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The miracle mix of Moringa: Status of Moringa research and development in Malawi

W.C.J. Sagona^{a,*}, P.W. Chirwa^b, S.M. Sajidu^c^a Forestry Research Institute of Malawi, Kufa Road, P.O. Box 270, Zomba, Malawi^b University of Pretoria, Department of Plant and Soil Sciences, 5-15 Plant Sciences Complex, Hatfield, Pretoria 0028, South Africa^c University of Malawi, Chancellor College, P.O. Box 280, Zomba, Malawi

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ABSTRACT

Moringa oleifera and *Moringa stenopetala* are grown in Malawi in different agro-ecological zones. *Moringa oleifera* is the most widely cultivated pan-tropical species of a monogeneric family, the *Moringaceae*, regarded as versatile because of its ability to provide edible food, oil and purify water for local communities. The tree is sometimes referred to as a “Miracle Tree” because of nutritional and pharmacological properties. Despite its great importance, *M. oleifera* is still not well exploited and hence considered as underutilized in Malawi. Natural distribution of *M. oleifera* in Malawi and elsewhere reveals rich variability in fruit types of semi-domesticated populations. Distribution pattern among others has had an influence on domestication trends in Malawi in terms of diversity. Despite the great variability of *M. oleifera*, there is no properly established genebank or database with either cultivated or spontaneous accessions in Malawi and elsewhere. Absence of elite varieties adapted to local conditions and use of seeds obtained through open pollination from planted plants are some of the major factors that limit productivity. In Malawi, there is limited knowledge of available genetic diversity present in *Moringa* species to warrant serious breeding programmes for meaningful scaling up. Furthermore, commercialization of *Moringa* products in Malawi is still very informal making it difficult to get reliable information of production volumes and prices thereby making it unattractive for scaling up. There is however a growing interest to upscale *Moringa* species distribution nationwide. *Moringa oleifera* is fairly distributed in specific agro-ecological zones of Malawi and easily adapted to new sites. This offers an opportunity to be planted much more widely by introducing the species within the existing farming systems as the species can also survive in degraded soils. As such, increased use of the species could have a positive impact on the nutritional and health status of people of Malawi.

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1. Introduction

The *Moringa* plant is regarded as versatile because of its ability to provide edible food, oil and purification of water for local communities (Rockwood et al., 2013). The monogeneric family of *Moringa* is the *Moringaceae*, which consists of the single genus *Moringa*. The botanical name *Moringa oleifera* Lam (syn. *Moringa pterygosperma* Gaertn), is the most widely cultivated species of the genus *Moringa*. The species is also known by such regional names as benzolive, drumstick tree, kelor, marango, mlonge, mulangay, saijhan and sajna. English common names include moringa, drumstick tree (from the appearance of the long, slender, triangular seedpods), horseradish tree (from the taste of the roots, which resembles horseradish), ben oil tree or benzoin tree (from the oil, which is derived from the seeds (Jiru, 2016).

Moringa oleifera and *Moringa stenopetala* are grown in Malawi with the former widely distributed and studied due its adaptability to a wider range of areas. These two *Moringa* tree species comprise different edible parts: pods, leaves, seeds, roots and stems. The green-bean looking pods of *M. oleifera* are the most desired parts, not only because of their taste, which is similar to asparagus but also because they are highly nutritious (Coote et al., 1997). The *Moringa* species are sometimes referred to as a “Miracle Tree” because of nutritional and pharmacological properties. Beyond providing food and water purification, the species serves many benefits in Malawi including making of some crafts and in ecosystem services (Daba, 2016).

Despite their nutritious edible parts, *Moringa* products are sometimes classified as “famine food,” consumed by humans in times of food scarcity. *Moringa* vegetables as a human food are often linked with low social class status (Yisehek et al., 2011). As such, *M. oleifera* is still not well exploited and hence considered as underutilized in Malawi.

One of the most innovative uses of the *M. stenopetala* and *M. oleifera* is the treatment of water and wastewater (Yisehek et al., 2011).

* Corresponding author.

E-mail addresses: willsagona@gmail.com (W.C.J. Sagona), Paxie.Chirwa@up.ac.za (P.W. Chirwa), ssajidu@cc.ac.mw (S.M. Sajidu).

Research conducted in Malawi (Sajidu et al., 2005; Sajidu et al., 2006) shows that mixing crushed moringa seeds with polluted water help to settle silt and other contaminants. This has been widely adopted in the rural parts of Malawi such as the Lower Shire as the water purification process since it is highly cost effective as a replacement of the expensive imported chemicals (Sajidu et al., 2006).

This review, therefore, is aimed at understanding the status of *Moringa* species and factors responsible for underutilisation of the species in Malawi with particular emphasis on *M. oleifera*. It focuses on the growth and distribution; management and use; potential for domestication and scaling up; and potential for commercialization of moringa. The paper further highlights the future research and development direction.

2. Moringa species growth and distribution in Malawi

Asians who came to settle in the country in the late 18th Century (Coote et al., 1997) introduced *Moringa* in Malawi. *Moringa oleifera* grows widely in the hot, low-lying semi-arid areas mostly along the Great Rift Valley of Africa that includes the lower Shire valley and along the Lakeshore (Fig. 1). Hence, *M. oleifera* is extensively distributed in the districts of Karonga, Rumphi, Mzimba, Nkhosha, Ntchisi, Salima, Ntcheu (Bwanje valley), Mangochi, Machinga, Balaka, Phalombe, Neno, Chikwawa and Nsanje (Fig. 1).

In Malawi, the *Moringa* species grow best between 100 and 700 m altitude, with 700–840 mm of rainfall and 22–25 °C mean annual temperature (Coote et al., 1997). It can also grow in areas up to 1000 m above sea level (masl), with 960 mm rainfall and mean temperatures of 19–21 °C (Coote et al., 1997). The wide range adaptability of the species has made it possible for different development projects to extend the species distribution into other parts of Malawi including Lilongwe, Dedza, Dowa and Kasungu. Table 1 provides some details on the biophysical environment suitable for *Moringa* species growth in Malawi.

The soil condition is an important factor that may influence growth and productivity of *Moringa* species (Dania et al., 2014). The species requires sandy or loamy soil with a slightly acidic to alkaline soils (pH of between 5 and 9). However, it will not grow well in soils with very high clay content (cotton soils) (Coote et al., 1997). Soil amendments have been reported to improve growth and productivity. For example, Dania et al. (2014), found that poultry manure gave better stem girth and vegetative growth on *M. oleifera* growth than application of phosphorous (P), potassium (K), sodium (Na) and manganese (Mn). The tree has been reported to grow even in marginal soils with very little care; and can survive drought as well as frost of between –1 and 3 °C (Folkard and Sutherland, 1996).

3. Use and management

In Malawi, local exploitation of *M. oleifera* was promoted since early 1990's as a drought resistant multipurpose tree (Coote et al., 1997). The distribution, uses and potential for development of *M. oleifera* in the country has been widely reported (Coote et al., 1997; Pratt et al., 2002; Henry et al., 2004; Sajidu et al., 2005, 2006; Sajidu et al., 2008).

Table 2 provides a summary of the uses of *Moringa* species by comparing Malawi with other countries in Africa and elsewhere. Fresh leaves from *M. oleifera* are widely eaten as a vegetable (FAO, 1988). The leaves are said to be more nutritious than other vegetables as they contain as much vitamin A as carrots and are richer in vitamin C than tomatoes, radishes, carrots and peas. In Malawi, leaf protein content is similar to peas recorded at 9.8–10.6 g per 100 g (Coote et al., 1997). FAO (1988) reports that calcium and phosphorus content is higher than in many other vegetables. Young leaves can be pureed and fed to infants (Price, 1985) and at the same time, young leaves may be used as cattle fodder to improve milk production (Bostock-Wood, 1992; Clarke, 1994). A study by Coote et al. (1997) uncovered widespread local use of *M. oleifera* in Malawi, which included live fencing, food, fodder, medicines and water treatment. Hunter and Stewart (1993)

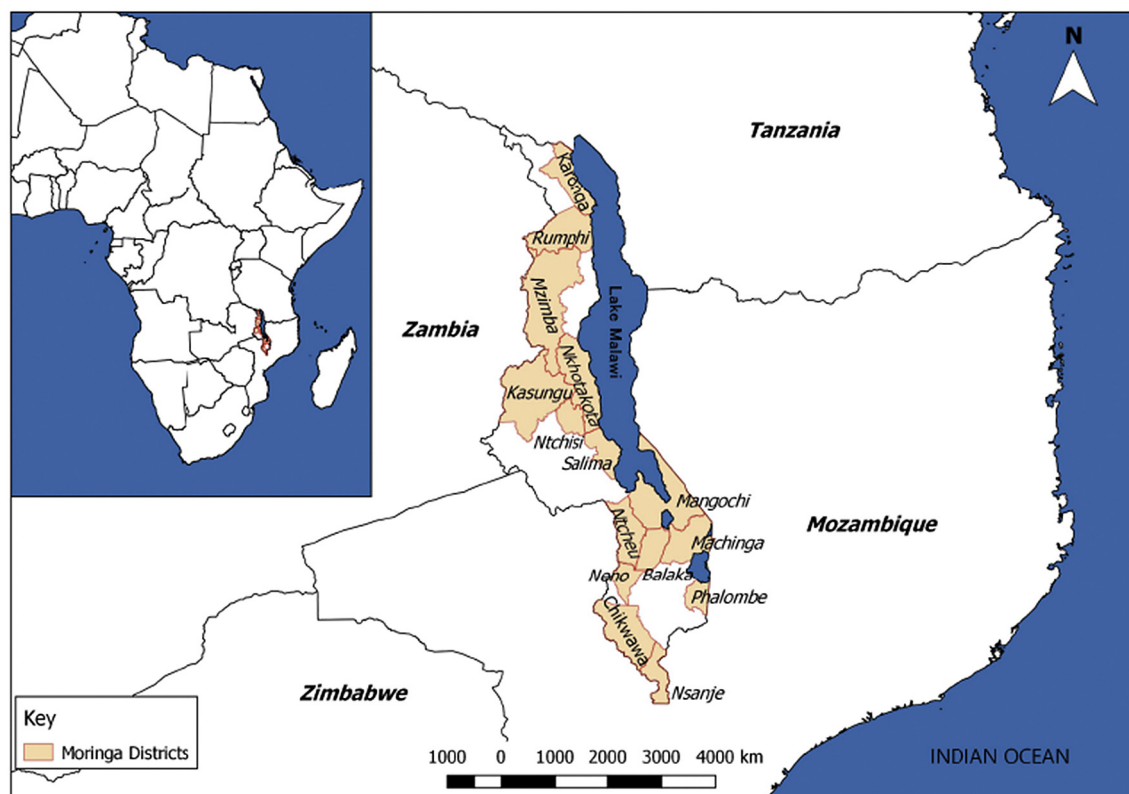


Fig. 1. *Moringa oleifera* distribution in Malawi.

Table 1Biophysical environment suitable for *Moringa* species in Malawi.

Source: Hardcastle (1977).

Location	Altitude range (metres)	Mean annual temperature (°C)	Rainfall range (millimeters)	Principal soil groups
Lower Shire Valley	0–200	25	700–840	Alluvial calcimorphic gray brown earths; Vertisols; Lithosols
Matandwe Foot hills; Central Shire valley; Salima; Mangochi Lakeshore; Central Karonga Lakeshore; South Rukuru; Kasitu valley.	200–700; 1000–1200	22–25; 20–22	700–840	Shallow ferruginous; Ferrallitic; Alluvial calcimorphic; Mopanosols; Hydromorphic; Regosols; Lithosols
Upper Shire valley; Bwanje valley; Phalombe plain; Ntaja; Karonga Lakeshore; Salima plain.	500–1000	21–23	840–960	Ferruginous; Ferrallitic; Alluvial calcimorphic; Vertisols; Lithosols.
Lilongwe; Kasungu; Mzimba.	1000–1200	19–21	840–960	Ferruginous; Weakly ferrallitic; Sandy ferrallitic; Hydromorphic; Lithosols
Nkhotakota Lakeshore; part of Karonga Lakeshore.	475–1000	23–25	1200–1600	Sandy ferrallitic; Alluvial soils; Hydromorphic; Regosols; Lithosols

reported that *Moringa* leaves have higher foliar nitrogen content than that of *Gliricidia sepium*, which is widely promoted as a fertilizer tree.

3.1. Live fencing

In most areas where the tree is found in Malawi, it is primarily planted as live fence posts around houses, cattle enclosures, bathing enclosures and toilets. The stakes are spaced at 1.5–2.5 m as a support for grass fencing. The spacing for fencing also happens to be suitable for production of leaves, flowers and pods. The species is termite resistant (Coote et al., 1997) and grows well where other tree species hardly grow.

3.2. Food

In Malawi, the use of the cooked leaves with or without flowers as vegetables was recorded long time ago by Williamson (1955). Generally, local communities in Malawi value *M. oleifera* trees for their pods and leaves that have a high protein, vitamin A and C, calcium, iron and phosphorus. An advantage is that, in other ecological sites, the leaves can be harvested during the dry season when no other fresh vegetables are available.

Williamson (1955) reported that the leaves are pounded then cooked with a solution of potashes and added with groundnut flour and tomatoes. In other instances, the leaves together with the flowers are boiled in water and salt and sodium bicarbonate are added to improve the taste followed by peanut butter and tomatoes. The sodium bicarbonate (Soda) is said to enhance the dish's viscosity, to make a dish locally known as *thelele* (wild okra) (Coote et al., 1997). The use of *Moringa* leaves in Malawi as vegetables, though widespread, appears to be mainly eaten during lean periods and is perceived as a low status food among Malawian communities. This perception militates against its wide adoption as a food crop and calls for robust extension to promote its consumption.

Moringa oleifera is one of the most nutrient-rich plants known to science as it contains over 90 nutrients, 46 antioxidants, 18 amino acids, including 8 essential amino acids (Asante et al., 2014). Both the pods and leaves of *M. oleifera* contain minerals such as calcium, iron, zinc and more, and vitamins A, B, C, D, E and K (Asante et al., 2014). The leaves contain antioxidant compounds such as ascorbic acid, flavonoids, phenolics and carotenoids (Asante et al., 2014). They also contain high levels of iron such that doctors have reportedly prescribed them for anemic patients (Coote et al., 1997). The seed powder of *M. oleifera* also contains significant concentration of selenium which acts as a powerful antioxidant; reduces the risk of certain cancers such as breast and colorectal cancer; protects against heart diseases; prevents mental decline; boosts the immune system; and also important for thyroid health (Sajidu et al., 2008).

3.3. Moringa oil

The demand for oil in Malawi is far greater than present production within the country and *M. oleifera* offers an economic opportunity to cottage industries. *Moringa* seed offers a good source of seed oil for village and commercial oil processing particularly because it fits into the existing farming system. *Moringa oleifera* seeds when pressed for oil have an oil content range of 35–40% (Nadeem and Imran, 2016).

3.4. Medicines

In Malawi, almost all parts of the plant have recorded uses in medicinal preparations. Locally, crushed leaves are used for treating conjunctivitis, scorpion bites and diarrhea. The roots are used for healing fevers in children, excising evil spirits and as a charm against witches. Oil from *Moringa* seed has been explored in cosmetics, folk medicines and skin care formulations. The commercial source has been found to be extremely rich in beneficial bioactive constituents considered to contribute towards prevention of life-style-related diseases (type-2-diabetes, cardiovascular disease and cancer), as well as provision of important micronutrients (Babbar et al., 1982). Research has revealed that *Moringa* plant extracts showed antiviral efficacy, which are a result of protein molecules physically resembling interferon (Babbar et al., 1982).

3.5. Water treatment

River water taken for household use can be full of suspended matter as the water carries silt particles, solids, bacteria and other microorganisms. Such material needs to be removed before the water is used. Water treatment centres do this by adding chemical coagulants to the water and such chemicals may be unavailable or too expensive. Pounded *M. oleifera* and *M. stenopetala* seed has been in use for water purification especially in rural areas of Malawi where there is a great need to improve water quality to avert the risk of using contaminated water and water-borne diseases (Coote et al., 1997).

The use of *Moringa* species for water clarification is a part of Malawian indigenous knowledge. Jahn (1991) first studied and confirmed the coagulating properties of *Moringa* seeds after observing women in Sudan use the seeds to clarify the turbid Nile waters. Although the water clarifying properties of *M. stenopetala* have not been as extensively studied as those of *M. oleifera*, it is reported that 100–150 mg/L of *M. stenopetala* was as effective in water clarification as 200 mg/L of *M. oleifera*, which indicates that *M. stenopetala* is more effective than *M. oleifera* (Seifu, 2015). The mechanism of coagulation by *Moringa* is not well understood but others have attributed it to existence of proteins and non-protein flocculating agents (Seifu, 2015). In Malawi, laboratory-scale studies have shown successful pH-dependent

Table 2
Uses of Moringa and tree management.

Use	Description	Africa	Asia	Elsewhere	References source
1. Uses					
Food	Leaves, flowers and pods eaten as vegetables	Malawi, Ethiopia, Ghana, Kenya, Sudan, Madagascar, Somalia, Benin and Zimbabwe	India, Pakistan, Philippines, Indonesia, Bangladesh	Europe, Latin America	FAO (1988), Price (1985), Jahn (1991), Williamson (1955), Coote et al. (1997)
Fodder/Animal feed	Leaves fed to or browsed by livestock such as goats, cattle, sheep and rabbits but also food for fish	Malawi, Ethiopia, Ghana, Kenya, Sudan, Somalia and Zimbabwe	India, Pakistan, Indonesia	Mexico	Edwards et al. (2000), Yisehek et al. (2011)
Medicine	Every part of the tree used widely for a variety of traditional medicine. Diseases treated include conjunctivitis, diarrhea, diabetes, cancer, fever, cardiovascular diseases, HIV and Aids, scorpion bites, excising evil spirits and charm against witchcraft.	Malawi, Ghana, Sudan, Ethiopia, Kenya, Zimbabwe and Benin	India, Indonesia and Pakistan	Mexico	Babbar et al. (1982), Coote et al. (1997), Price (1985), Yisehek et al. (2011)
Oils	Moringa seeds can be pressed to yield high quality oil which has both nutritional and industrial application. The oil is said to be pleasantly flavored, resembling olive oil. The oil from the seeds has also been used as industrial oil popularly known as Ben or Behen within the oil trade.	Malawi, Zimbabwe, Sudan, Ghana, Ethiopia, Kenya, Tanzania and Madagascar	India, Bangladesh, Pakistan and Philippines	United Kingdom, Mexico	Ramachandran et al. (1980), Coote et al. (1997), Nadeem and Imran (2016), FAO (1988)
Water purification	Pounded Moringa seed can be used for small-scale water purification especially in rural areas where there is a great need to improve water quality to avert the risk of using contaminated water and water-borne diseases. It is reported that powdered seeds are used to treat highly turbid river water where coagulation and sedimentation for 1–2 h remove 98–99% of coliform bacteria. The seeds have flocculating and anti-microbial properties.	Malawi; Sudan, Egypt, Ethiopia, Zimbabwe, Kenya and Benin	India, Indonesia and Pakistan	United Kingdom	Jahn (1991), Price (1985), Edwards et al. (2000)
Live fencing	In most areas the tree is primarily planted as live fence posts around houses, cattle enclosures, bathing enclosures and toilets. The stakes are spaced at 1.5 to 2.5 m as a support for grass fencing. The spacing for fencing also happens to be suitable for production of leaves, flowers and pods. The species is termite resistant and grows well where other tree species hardly grow.	Malawi, Benin, Sudan, Ghana, Ethiopia, Zimbabwe, Kenya and Tanzania	India	Mexico	Coote et al. (1997), Yisehek et al. (2011), Edwards et al. (2000)
Alley cropping/inter cropping	Moringa trees are one of the best multi-purpose trees for use in alley cropping systems. The species is also traditionally grown in mixed multi-storey stands with food crops. This is due to the tree's rapid growth, long tap roots, few lateral roots, minimal shade and large amount of biomass yield rich in protein.	Malawi, Ethiopia, Benin, Ghana and Kenya	Indonesia	Mexico	Coote et al. (1997), Yisehek et al. (2011), Price (1985), Edwards et al. (2000)
Honey production	Flowers are a good source of nectar for honey bees.	Malawi and Ethiopia			Yisehek et al. (2011), Coote et al. (1997), Price (1985)
Ornamental	Moringa trees are planted in gardens and along streets as ornamental plants	Ethiopia, Sudan, Kenya, Zimbabwe and Malawi	India and Bangladesh		Yisehek et al. (2011), Coote et al. (1997), Price (1985), Edwards et al. (2000)
Plant disease prevention	Incorporating Moringa leaves into the soil before planting can prevent damping off disease (<i>Pythiumdebaryanum</i>) among seedlings.	Ethiopia and Malawi			Yisehek et al. (2011), Coote et al. (1997), Price (1985), Edwards et al. (2000)
2. Management					
Propagation	Moringa is planted by either use of stem cuttings or seed	Malawi, Ghana, Kenya, Ethiopia, Benin, Madagascar, Sudan and Tanzania	India, Indonesia, Pakistan and Philippines		Bezabeh (1993), Teketay (1995), Coote et al. (1997), Yisehek et al. (2011), Price (1985)
Season and propagation method	In perennial types, stem cuttings of 100–150 cm are in length with diameter of 14–16 cm are planted insitu during the rainy season	Malawi, Ghana, Kenya, Ethiopia, Sudan, Tanzania and Benin	India, Pakistan and Philippines		Bezabeh (1993), Teketay (1995), Coote et al. (1997), Yisehek et al. (2011), Price (1985)
	Cuttings are planted in pits of 60 × 60 × 60 cm at a spacing of 5 × 5 m between June and August. When planting, 1/3 of the cutting should be buried in the pit.	Malawi, Ghana, Kenya, Ethiopia, Benin, Madagascar, Tanzania and Sudan	India, Indonesia, Pakistan and Philippines	Mexico	Bezabeh (1993), Teketay (1995), Coote et al. (1997), Yisehek et al. (2011), Price (1985)
	Moringa seeds may be directly sown in the pit to ensure fast germination and growth of the seedlings at a spacing of 2.5 × 2.5 m between March and August.	Malawi, Ghana, Kenya, Ethiopia, Tanzania and Sudan	India, Pakistan and Philippines	Mexico	Bezabeh (1993), Teketay (1995), Coote et al. (1997), Yisehek et al. (2011), Price (1985)
	Time of seed sowing in each locality should be strictly followed to avoid flowering phase coinciding with rainy season which results in heavy flower shedding. Moringa seeds may be inoculated with <i>Azospirillum</i> cultures at a rate of 100 g per 625 seeds before sowing to enhance seed germination and increased seedling vigor, growth and yield.	Malawi, Ghana, Kenya, Ethiopia, Tanzania and Sudan	India, Pakistan and Philippines	Mexico	Bezabeh (1993), Teketay (1995), Yisehek et al. (2011), Price (1985)
Weeding	Removal of weeds is required to promote tree growth and avert bush fires. Weeding has been especially necessary when Moringa is intercropped with maize and sorghum.	Malawi, Ghana, Kenya, Ethiopia, Benin, Madagascar, Tanzania, Zimbabwe and Sudan			Bezabeh (1993), Teketay (1995), Yisehek et al. (2011), Price (1985)

Table 2 (continued)

Use	Description	Africa	Asia	Elsewhere	References source
Pollarding	Removal of the upper branches of Moringa tree promotes a dense head of foliage and branches.	Malawi, Ghana, Kenya, Ethiopia, Benin, Madagascar, Tanzania and Sudan	India, Indonesia, Pakistan and Philippines		Bezabeh (1993), Teketay (1995), Coote et al. (1997), Yisehek et al. (2011), Price (1985)
Coppicing	2–3 coppices are allowed to grow from stumps of elite trees cut at 90 cm above ground. From these coppice shoots, cuttings 100 cm long and 4 to 5 cm in diameter are selected and used as planting material.	Malawi, Ghana, Kenya, Ethiopia, Sudan, Madagascar, and Benin,	India, Indonesia, Pakistan and Philippines		Bezabeh (1993), Teketay (1995), Coote et al. (1997), Yisehek et al. (2011), Price (1985)
Pruning	Older flowering branches can be pruned repeatedly to stimulate production of new branch shoots as additional sources of leaves.	Malawi, Ethiopia, Kenya, Benin, Madagascar, Tanzania and Sudan	India, Indonesia, and Pakistan		Edwards et al. (2000), Yisehek et al. (2011)
Moringa preservation	Moringa can be stored for a long time without loss of nutrients. Drying or freezing can be done to store leaves. Low temperature oven used to dehydrate the leaves retains more nutrients except vitamin C. Leaf drying done using household stove ensures a continuous supply of nutrients in the leaves. Dehydration improves the shelf life of Moringa without changing nutritional value.	Ethiopia, Malawi, Kenya, Tanzania and Sudan	India and Pakistan		Edwards et al. (2000), Yang et al. (2006)

sorption of heavy metals such as cadmium, zinc, copper and chromium on seed extracts of *M. stenopetala* and *M. oleifera* (Sajidu et al., 2006).

The seed cake left from oil processing is also used in water purification and laboratory tests confirmed that the seedcake remaining after oil extraction contains the active coagulants (Sajidu et al., 2006). It is therefore undisputable that the seedcake can be used to treat water in just the same way as crushed seeds. The seedcake can also be dried and stored and as such is another useful Moringa product obtained without additional cost as a by-product of oil extraction.

Other uses of Moringa species which are not yet recognized in Malawi include domestic cleaning agent which is popular in Nigeria; dye in Senegal and Jamaica; fertilizer from seed cake; gum; honey purifier; rope making; and tanning of hides done in Ethiopia (Yisehek et al., 2011; Edwards et al., 2000; Price, 1985).

4. Moringa species domestication and scaling up in Malawi

Moringa oleifera shows diversity in many characters including high morphological variability (Leone et al., 2015), which provides an opportunity for its improvement in Malawian landraces. In spite of the great variability of the species, there is no properly established genebank or database with either cultivated or spontaneous accessions in Malawi and elsewhere. The absence of elite varieties adapted to local conditions and use of seeds in Malawi obtained from open pollinated local plants are some of the major factors that limit productivity (Leone et al., 2015). Although substantial variation in quantitatively inherited traits has been documented in natural populations of Moringa elsewhere (Ramachandran et al., 1980), genetic approach and its potential application in Moringa breeding programmes are yet to be developed in Malawi. As such, there is limited knowledge of available genetic diversity in Moringa species found in Malawi to warrant serious breeding programmes for meaningful scaling up.

Variability in Moringa species due to various agro-ecological conditions in which the species grows and the various management practices (Leone et al., 2015) are factors that can be exploited during species scaling up in Malawi. Significant variation in morphological traits found in different agro-ecological zones may be attributed to ecological conditions, which are expressed as a function of time of leaf harvesting, harvesting frequency and plant density. However, to what extent variations in ecological conditions and farmers' management practices influence morphological traits of the plant parts of the Moringa species, is not well understood locally to warrant large-scale domestication. This has had serious implications for genetic improvement and conservation, and development of domestication strategies for species scaling up in Malawi. In addition, according to Popoola and Obembe (2013), unequal traditional knowledge, unequal valuation and ethnic differentiation are

sources of information on genetic variability that can be exploited during scaling up in Malawi to facilitate understanding of the species diversity. Such diversities from traditional knowledge could also be expressed in the form of morphology, chemical components, taste, anatomy and other characters of the species for successful domestication in Malawi.

The fact that *M. oleifera* is perennial, performs well in less fertile soils, frost hardy and drought resistant, is a motivation for domestication in most agro-ecological zones of Malawi. Due to its wide adaptability, the species is also likely to be more resistant and well adapted to future climatic changes as a mitigation and/or adaptation intervention. Regarded as a "miracle tree," it has been described by many as a "nutritional and medicinal cornucopia" and all parts of the plant are edible. These characteristics of Moringa species call for extensive scaling up of its domestication drive for climate change adaptation and mitigation besides other benefits discussed. Potentially, the species will do well in Malawi's degraded soils while improving land productivity through soil amelioration where the trees are grown. These are enough reasons to promote the species' domestication in Malawi.

Proper understanding of *M. oleifera* seed biology and seed technology has had an influence on domestication efforts as they determine seed quality, viability, handling, storage and related shelf life. Studies conducted on *M. oleifera* seed in the Lower Shire region of Malawi (Chikwawa and Nsanje districts) under farmer-managed trees showed that seedlots from Nsanje seed sources contain more seeds (9600 seeds per kg) than that from Chikwawa seed sources (Coote et al., 1997). The combined data from both districts/provenances indicate mean production figures of 375 pods per tree with some 20 seeds per pod length of 29–42 cm. Seed yield range from 0.3–1.75 kg with a mean value of 0.8 kg of dried and processed seeds per tree. This information provides a basis for planning *M. oleifera* domestication and scaling up programmes in Malawi.

There is little information available regarding seed dispersal of Moringa species to drive scaling up. However, much can be determined from its seed morphology and the locations in which it has become naturalized. Moringa seeds are relatively large but strongly winged and this feature is likely to allow them to spread over short distances from the parent tree by wind (Edwards et al., 2000). The fact that the species readily produces viable seeds offer an opportunity for scaling up in Malawi as it is a clear indication that Moringa species do not seem to require any specific pollinators. Multiple pollinators of the species from Malawi's rich insect diversity enhance successful seed production and development of the species for effective scaling up.

Domestication of Moringa species and subsequent scaling up in Malawi may be easily promoted due to the species' ability to fight

malnutrition, which is common among Malawi's rural population. *Moringa oleifera* growing provides a window of opportunity for the production of a high protein, micronutrient rich tree crop, which may be locally grown by smallholder farmers extensively and processed on-site to contribute to Malawi's various nutritional programmes. Apart from contributing towards nutritional security for the poorest and most vulnerable in rural areas of Malawi, increased domestication of the species will deliver additional economic benefits through two commercialization opportunities: provision of functional plant-based protein isolates as an increasingly desirable food ingredient for local and export markets; and scientifically evaluated fair trade products to enter the growing international market for nutraceuticals. There is a need to properly package extension messages on *Moringa* species focusing on nutrition and economic benefits, among others, in order to promote the species domestication in Malawi.

Limited diverse diets constrained by wealth and/or education including lack of traditional knowledge of indigenous crops have slowed scaling up of *M. oleifera* development in Malawi. Consumption of diverse diets, with balanced supplies of macro- and micro-nutrients have unconsciously been overlooked in food systems where agricultural production has focused more on provision of sufficient energy and less on nutrient rich crops (Asante et al., 2014). Rural populations in Malawi survive mainly on cereal-based diets with low nutrient density. Consequently, *Moringa* species are underutilized tree species in Malawi that can play an important role in dietary diversification and contribute to alleviation of hidden hunger. The perennial nature, multiple uses and resilience to drought of *Moringa* species make them a suitable target for scaling up in more agro-ecological zones of the country for nutrition diversity.

Nonetheless, there is a growing interest to upscale *Moringa* species in Malawi and worldwide. International initiatives such as the Moringa Fund, Trees for Life, Global Moringa Network, Moringa initiative, Africa Moringa Hub and others have been established to improve the production and uses especially for human nutrition. Non-Governmental Organizations (NGOs) in Malawi have been lobbying Malawi government through Ministry of Agriculture, Irrigation and Water Development to remove existing extension barriers on *M. oleifera* development to raise public awareness regarding the importance of increasing plant protein in the diet to benefit the public, especially women in terms of improved nutritional health. In Malawi, the Hunger Project (an international NGO) promotes the species based on its potential for health and nutrition improvement. The Hunger Project has promoted *M. oleifera* planting in all the districts most suited to the species and raised awareness of *M. oleifera* in order to influence policy on promotion, production and consumption of *Moringa* products.

In many African countries such as Ghana, Benin, South Africa, Zambia, Zimbabwe and Malawi among others, national associations have been established which organize people, including producers, consumers, processors and researchers to speak on a common platform on issues of *M. oleifera*. This review and many others on the species will more likely promote scaling up of *Moringa* species in all suitable agro-ecological zones of Malawi. This review will likely stimulate rigorous research studies on cultivation, management, genetic, ethnopharmacology, phytochemistry and pharmacology including commercialization of *Moringa* species among other issues further promoting scaling up of the species.

5. Commercialization potential of *Moringa* species

Commercialization of *Moringa* products is still very informal making it difficult to get reliable information of production volumes and prices (Sutherland et al., 2001) thereby making it unattractive for scaling up in Malawi. The international market for *Moringa* species is not sufficiently developed to qualify as a commodity on the global market. Commercialization of *Moringa* species in Malawi should become structured and formalized by developing value chains to effectively exploit the

existing market potential and influence species domestication including scaling up. The value chains for *Moringa* products, if properly developed in Malawi, will present considerable investment opportunities just like other legumes of high value. This in turn will translate into potential job creation, foreign exchange earnings and export diversification (Sutherland et al., 2001). However, to effectively scale up *M. oleifera* development in Malawi, growers need to be able to ensure compliance with international requirements and standards but also be able to offer high quality products and continuous supply especially to lucrative markets such as European Union.

Stakeholder involvement is key in commercialization drive to achieve a well coordinated *M. oleifera* development and marketing in Malawi. Smallholder farmers, co-operatives and food processors in Malawi are yet to appreciate that *Moringa* products have the potential to enter the global market as both functional food ingredients and a fair-trade nutraceutical. Scientific evidence for the benefits of growing and utilization of *M. oleifera* as a crop and export product in Malawi should be provided to benefit the investors or existing projects in terms of expanding their investment and reinvestment. Innovations that are likely to add value to *Moringa* species could provide new opportunities and significant economic benefits for growers, producers, processors, distributors and act as an incentive to scaling up. By scaling up its domestication in Malawi, *Moringa* species could stimulate new industry and more opportunities will therefore be created for small-scale investors to facilitate re-investment in nutritional programs that bring economic gains and other benefits to the wider community in Malawi.

However, there is gradual intensification on various innovations towards developing the marketing process and value addition of *M. oleifera* in Malawi by both individuals and organizations. These business entities have also assumed the role of informal extension agents to promote growing and increase productivity of *M. oleifera* for their market needs while ensuring a more sustainable and resilient *Moringa* products supply chain. As alluded to earlier, the Hunger Project has also been among those influencing policy on marketing of the products.

In Malawi, for example, *Moringa* seed oil has scored better than other commercial cooking oils when evaluated in terms of viscosity, smell and taste (Coote et al., 1997). Oil yields of up to 42% have been recorded elsewhere by FAO (1988), and in Malawi, higher rates ranging from 50% to 90% were recorded using chemical extraction (Coote et al., 1997).

According to Nadeem and Imran (2016), *Moringa* seed oil has light yellow color with mild nutty flavor and fatty acids composition suggests that the oil is highly suitable for both edible and non-edible applications. The oil is extremely resistant to autoxidation, which can be used as an antioxidant for the long-term stabilization of commercial edible oils. Studies have revealed that thermal stability of *Moringa* seed oil is greater than soybean, sunflower, canola and cotton seed oils (Nadeem and Imran, 2016).

Moringa seeds can be pressed to yield high quality oil, which has both nutritional and industrial application. The oil is said to be pleasantly flavored, resembling olive oil (Ramachandran et al., 1980). The oil from the seeds has also been used as industrial oil popularly known as Ben or Behen within the oil trade. It has also been used in perfume manufacturing and in lubrication of fine watches. The oil is of equal value, both for cooking oil as well as main ingredient for soap manufacture. The seed cake after oil pressing though not edible and high in Saponin can be used as fertilizer (FAO, 1988). *Moringa* seeds can be used first for oil extraction, without reducing their effectiveness for water treatment.

6. Opportunities for future research

Since there are some uses of *Moringa* species not recognized in Malawi, further research and extension is required to ascertain certain technical aspects and prospects including feasibility for such uses and

their promotion. The divergence between genetic variability inherent to Moringa species and the limited proven variability reflected in locally available Moringa sources represents an obstacle for the progress of breeding programmes. The extent of perceived genetic differences among trees growing in different agro-ecological zones of Malawi is not well known or documented. Nonetheless, limited evidence suggests that there may be genetic differences looking at pod sizes from trees growing in different parts of the country. This presents a ray of hope that improvements to Moringa yield can be achieved through tree breeding via selection. Genetic studies of the species may offer a potential to breeding and tree improving programmes that may produce bigger pods that are likely to contain more seeds than the current Malawian landraces.

In Malawi, few studies have assessed the ethnobotany of Moringa, and these have focused primarily on their medicinal uses (Moyo et al., 2011). There is a lack of information on the ethnobotany of the species on its use as human food to help identify existing challenges and opportunities to widen the use of Moringa and reduce human mineral micronutrient deficiencies. The nature, multiple uses, and resilience to drought of Moringa species make them suitable for silvicultural, nutritional and pharmacological research. Comprehensive, integrated and multi-disciplinary research efforts are required to develop the species not only as a crop to contribute to the alleviation of hidden hunger, but also to potentially develop a commodity crop that can improve some of the multifaceted socioeconomic problems in Malawi and beyond.

The fact that crudely processed Moringa oil evaluation in comparison with other commercial oils scores better than other oil types indicates that it has a high commercial potential. More research is therefore required to generate information on biochemistry of *M. oleifera* to exploit the numerous potential uses of the plant, create a huge demand for its products and make them competitive on the local and international markets.

Knowledge needs to be generated on Moringa species seed biology in order to establish appropriate seed handling and storage techniques to ensure good seed viability and ascertain its shelf life. Such information may facilitate domestication efforts and respond to planned large scale planting while satisfying any increasing seed demand. Though widely adapted to most parts of Malawi, Moringa species seed yield under high-density orchard design under different growing conditions has been questioned in the absence of research. Another concern is related to scarce information regarding available commercial varieties and their agronomic suitability in different biophysical environments. Research is therefore required to address the perceived knowledge gaps. Understanding Moringa seed biology would improve Moringa seed yields to satisfy the anticipated growing demand for the species; ascertain ease and cost of production including growing habits and palatability of the Moringa products.

Moringa species contain numerous phytochemical compounds with pharmacological activity as reported in various literature based on animal and cellular models yet there has been no study of their pharmacological activity in humans. In the absence of research based on humans, it would be premature to sustain the use of Moringa plant parts as a natural medicine. This knowledge gap should encourage further research studies on Moringa species to obtain clear and definitive information on the human health benefits of consuming the seeds and other plant parts.

7. Conclusion

In conclusion, *M. oleifera* offers attractive products for human well-being. The use of the Moringa species could have a positive impact on the nutritional status and health of people of Malawi. *Moringa oleifera* is widespread in specific agro-ecological zones of Malawi and easily adapted to new sites. This offers an opportunity to be planted much more widely by accommodating the species within the existing farming

systems as the species can also survive in degraded soils. An appropriate extension package is required to promote its domestication and scaling up focusing on management, distribution, use, nutritional and commercial value for an accelerated domestication. The great potential of the Moringa tree species and its various products need to be promoted widely in Malawi through a spirited extension setup for wider domestication and scaling up. Research should be promoted to understand the species genetic diversity and ethnobotany to improve Moringa species' management, productivity and address existing knowledge gaps. This review has set a pace for Moringa species research and development in Malawi and beyond by highlighting its status and existing knowledge gaps so that the true potential of the species and its many benefits and products are extensively realized.

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