also been tentatively valorized using diverse approaches, particularly for water purification, including industrial wastewaters [93]. Its richness in protein, superior to 50% on a dry basis, makes it a highly potential source of protein for food purposes, similarly to soybean, providing that adequate nutritional studies are performed [94].

For food purposes, the universe of applications of *Moringa* oil is huge, due both to its monounsaturated nature, vigorously pursued presently due to its health effects, and the high stability toward oxidation. Altogether, *Moringa* oil has a high stability under frying conditions, even superior to that of similar mono-unsatured oils providing that it is refined to eliminate saponins [95]. When used in blends for frying, it also delayed the degradation of the oil, with economic impacts for users and health benefits for consumers [96,97]. Crude oils can be used for other applications than frying, being naturally enriched in bioactive compounds, with increased stability toward oxidation than refined ones. This will be reflected in a high shelf life time of the oil, when used as is or when used as an oil source in processed foods, as cookies [5]. Additionally, the melting properties of *Moringa* oil are also indicated as being highly interesting for the industry of spread products and margarines, as a healthy alternative to partially hydrogenated fats [5]. Also, *Moringa* oil can be used in blends, to enhance the oxidative stability of commercial oils or margarines. A 50% blend with butter results in a functional spread with increased stability and lower cholesterol content, and a highly interesting melting temperature of 35.5 °C [7]. Fractionation, into high oleic and stearin fractions, was also tested by dry crystallization, with the elevated content of behenic acid (C22:0) being described as favorable for the crystallization process [7]. Martins et al. [83] have also optimized a process of sterol concentration by distillation with economic feasibility.

The biodiesel industry can also look into this oil with high expectations. The recent attention into biodiesel production has put several crops under a huge stress with an urgent need to find sustainable alternatives. *Moringa* species, due to their ease of production, high oil yields and increased oil stability toward oxidation, represent interesting alternatives, with effective research already demonstrating the effectiveness of *M. oleifera*, *M. stenopetala* and *M. peregrina* [8,48,98]. The low free fatty acid content, high saponification value and increased stability has motivated several researchers to explore the optimization of oil extraction and methylation for biodiesel production. The quality of biodiesel prepared from *Moringa* oil is of superior quality than other oil sources, with increased stability and octane number [7].

8. Conclusions

The *Moringa* genus has a great biodiversity reserve that should be better explored, particularly in sub-tropical countries. Current knowledge has demonstrated that the efforts applied to *M. oleifera* have proven its potential as a multipurpose plant, particularly as a profitable source of vegetable oil for food and industrial purposes. There have been recent efforts to find efficient methods to optimize production yields (select adapted varieties, appropriate cultivating methods, spacing areas, fertilizers and irrigating systems) and oil extraction (classical and emergent technologies). However, other *Moringa* species present characteristics that point to similar abilities, providing that they receive equal attention by cultivators, researchers and financial institutions in general. In particular, *M. stenopetala* has an interesting adaptation to severe drought, of potential interest in a climate change scenario. The same applies to *M. peregrina*, showing great resistance to pests and diseases. Knowing that field studies take a huge time to accomplish sustained conclusions, even if supported by the knowledge already assembled from *M. oleifera* studies, there is an urgent need to increase attention about these species. In the search for alternative oil sources, particularly those rich in monounsaturated fatty acids, *Moringa* species have valuable promise in the years to come.

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