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STATUS AND UTILISATION OF *Moringa oleifera* Lam: A REVIEW

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ABSTRACT

Moringa oleifera (Moringaceae) is a medium-size agroforestry tree that originated from south Asia, but has become naturalised in many countries globally. *Moringa oleifera* has gained importance due to its multipurpose uses and good adaptability to both humid and dry climates. Almost all parts of the plant are used. The species is considered as a neglected and underutilised as its potential is still not well economically known and valued. This review presents the status and factors responsible for underutilisation of this, otherwise important crop as a basis for formulation of viable development strategies of knowledge on taxonomy, distribution, diverse utilisations, nutritional value, socioeconomic importance, morphological and genetic diversity, domestication, propagation and management of *M. oleifera*. Knowledge gaps, and research and development avenues are suggested and discussed for improved valorisation. To that purpose, articles were searched in Google Scholar, Web of Science and BioMed Central database with relevant keywords on *M. oleifera*. All the articles found, including reviews and peer-reviewed articles were critically read and analysed for inclusion in this review. Findings revealed that the species is one of the most studied and used species with various uses stretching from food and medicinal uses to water purification, biopesticide and production of biodiesel. Findings also highlight high morphological and genetic diversity of the species, which may become a resource for the conservation and the selection of germplasm. However, many aspects of the species are still waiting for further research.

Key Words: Domestication, economy, genetic resources, *Moringa oleifera*, nutrition value

RESUME

Moringa oleifera (Moringaceae) est un arbre de taille moyenne originaire du sud de l'Asie, mais naturalisé dans de nombreux pays d'Afrique, d'Asie, d'Amérique et d'Australie. *M. oleifera* jouit d'une grande importance en raison de ses multiples usages et de sa bonne adaptabilité aux climats humides et secs. Les feuilles du Moringa sont parmi les légumes à feuilles les plus promus pour assurer la sécurité alimentaire et nutritionnelle des mères et des nourrissons dans les pays en développement. Presque toutes les parties de la plante sont utilisées en médecine. Jusqu'à présent, l'espèce est considérée comme négligée et sous-utilisée car son potentiel n'est toujours pas bien valorisé. Cet article résume l'état actuel des connaissances sur la taxonomie, la distribution, les utilisations diverses, la valeur nutritionnelle, l'importance socioéconomique, la diversité morphologique et génétique, la domestication, la propagation et la gestion de *M. oleifera*. Les gaps en termes de connaissances sur l'espèce ont

été identifiées et des axes de recherche-développement ont été proposés et discutés pour améliorer sa valorisation. A cet effet, des articles ont été recherchés dans les bases de données Google Scholar, Web of Science et BioMed Central avec des mots-clés pertinents sur l'espèce. Tous les articles trouvés, y compris les revues et les articles évalués, ont été lus et analysés de manière critique pour leur inclusion dans cet article. Les résultats ont révélé que le Moringa est l'une des espèces les plus étudiées et utilisées au monde avec de multiples usages allant de l'alimentation et la médecine à la purification de l'eau, au biopesticide and à la production de biodiesel. Les résultats ont également révélé une grande variabilité morphologique et génétique de l'espèce, qui peut être une ressource pour la conservation et l'amélioration génétique de l'espèce. Cependant, beaucoup d'autres aspects de l'espèce nécessitent encore des investigations.

Mots Clés: Domestication, économie, ressources génétiques, *Moringa oleifera*, valeur nutritionnelle

INTRODUCTION

Moringa oleifera Lam. is the most widely cultivated species of the tropical flowering plant family Moringaceae containing thirteen diverse species (Shahzad *et al.*, 2013). *Moringa oleifera* is indigenous to south Asia, where it grows in the Himalayan foothills from North-Eastern Pakistan to North-Western Bengal, India (Sharma *et al.*, 2011). The species was introduced and became naturalised in other parts of the world including East and West Africa (Paliwal *et al.*, 2011). It has a great potential to serve as a high-value food crop, medicinal products, as well as fodder for animals, particularly in developing countries (Shahzad *et al.*, 2013).

The key uses of Moringa include human nutrition (leaves, seeds, flowers), alley cropping (biomass production for biodiesel and fertilising), animal forage (leaves and treated seepod-cake), biogas (from leaves), domestic cleaning agent (crushed leaves), blue dye (wood), fencing (living trees), fertiliser (seed-cake), foliar nutrient (juice expressed from the leaves), green manure (from leaves) (Fuglie, 1999; Adebayo *et al.*, 2011; Popoola and Obembe, 2013; Leone *et al.*, 2015). The species is also mainly used as gum (from tree trunks), honey and sugar cane juice-clarifier (powdered seeds), honey (flower nectar), medicine (all plant parts), ornamental plantings, biopesticide (soil incorporation of leaves to prevent seedling damping off), pulp (wood), rope (bark), tannin for tanning hides (bark and gum), water purification (powdered seeds) (Fuglie, 1999; Adebayo *et al.*, 2011; Popoola

and Obembe, 2013; Leone *et al.*, 2015). *Moringa oleifera* is the cheapest and credible alternative to not only providing good nutrition, but also to cure and prevent a lot of diseases (Paliwal *et al.*, 2011). Actually, the great interest in *M. oleifera* is related to its multipurpose uses and its ability to guarantee a good yield, where other crops cannot, in countries where people are mostly at risk of suffering from nutritional deficiencies (Leone *et al.*, 2015). Indeed, its cultivation is localised in developing countries where different parts of the plant are utilised.

Some international initiatives such as the Moringa Fund, Trees for Life, Global Moringa Network, Moringa initiative, and Moringa News have been established to improve the production, uses especially for human nutrition, and to develop the marketing process and value addition. In Benin, The Hunger Project (an international NGO) promotes the species during its campaign for health and nutrition improvement. In many countries (e.g. Ghana, Benin, etc.) there is a National Association of Moringa which aims to organise people, including producers, consumers, processors and researchers to speak on a common platform on issues of Moringa in order to influence policy on promotions, production, consumption and marketing of the products. There is increasing number of literature reviews on the species of which one of the best and recent is performed by Leone *et al.* (2015) and has addressed cultivation, genetic, ethnopharmacology, phytochemistry and pharmacology of the species.

Despite the great economic importance, *M. oleifera* is still not well exploited and hence considered as underutilised (Pandey *et al.*, 2011). The present review aims at understanding the status and factors responsible for underutilisation of Moringa in West Africa.

METHODOLOGY

This literature review was entirely based on online published materials ranging from the year 1970 to 2017. Google Scholar, Web of Science and BioMed Central were searched as literature database with subsections: taxonomy, conservation biology, biodiversity, breeding, ethnobotany, nutritional values, pharmacology, socioeconomy, cultivation practices and domestication. The search was conducted using *M. oleifera* as a keyword within the title of the article. Articles dealing with species other than *oleifera* were also included. All the searched articles, including reviews, and peer-reviewed articles presenting results of experimental studies, in animals or humans, on *M. oleifera* were analysed and vital outputs included in this review. The analysis focused on the current state of knowledge on taxonomy, distribution, diverse utilisations, nutritional value, socioeconomic

importance, morphological and genetic diversity, domestication, propagation and management of the species. Of the 188 articles found, 85 have been considered for this review.

TAXONOMY AND DISTRIBUTION

Moringa oleifera belongs to the family Moringaceae, order Capparales, class Magnoliopsida and division Magnoliophyta. The family includes other 12 species of shrubs and trees (Verdcourt, 1985; Olson, 2002). The 13 species of the genus *Moringa* (Table 1) are indigenous to Arabia, Africa and Asia (Olson, 2002). Among all these species, *M. oleifera* (hereafter referred to as Moringa) has so far become the most used and studied (Leone *et al.*, 2015). *Moringa oleifera* was utilised by the ancient Romans, Greeks and Egyptians, and is now widely cultivated throughout the tropical and subtropical regions of the world (Fahey, 2005).

Moringa has been widely naturalised in other tropical regions of the world (Fig. 1). It has been reported from large parts of southern and eastern Asia (Verdcourt, 1985; Lu and Olson, 2001). It has been also widely naturalised in Africa mainly in sub-Saharan Africa (Verdcourt, 1985; GBIF, 2007). In

TABLE 1. Species of genus *Moringa* and their native countries/regions

Species	Native countries/regions
<i>Moringa arborea</i> Verdc.	Kenya
<i>Moringa rivae</i> Chiov.	Kenya and Ethiopia
<i>Moringa stenopetala</i> Cufod.	Kenya and Ethiopia
<i>Moringa borziana</i> Mattei,	Kenya and Somalia
<i>Moringa longituba</i> Engl.	Kenya and Somalia
<i>Moringa pygmaea</i> Verdc.	Somalia
<i>Moringa ruspoliana</i> Engl.	Kenya, Ethiopia and Somalia
<i>Moringa ovalifolia</i> Dinter and A. Berger	Namibia and Angola
<i>Moringa drouhardii</i> Jum.,	Madagascar
<i>Moringa hildebrandtii</i> Engl.	Madagascar
<i>Moringa peregrina</i> Forssk.	Arabia, Red sea and Dead sea
<i>Moringa concanensis</i> Dalzell and A. Gibson	Sub-Himalayan tracts of India subcontinent
<i>Moringa oleifera</i> Lam.	Sub-Himalayan tracts of India subcontinent

Source: Olson, 2002

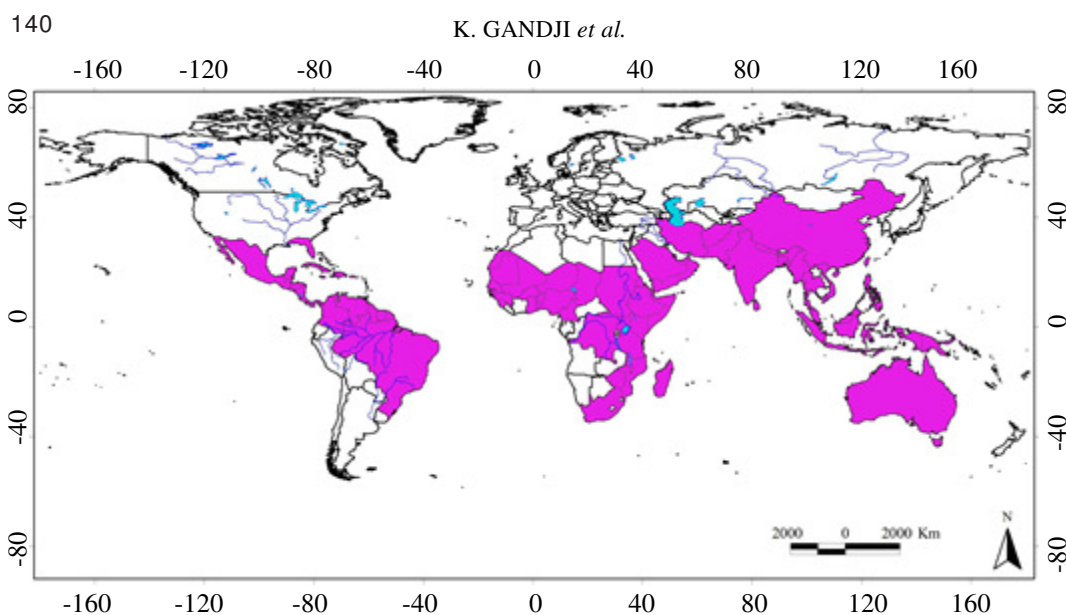


Figure 1. Countries where *Moringa oleifera* has been recorded as either native or naturalised. Adapted from Navie and Csurhes (2010).

tropical America, *Moringa* is naturalised in both north and South America (ICRAF, 2001; Liogier and Martorell, 2000). *Moringa* is also naturalised on several Pacific islands (Hancock and Henderson, 1988; ICRAF, 2001; PIER, 2007). With such naturalisation in so diverse regions, *Moringa* can be considered a highly plastic species.

With such naturalisation in so diverse regions, *Moringa* can be considered a highly plastic species that adapts well to hot, semi-arid regions with as little as 500 mm annual rainfall (Bosch, 2004; Ebert, 2014). Once it has been established, its strong antioxidant system helps coping with moderate saline conditions, experiencing only a mild reduction in its mineral quality (Nouman *et al.*, 2012). In general, *Moringa* grows best in lowland cultivation, but it also adapts to altitudes above 2000 m (Ebert, 2014). Slightly alkaline clay and sandy loam soils are considered the best media for *Moringa* due to their good drainage (Ramchandran *et al.*, 1980, Abdul, 2007, Nouman *et al.*, 2014). *Moringa* tolerates a wide range of soil types and pH (4.5-9) but prefers well-drained soils in the neutral pH range (Paliwal and Sharma, 2011).

SIGNIFICANCE OF MORINGA

Moringa oleifera is one of the world's mostly used plants (Palada and Chang, 2003). All parts of the species are traditionally used for different purposes, but leaves are generally the most used (Popoola and Obembe, 2013; Sivasankari *et al.*, 2014). Seven use categories of *M. oleifera*, namely medicine, food, fodder, fencing, firewood, coagulant and gum have been identified (Popoola and Obembe, 2013; Agoyi *et al.*, 2014; Sivasankari *et al.*, 2014). The species is mostly used as a traditional medicine and food (Popoola and Obembe, 2013; Agoyi *et al.*, 2014; Sivasankari *et al.*, 2014).

Food uses and nutritional value. Each part of the *Moringa* tree (fruits, seeds, leaves, flowers, bark and roots) is associated with the presence of at least one, or in most number of benefits (Zaku *et al.*, 2015). Leaves are rich in protein, mineral, beta-carotene and antioxidant compounds, which are often deficient among the diets of developing countries (Leone *et al.*, 2015). Through research, the *Moringa* parts were found to

contain many essential nutrients (Fahey, 2005; Kasolo *et al.*, 2010). Moringa leaves contain high levels of vitamin C, calcium and potassium, as well as protein (Table 2) (Zaku *et al.*, 2015). Due to the presence of several kinds of antioxidant compounds such as flavonoids, ascorbic acid, carotenoids, and phenolics, Moringa leaves are able to extend the shelf life of food containing fats (Dillard and German, 2000; Siddhuraju and Becker, 2003). In addition, Moringa was found to have a group of unique compounds containing sugar

and rhamnase, which are uncommon sugar modified glucosinolates (Fahey *et al.*, 2001; Fahey, 2005). These compounds were reported to demonstrate certain chemopreventive activity, by inducing apoptosis (Brunelli *et al.*, 2010). The species has a particularly high level of oleic acid (70%), making it a great moisturiser, as well as a potentially healthy source of fat in the diet (other vegetable oils normally contain only about 40% oleic acid). Moringa leaves are added to food preparations as integrators of the diet (Leone *et al.*, 2015). Moringa leaves are eaten as salad, vegetable soup for human nutrition (Popoola and Obembe, 2013) and as forage for animal feed (Nouman *et al.*, 2014). Seeds are roasted and eaten like groundnut (Popoola and Obembe, 2013). In India, Moringa leaves have been processed into an innovative drink named Zija (Ansari and Kumar, 2012). Moringa is also used and valorised through food fortification. For instance, in Nigeria, it is used to fortify food formulations of corn, soy and peanut (Shiriki *et al.*, 2015); and as food fortificant in amala (stiff dough), ogi (maize gruel), bread, biscuits, yoghurt, cheese and in making soups (Oyeyinka and Oyeyinka, 2016). However, validation works are needed to substantiate food fortification potential of the species. In addition, limited studies have assessed the shelf stability of the fortified samples (Oyeyinka and Oyeyinka, 2016).

Medicinal uses. Moringa is considered rich with several medicinal properties, as all the parts have been reportedly singly or with other plants for treating diverse illnesses and diseases (Fuglie, 1999; Pamok *et al.*, 2011). In traditional medicine, the leaves are used to treat ailments including malaria, typhoid fever, parasitic diseases, arthritis, swellings, cuts, diseases of the skin, genito-urinary ailments, hypertension and diabetes (Leone *et al.*, 2015). They are also used to elicit lactation and boost the immune system (to treat HIV/AIDS related symptoms) (Anwar *et al.*, 2007; Popoola and Obembe, 2013; Sivasankari *et al.*, 2014), as well as cardiac stimulants and contraceptive

TABLE 2. Chemical composition of dried leaf powder of Moringa per 100 g of edible portion of leaves

Nutritional value per 100 g	Values
Moisture (%)	7.5
Calories (Kcal)	205
Protein (g)	27.1
Fat (g)	2.3
Carbohydrate (g)	38.2
Fiber (g)	19.2
Trace minerals	
Calcium (mg)	2,003
Magnesium (mg)	368
Phosphorus (mg)	204
Potassium (mg)	1,324
Iron (mg)	28.2
Sodium (mg)	870
Vitamins	
Vitamin A-Beta Carotene (mg)	16.3
Vitamin B ₁ - thiamin (mg)	2.64
Vitamin B ₂ - riboflavin (mg)	20.5
Vitamin B ₃ - nicotinic acid (mg)	8.2
Vitamin C ascorbic acid (mg)	17.3
Vitamin E tocopherol acetate (mg)	113
Amino acids	
Arginine (g 16 ⁻¹ g N)	1.33
Histidine (g 16 ⁻¹ gN)	0.61
Lysine (g 16 ⁻¹ gN)	1.32
Tryptophan (g 16 ⁻¹ gN)	0.43
Phenylalanine (g 16 ⁻¹ gN)	1.39
Methionine (g 16 ⁻¹ gN)	0.35
Threonine (g 16 ⁻¹ gN)	1.19
Leucine (g 16 ⁻¹ gN)	1.95
Isoleucine (g 16 ⁻¹ gN)	0.83
Valine (g 16 ⁻¹ gN)	1.06
Other constituents	
Oxalic acid (mg)	1.6

Source: Jahn (1996); Zaku *et al.* (2015)

remedy. For the treatment of these ailments, one can directly consume either raw and dried leaves, or the extract of an aqueous infusion (Leone *et al.*, 2015). The uses of the species leaves in the treatment of HIV infections and cancer have been reported by local people in Nigeria (Popoola and Obembe, 2013). There are few published works on these specific uses because of the lacking sufficient scientific based information.

Barks are boiled in water and soaked in alcohol to obtain decoction and extract, respectively, that can be used to treat stomach ailments (ease stomach pain, ulcer and aiding digestion), poor vision, joint pain, diabetes, anemia and hypertension (Abe and Ohtani, 2013; Popoola and Obembe, 2013), toothache, hemorrhoids, uterine disorder (Popoola and Obembe, 2013; Yabesh *et al.*, 2014). In a well-known practice to local people in Nigeria, Moringa seeds are used to sediment impurities of water (Popoola and Obembe, 2013). Roots are soaked in water or alcohol and boiled to obtain decoction and extract as remedies for toothache, as anthelmintic and antiparalytic (Anwar *et al.*, 2007; Popoola and Obembe, 2013; Sivasankari *et al.*, 2014) drugs and as sex stimulant. Finally, flowers are used to produce aphrodisiac substances and to treat inflammations, muscle diseases, hysteria, tumours and enlargement of the spleen (Anwar *et al.*, 2007; Yabesh *et al.*, 2014). The activities against the above diseases were confirmed in several screening tests and ethnopharmacology studies (Pamok *et al.*, 2011; Abe and Ohtani, 2013; Popoola and Obembe, 2013; Sivasankari *et al.*, 2014; Yabesh *et al.*, 2014).

Other uses. Besides being consumed by humans for food and health purposes, Moringa is used as animal fodder (Sanchez *et al.*, 2006; Nouman *et al.*, 2013, 2014) and as a natural coagulant of turbid water (Suarez *et al.*, 2003). Actually, Moringa seed powder can be used for water purification, replacing dangerous and expensive chemicals such as aluminium sulfate

(Popoola and Obembe, 2013). The species is used as a natural plant growth enhancer because its leaves are rich in zeatin, a plant hormone, which belongs to the cytokinin group (Leone *et al.*, 2015). Leaf extracts can stimulate plant growth and increase crop yield. For instance, application of Moringa leaf extract at 2 weeks after emergence and at every 2 weeks thereafter, significantly increased growth performances of maize in terms of plant height, shoot length, fresh and dry weight of shoots, number of grains cob⁻¹, 100-grain weight, and grain weight plant⁻¹ (Biswas *et al.*, 2016).

Therefore, the species would be a very useful species for the improvement of food security.

The suitability of Moringa seed oil as biodiesel feed source has been proved, and oil could be used as pure biodiesel or petro-diesel mixture on engine (Da Silva *et al.*, 2010). Moringa oil has also excellent characteristics, making it a highly valued ingredient in a variety of applications, ranging from vegetable food oil to use in cosmetic products and other industrial applications such as lubricant for fine machinery (SFA, 2015).

There are lots of opportunities for Moringa production as the species has been observed to be well suited to all kinds of soils and wide range of environment, especially tolerant to poor soils of arid and semi-arid regions (Navie and Csurhes, 2010; Padulosi *et al.*, 2011). Besides its nutritional and medicinal value and multiple uses, Moringa improves livelihood security and crop diversification (Gadzirayi *et al.*, 2013), and is of considerable interest for future adaptation of agriculture to climate change (Padulosi *et al.*, 2011). In Niger, Tabbo and Amadou (2017) found that the introduction of *M. oleifera* into agricultural systems was among the most important adaptation strategies to climate change for farmers among rural households. Actually, the species can be used as soil improver as green manure and seed cake as fertiliser and also provides important ecosystems services (Mridha, 2015). These

ecosystems services includes reforestation, in alley cropping, erosion control, boundary, barrier and support (Mridha, 2015).

The anti-erosive potential of the species has demonstrated by Avakoudjo *et al.* (2013); while Noulékoun *et al.* (2017) have demonstrated its suitability for the afforestation of degraded croplands. Moreover, the rate of Moringa tree to absorb carbon dioxide (CO₂) is fifty times (50x) higher when compared to the Japanese cedar tree; and also twenty times (20x) higher than that of general vegetation (Villafuerte *et al.*, 2009; Hernandez *et al.*, 2015; Potadar and Patil, 2017). As such, integration of the species in agroforestry systems will mitigate the impacts of climate change (Kumar *et al.*, 2017).

As the nutritional values of *M. oleifera* significantly contribute to reduced food insecurity, the maintenance of these value under climatic change become a great challenge which need to be fixed. Also, further studies are needed to assess the carbon sequestration potential of the species in many geographical zones and under different ecological conditions in the context of climate change.

Socioeconomic importance of Moringa. The relative ease with which Moringa is propagated through both non-clonal and clonal means, and its low demand for soil nutrients and water makes its production and management easy (Paliwal *et al.*, 2011). Introduction of this plant into a farm which has a diverse environment can be beneficial for both the owner of the farm and the surrounding ecosystems (Fuglie, 1999). The great socioeconomic importance of Moringa has been demonstrated by Torimiro *et al.* (2009), Madi *et al.* (2012), Animashaun and Toye (2013), and Azeez *et al.* (2013). For instance, in western Nigeria, the analysis of the profitability of a leaf-based Moringa production indicated an average net profit of 59.81% per hectare and per year from the sale of leaves (Animashaun and Toye, 2013).

Otherwise, the majority (51.66%) of sellers-retailers believe that the sale of Moringa leaves is profitable and even 26.66% of them claim it is twice as profitable as other leafy vegetables in northern Cameroon (Madi *et al.*, 2012).

Currently, the international market for Moringa is not sufficiently developed to be qualified as a commodity on the global market; hence trade statistics for Moringa products are only available in an aggregated form (SFA, 2015). The global market for Moringa products is considered substantial, however, with current estimates of over US\$ 4 billion a year worldwide (CJP, 2014). While Moringa is used for a wide variety of purposes, two Moringa products in particular stand out in terms of their commercial potential: Moringa leaf powder and Moringa oil as an ingredient for cosmetic products. Over the past few years, an increasingly large variety of Moringa products has spread into many markets, and are now available on most health food websites and in many health stores worldwide (SFA, 2015). Moringa leaf powder can be sold simply or in containers or in plastic bags that prevent moisture absorption. Moringa leaves powder is also sold in the form of tea or mixed with chocolate.

The commercialisation of Moringa products is still very informal and makes it difficult to get reliable information of production volumes and prices (SFA, 2015). Therefore, to effectively exploit the existing market potential, commercialisation should become structured and formalised. In addition, there is need to develop value chains for the species. Actually, the value chain for Moringa product, if properly developed, offers considerable investment opportunities, and potential job creation, foreign exchange earnings and export diversification (Animashaun and Toye, 2013). However, growers need to be able to ensure compliance with international regulation and standards, be able to offer high quality and continuous supply.

MORPHOLOGICAL CHARACTERISTICS, GENETIC DIVERSITY AND DOMESTICATION

Morphological characteristics. The variation in morphological traits of Moringa has been investigated worldwide through characterisation of morphological traits (Table 3). The great variability is probably due to various ecological conditions in which the species is grown and the various management practices. Actually, the significant variation in morphological trait found in Southern Benin may be due to ecological conditions, time of leaf harvesting, harvesting frequency and plant density (Agoyi *et al.*, 2015). However, to what extent variations in ecological conditions and farmers' management practices influence morphological traits of the plant parts of *M. oleifera*, have received little attention. Yet, this has implications for genetic improvement and conservation, and development of domestication strategies. Actually, unequal traditional knowledge, unequal valuation, and ethnic differentiation are strong sources of genetic diversity that can help determine diversities available in the morphology, chemical components, taste, anatomy and other characters of the species (Popoola and Obembe, 2013).

Genetic diversity. Cytological studies revealed that Moringa has 2c genome size of 1.2 pg (Ohri and Kumar, 1986), and it is a true diploid, with $2n = 28$ (Ramachandran *et al.*, 1980). Moringa is a cross-pollinated tree; hence high heterogeneity in form and yield is expected (Leone *et al.*, 2015). Through investigations on variability in the species variability was reported in flowering time (from annual type to perennial type) (Raja *et al.*, 2013), tree nature (from deciduous to evergreen), tree shape (from semi spread to upright), and resistance to hairy caterpillar (Mgendi *et al.*, 2011; Raja *et al.*, 2013). Although Moringa shows diversification in many characters and high morphological variability (Ganesan *et al.*, 2014; Popoola *et*

TABLE 3. Some morphological traits recorded for diverse populations of *M. oleifera* and physical properties of pods and seeds

Morphological traits	Ferrao and Ferrao (1970)	Proyecto Biomasa (1996)	Popoola <i>et al.</i> (2014)	Ganesan <i>et al.</i> (2014)	Agoyi <i>et al.</i> (2015)
Average tree height (m)	-	-	-	4.24	5.22
Average tree diameter (cm)	-	-	-	43.31	7.18
Average pod length (cm)	-	-	38	57.05	30.74
Average pod diameter/width (cm)	-	-	2.19	8.52	1.89
Average fresh pod weight (g)	-	-	-	110	72.87
Average dry pod weight (g)	7.60	7.95	7.24	-	-
Average number of seeds/pod	12	16	11.98	20.17	-
Average number of locules/pod	-	-	12.9	-	-
Average seed weight (g)	0.299	0.302	0.32	-	-
Average weight of kernels/seed	0.212	0.225	-	-	-
Percent weight of kernel in relation to entire seed	72.5	74.5	-	-	-
Percent weight of hull in relation to entire seed	27.5	25.5	-	-	-

al., 2014; Agoyi *et al.*, 2015), which may become a resource for its improvement, the major factors that limit productivity are the absence of elite varieties adapted to local conditions and the use of seeds obtained through open pollination from plants in the planted area (Leone *et al.*, 2015). *Moringa oleifera* being indigenous to India, many ecotypes exist with various morphological traits. Several varieties have been developed and are available in India. For instance, to improve pod production, two varieties (PKM-1; PKM2) have been developed at the Horti Nursery Networks, Tamil Nadu in India. Usually those varieties are grown as annual; after two harvests the tree is dragged out and new seedlings are planted (Saint Sauveur, 2001).

A recent morphological study of three hundreds genotypes belonging to twelve populations of *Moringa* in India, revealed that yellow, white and pinkish are the main colours of the species' flowers (Ganesan *et al.*, 2014). Many research centres focusing on *M. oleifera* improvement have been established across the world; namely AVDRC (Taiwan), rural development initiative (Zambia), Moringa Philippines foundation (Philippines) and Moringa community (Zambia). In spite of the great variability of *Moringa*, no institution has a germplasm bank or database with either cultivated or spontaneous accessions (Leone *et al.*, 2015). It is recommended that the divergence between genetic variability inherent to the species and the poor variability reflected in germplasm banks be fixed since it represents an obstacle for the progress of breeding programmes.

The genetic approach and its potential application in breeding programmes for *Moringa* are just at the infant stage (Leone *et al.*, 2015). Thus far, there is limited knowledge of available genetic diversity present in *Moringa* (Shahzad *et al.*, 2013). However, substantial variation in quantitatively inherited traits has been documented in natural populations of *Moringa* in India (Ramachandran *et al.*, 1980). Moreover, limited

studies have been conducted using DNA-based markers to identify and assess diversity among various genotypes of *M. oleifera* (Shahzad *et al.*, 2013). Muluvi *et al.* (1999) and Ulloa (2005) used amplified fragment length polymorphism (AFLPs) to investigate *M. oleifera* populations present in Kenya, revealing significant differences between regions and populations. Random amplified polymorphic DNA (RAPD) were used to investigate cultivated and non-cultivated populations of *M. oleifera* in Tanzania (Mgendi *et al.*, 2010), different accessions in Nigeria (Abubakar *et al.*, 2011), accessions present in Brazil (Da Silva *et al.*, 2012), commercially grown varieties in India (Saini *et al.*, 2013), and new genotype developed in different countries (Thailand, USA, India and Malaysia, Tanzania, Taiwan) (Rufai *et al.*, 2013). These studies provided evidences of a high level of genetic diversity in natural population compared to the cultivated ones (Leone *et al.*, 2015), concluding that conservation strategies should be adopted (Shahzad *et al.*, 2013).

Wu *et al.* (2010) have developed 20 microsatellite or simple sequence repeat (SSR) markers for *Moringa* that serve as useful markers for pursuing additional genetic diversity studies. The first successful estimates of genetic diversity and population structure of the species were obtained with Simple Sequence Repeat (SSR) in 2013 by Shahzad *et al.* (2013). These authors evaluated accessions collected in different locations of Pakistan and accessions from different countries (India, Tanzania, Senegal, Mozambique, Zimbabwe, Florida, Mexico, Haiti, and Belize) obtained from Educational Concerns for Hunger Organisation (ECHO). They found high genetic diversity in wild Pakistan accessions; whereas low genetic diversity in ECHO accessions. Later on investigation on twelve Indian populations, from northern and southern regions of India, was performed through simple sequence repeat (SSR) together with morphological markers (Ganesan *et al.*, 2014). In this study too, individuals from various geographical areas

were not significantly different genetically, while a large variability exist in Indian populations. More SSR were identified in 2014 thanks to expressed sequence tags (EST) examination involving several plant species (Haq *et al.*, 2014) and not utilised so far in Moringa genetic investigation (Leone *et al.*, 2015). Today, next generation sequencing (NGS) (Davey *et al.*, 2011) is an approachable tool to discovery genome-wide genetic markers. Thanks to NGS a saturated genetic map could be obtained within reasonable cost and time, in turn interesting characters could be identified and exploited in breeding programmes (Leone *et al.*, 2015). Although all the reported findings are valuables and essentials for the conservation, selection and collection of *M. oleifera* seeds, more scientific based information are needed in order to develop improved cultivation and management practices of the species.

Domestication trends. Analysis of diversity distribution pattern, utilisation based socio-economic study and dependence of population on local useful genetic resources throw light on folk domestication trends in regions with rich diversity (Arora, 1987; Pandey *et al.*, 2011). In areas of natural distribution of Moringa (the west and central Himalaya and the foothills and parts of central India), the species exhibits rich variability in fruit types in wild/semi-domesticated populations, with minimal recorded use of plant (Samant and Dhar, 1997; Tiwari *et al.*, 2010). This trend is obviously more observed in areas where the species have been naturalised. For instance, in Southern Benin, significant differences were observed in pods length and diameter; while the species is not widely used and leaves are the most plant part used (Agoyi *et al.*, 2015). Similar trends were recorded in India for the use of edible oil (Vishnu, 1981), vegetable and pickled fruits (Jain, 1981; Sawian *et al.*, 2007) and edible leaves, flowers, fruits (Bhargava, 1981). However, frequent cultivation and wider use of Moringa as vegetable crop and

as multipurpose species suggests a long history of domestication (Pandey *et al.*, 2011).

PROPAGATION, INITIAL GROWTH AND MANAGEMENT

The bisexual flowers of Moringa are highly cross-pollinated, and pollination is mainly facilitated by animals (i.e. the flowers are zoophilous). For example, bees (*Xylocopa* spp.) and sunbirds (*Nectarinia* spp.) have been observed to be active and reliable pollinators in many parts of the world (ICRAF, 2001). *Moringa oleifera* does not seem to require any specific pollinators, as it readily produces viable seeds. There is little information available regarding the dispersal mechanisms of *M. oleifera*; however, much can be determined from its seed morphology and the locations in which it tends to become naturalised (DuPuy, 1993; Navie and Csurhes, 2010; Okorochoa *et al.*, 2015). Although the seeds are relatively large, they are strongly winged. This may allow them to be spread short distances from the parent tree by wind (DuPuy, 1993; Navie and Csurhes, 2010; Okorochoa *et al.*, 2015).

Moringa oleifera is propagated in two main ways; by sowing and by cutting. The preference for a propagation mode varies among countries. Traditionally, in Sudan seeds are preferred; while vegetative propagation is common in India, Indonesia and in some areas of West Africa (Palada, 1996; Leone *et al.*, 2015). To lift the dormancy of the seeds, they are soaked in water for 12 hours of time. Seeds germinate within two weeks, at a maximum of 2 cm depth. When sowing is planned in nursery, the seedlings can be transplanted when they reach about 30 cm (3-6 weeks after germination) (Ojiako *et al.*, 2011). Under ideal storage conditions (3 °C, 5-8% moisture), the germination rate is approximately 80-90% (Leone *et al.* 2015). However, the viability decreases when seeds remain at ambient temperature and high relative humidity; their germination rate dropping to 7.5% after three months (Morton, 1991; Roloff *et al.*, 2009).

Cutting is preferred when seed availability is scarce and/or when labour is not a limiting factor (Leone *et al.*, 2015). Plants raised from seeds produce fruits of poorer quality (Ramachandran *et al.*, 1980). Animashaun (2013) argues that trees grown from seeds develop longer roots (an advantage for stabilisation and access to water) compared to those grown from cuttings that have much shorter roots. Since the tree vigorously re-sprouts after cutting, pruning or pollarding are usually practiced to enhance lateral branching and give the tree a bush shape in order to facilitate the harvest (Leone *et al.*, 2015). Nevertheless, there are no figures to support those practices.

For the intensive production of *M. oleifera* leaves, plantation can be designed with spacing ranging from 10 cm x 10 cm to 20 cm x 20 cm; harvest interval between 35 to 45 days; while irrigation and fertilisation are needed (Leone *et al.*, 2015). The semi-intensive production of leaves can be made with spacing of 50 cm x 100 cm, harvest interval between 50 to 60 days; while irrigation and fertilisation are suggested. Plantations for leaf production can also be integrated in agroforestry systems with spacing distance of 2-4 m between rows, harvest interval around 60 days, fertilisation and irrigation are not necessary (Leone *et al.*, 2015). Gadzirayi *et al.* (2013) recommended in Zimbabwe 20 cm x 20 cm as plant spacing and 60 and 75 days as harvest intervals according to provenances.

In Ghana, the optimum plant spacing is 5 cm x 15 cm with 35 to 40 days as optimum harvest intervals (Newton *et al.*, 2006). In Nicaragua, 20 cm x 20 cm and 75 days are optimum plant spacing and harvest intervals, respectively (Sanchez *et al.*, 2006). This wide range of cutting frequencies (40-75 days) is likely due to differences in the climatic conditions in which the species is grown (Nouman *et al.*, 2014).

Production decreases from intensive production to less dense spacing (agroforestry system), although a tremendous variability can

be observed for a given spatial distribution and the same cultivation management. Moringa leaf's production varies according to planting densities and cutting frequencies (Table 4).

Fruits, referred to as pods, ripen at about three months after flowering and must be harvested as soon as possible. A single tree can produce 300 to 400 fruits per year within three years of planting; while a mature tree can produce up to 1000 fruits per year (HDRA, 2002). As noticed for leaves, the production of seed is also highly variable. As each fruit contains approximately 20 seeds, a mature tree can therefore produce about 20 000 seeds per year (Navie and Csurhes, 2010).

A single seed weights on average is 0.3 g (Ayerza, 2011). Early flowering varieties produce pods in six months; while other varieties require more than one year (Leone *et al.*, 2015). After pruning, branches develop new pods within 6 months (Paliwal *et al.*, 2011). Regarding the cultivation systems, *M. oleifera* is cultivated around homesteads, or in association with other vegetables in home gardens, or in association with fruit trees in orchards (Gadzirayi *et al.*, 2013).

The species is resistant to most pests and diseases, but outbreaks may occur under certain conditions (Palada and Chang, 2003). For example, diplodia root rot may appear in waterlogged soils, causing severe wilting and death of plants (Palada and Chang, 2003). Mite populations can increase during dry and cool weather. These pests induce yellowing of leaves, but plants usually recover during warm weather. Other insect pests include termites, aphids, leaf miners, whiteflies, and caterpillars (Palada and Chang, 2003). In Zimbabwe, farmers experienced problems with sap sucking insects (red spider mite and aphids), leaf eating insects (caterpillars) and termites (Gadzirayi *et al.*, 2013). Chemical control of insect pests should be used only when severe infestations occur. Choose a pesticide that targets the specific pest causing the damage, and avoid pesticides that kill or inhibit the development of beneficial organisms (Palada

TABLE 4. Some *M. oleifera* leaf production on various planting densities and cutting frequencies

Fresh biomass (kg ha ⁻¹)	Dry biomass (kg ha ⁻¹)				References
	1 st year	2 nd year	1 st year	2 nd year	
Planting densities (plants ha ⁻¹)					
95,000	19,600	-	3,330	-	Foidl <i>et al.</i> (2001)
350,000	29,700	-	5,050	-	
900,000	52,600	-	8,940	-	
1,000,000	78,000	-	13,260	-	
4,000,000*	97,400	-	16,560	-	
16,000,000*	25,900	-	44,030	-	
250,000	80,200	41,100	17,600	7600	Sanchez <i>et al.</i> (2006)
500,000	79,100	46,200	16,900	8100	
750,000	88,000	36,100	18,900	6200	
Cutting frequency (days)					
45	71,400	26,700	13,500	4700	Sanchez <i>et al.</i> (2006)
60	75,300	39,400	15,200	6800	
75	100,700	54,700	24,700	10,400	

*: Test plots with higher planting densities

and Chang, 2003). They also recommended choosing pesticides that last only a few days. Many animals like cattle, sheep, pigs, and goats feed with Moringa seedlings, pods and leaves. It is recommended to protect Moringa seedlings from livestock by installing fence or by planting a hedge around the plot.

Gadzirayi *et al.* (2013) identified the following constraints in cultivating *M. oleifera*: lack of knowledge on efficient production practices, competition for land with other food crops, difficulty in the procurement of planting materials, shortage of water for irrigation during dry months, animal damage, low yield levels, theft, pests and diseases, and lack of markets. Regarding the lack of knowledge on efficient production practices, farmers lack efficient cultivation systems which make use of improved models. They have to abandon subsistence production to venture into monoculture of Moringa at very high tree densities on small pieces of land or they do it in various agroforestry patterns that give them better yields like in Niger and northern Nigeria (Gamatie, 2001; Saint Sauveur, 2001).

KNOWLEDGE GAPS AND RESEARCH AVENUES

The present review summarises the information available on the potential of *M. oleifera* in terms of cultivation, biodiversity and uses. However, many aspects of the species from the most convenient agricultural practices to its better use are still waiting for further research.

Utilisations. Due to the fact that the species is still neglected and underutilised, there is a true need to increase its level of use. This could be achieved not only through ethnobotanical assessment, food processing and nutrition work, but also through identification of factors which influence adoption of the species. The ethnobotanical assessment will highlight knowledge of local people on the uses of the species but also factors limiting its uses. The

food processing and nutritional will identify ways to improve traditional use for a better nutritional health. Investigations on the drivers of the species use will improve understanding of factors limiting its adoption and provide ways forward to promote the species.

Production. According to knowledge highlighted by this review, there is also a need to increase the level of cultivation of the species. This could be firstly made through identification of the factors influencing the species cultivation. Considering the cultivation challenges, cultivation systems need to be explored. The spacing in planting *M. oleifera* trees must be designed to facilitate the relevant harvest and the management practices. Since literature reports about the good management practices of *M. oleifera* are scant, more practical trials are needed. For instance, there is not a consensus about the proper sowing densities and harvesting frequencies. Further studies have to assess optimum spacing and harvest intervals that comply with the different climates and production systems. Information about the production in other countries than India is scarce, so the production has to be estimated through experimentations.

So far, few studies have focused on Moringa cultivation system and this may explain why some important cultivation systems like fencing and agroforestry systems were not found in literature as cultivation system. Investigating the cultivation systems of Moringa are needed to understand how the species is cultivated, the species performance according to cultivation systems and factors determining the choice of a cultivation system. This way, constraints as gender associated with the species adoption at local level will be highlighted.

Breeding. Collection and characterisation of world accessions, both cultivated and natural, have to be prioritised in order to obtain a true understanding of the genetic diversity and structure of *M. oleifera*. This will help to have

a reliable access to information about genetic materials to develop better Moringa varieties and technologies for farming practices. For the accessions evaluation, phenotypic characterisation is a priority to identify important plant traits. Studies are needed on breeding biology, genetic improvement and hybridisation, especially with the close relatives, identifying ecotypes for industrial value with higher percentage of seed oil, proteins, medicine and wide adaptability to agro-climate.

A collaborative network among National and International Research Centre, NGOs, farmers that already work on *M. oleifera* have to be set. Policy makers, research and extension institutions should formulate programs focusing on generating awareness among local communities and farmers.

Ecological services. The changing temperatures and wind patterns associated with climate change can affect precipitation factors, giving the species the ability to grow taller in some areas. Therefore, investigations on the potential impacts of climate change on the species growth are needed to efficiently design cultivation practices. Further studies are also needed to assess the carbon sequestration potential of the species under different ecological conditions taking into account the global warming.

Socio-economics and value addition. Temperature stress can affect the chemical composition of the species and therefore the nutritional value affecting negatively food security. As such, assessing the effects of temperature stress on the chemical composition of its leaves would allow to understand how climate change can affect its nutritional value. An analysis of sociocultural perceptions on the species would also provide further understanding of the behaviour of local people regarding the species. Considering the very important market value of *M. oleifera*, investigations are needed to assess the

profitability of its marketing and to establish the value chain.

CONCLUSION

Moringa oleifera is one of the most studied and used species with various use categories stretching from food and medicinal uses to water purification, biopesticide and production of biodiesel. The species shows discrepancies in many features and high morphological and genetic diversity, which may become a resource for the conservation and the selection of germplasm. There is tendency of researches to associate phenotypical and molecular data in order to identify genes needed within the contest of breeding. Next generation sequencing (NGS) could be an approachable tool to discover genome-wide genetic markers and building saturated genetic map within reasonable cost and time. The cultivation of the species is relatively easy with diverse density according to the aim of the production. Actually, *M. oleifera* opens new dimension in field of agroforestry due its easily established, fast growing, diversify nature of its products, multiple benefits to people and their livestock and several other direct and indirect benefit to people worldwide. However, there are some constraints in cultivating *M. oleifera* which slow down the species adoption. With its easy propagation, its different parts with their various uses and its high morphological and genetic diversity, *M. oleifera* hold great potentials for in-depth investigation for the purpose of improvement and valorisation especially for food and nutrition security. There is need to increase the level of use and cultivation of the species through identification of factors which influence its adoption through its use and cultivation. Further studies are needed on breeding and genetic improvement of the species, on identification of ecotypes for industrial value with higher percentage of seed oil, proteins, medicine and wide adaptability to agro-climate. Finally, there is a very scanty scientific information on the

potential of the species to mitigate effects climate change including food insecurity.

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