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Multifaceted applications of different parts of *Moringa species*: Review of present status and future potentials

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Abstract
Moringa species are commonly known as miracle tree because of its manifold benefits that have tremendous potential in combating malnutrition and alleviating nutritional deficiencies. It emerges as low cost nutritional supplement especially for the vegetarians with its enriched protein content. In this review, we tried to emphasis the importance of *Moringa spp.* particularly the nutritional, medicinal, bioremediation and ecosystem services. This tree with its worldwide distribution can be grown in almost all environment and mostly suited to arid and semiarid regions. Leaves of *M. spp.* are rich in protein, mineral, beta-carotene and antioxidant compounds, which are often lacking among the poor populations of underdeveloped or developing countries. Benefits of this wondrous tree need to be disseminated to poor people in developing countries to combat malnutrition. *M. spp.* can be promoted as food fortificant to enhance the nutritive value of food items. Moringa with its multifaceted benefits seems promising in achieving the sustainable development goals for a healthy and brighter future.

Keywords: malnutrition, nutrition, ecosystem services, bioremediation, medicinal, anticancer properties

Introduction
Protein-energy malnutrition and mineral element deficiencies affect about 1 out of 3 people, and mostly malnourished children are in poor countries (Gonzalez, 2015) [21, 23]. In 2011 alone, some 45% of child deaths involved malnourished (Black *et al.* 2013) [6]. An urgent priority is therefore required to increase the access to healthy and nutritious food with affordable cost. Most of the poor people live in the tropical areas of the world on earth, and of these major portion present in seasonally dry low lands (Black *et al.* 2013) [6]. As many easily available plants provide the richest resource of nutrient, mineral compounds, which are used for a wide range of applications in the wellbeing of humans and domestic animals. Out of 250,000 to 500,000 species available on our planet earth, only the 1-10% are being potentially used (Cowan, 1999) [10]. So, the development of trees, shrubs, plants etc., not only with high nutrient levels but also exceptional resilience and drought resistance is essential to suit in a different environment. One of the well-used plant food for the dry tropics is a leaf of the Moringa tree especially *M. oleifera* that belongs to Moringaceae family (Thurber *et al.* 2009 and Mishra *et al.* 2018) [88, 40]. The indigenous knowledge and various uses of Moringa are referenced in approximately 80 countries and it is well known in more than 200 local languages. This family (Moringaceae) contains 13 diverse species and is well-known as the "drumstick" or "horseradish" tree. Among all 13 species of Moringa, this current research mainly focuses to *M. oleifera*, *M. stenopetala*, *M. concanensis*, and *M. peregrine* because of their wide distribution, enriched nutrients and higher adoption in arid and semiarid regions of the world (Bosch, 2004 and Ebert, 2014) [8, 11]. It is a fast growing, deciduous tree, medium range in size and also propagated as a perennial plant from cuttings and seeds (Ramachandran *et al.* 1980 and Seshadri and Nambiar, 2003) [71, 77].
Main uses of Moringa, namely food, fodder, fencing, firewood, coagulant, traditional medicine and gum have been identified (Popoola and Obembe, 2013 and Sivasankari *et al.* 2014) [67, 80]. Once this tree has been established, its antioxidant system helps to cope with moderate saline conditions and make it viable there, experiencing just a mild reduction in its nutrient & mineral quality (Nouman, *et al.* 2012) [52].

In common, Moringa suits best in lowland cultivation but also adapts well the altitudes above 2000 m (Ebert, 2014) [11]. Slightly alkaline clay and sandy loam soils are the best growing media for Moringa due to their good drainage property (Ramchandran, *et al.* 1980 and Nouman, *et al.* 2014) [71, 51]. Much scientific research on Moringa genus has been conducted and still going on to know its biological, nutritive and medicinal properties, particularly on *M. oleifera* (Mahmood *et al.* 2010) [31]. Recently, more research has been conducted on some other species such as *M. stenopetala*, *M. peregrine* and *M. concanensis*.

Even after well known facts that the Moringa is fast growing, drought tolerant and adaptable to arid semiarid and poor soil conditions, however, no profound research on other remaining species has been found. It has not received any significant research attention to select and develop potential ecotypes that might be more valuable both as food and medicinal crops. But because of Moringa's multiple uses, ease of propagation and potential to thrive under harsh ecological conditions, its acreage as a cultivated crop is on the increase in near future, as an increase in the demand for its products (Tenaye *et al.* 2009) [86]. The objectives of this review are to improve our understanding and present state of knowledge on multifaceted benefits of Moringa and future strategies for better utilization among the poor people. This study also highlights the potentials of Moringa to ameliorate soil, eradicate malnutrition, treat waste water, and improve the health of humans and animals. In this review, we tried to emphasis the importance of Moringa particularly the nutritional, medicinal, bioremediation and ecosystem services (Fig. 1).

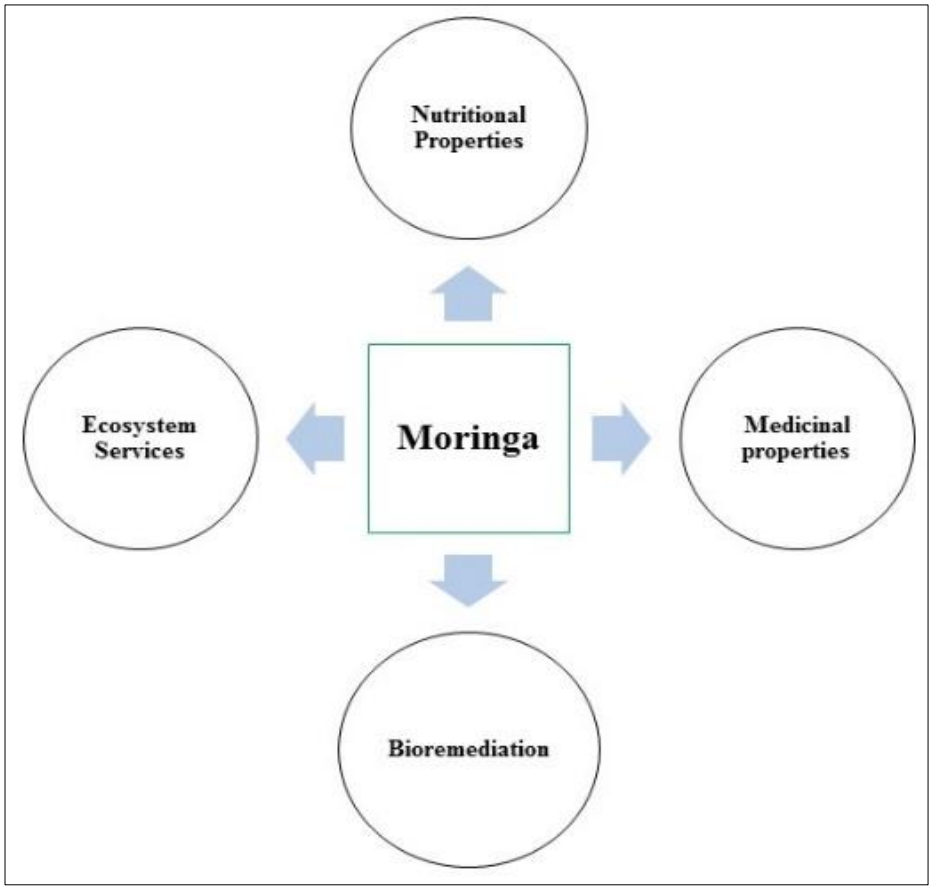

Fig 1: Multifaceted benefits of moringa highlighted in this review

Taxonomic and geographical distribution of Moringa species

The well-known *M. oleifera*, along with *M. concanensis*, are native and well known species of the Indian subcontinent. The Horn of Africa is considered as an area with the highest number of the species having at least seven species growing in Kenya, Ethiopia, and Somalia (*M. arborea, M. borziana, M. longituba, M. pygmaea, M. rivae, M. ruspoliana* and *M. stenopetala*). *M. ovalifolia* is found in Namibia and Angola, whereas, *M. peregrine* grows around the Red Sea, near the Dead Sea, and around the Southern Arabian Peninsula. The two massive pachycauls (any of several primitive tropical trees that have a thick stem and few or no branches) species *M. drouhardii* and *M. hildebrandtii* are native and endemic to Madagascar (Olson, 2000) [57]. Some of the information about various species of Moringa is presented in Table 1.

Main species of Moringa is underutilization

The *Moringa* species are currently the topic of major interest because of their outstanding socio-economic potential. Amongst these species, *M. oleifera* is the most prevalent and famous for its numerous medicinal uses, nutritional values and that has been appreciated for many centuries in various parts of the world (Mossa, 1985 and Nikkon, 2003) [43, 50]. Now-a-day, a few others species *M. stenopetala, M. peregrina* and *M. concanensis* have been under utilization and scientific research is going on these species as they supposed to be having equal potential such as high-quality seed oil, nutritious fruits and vegetables, antibiotics, anticancer and water clarification agents just like the *M. oleifera*.

Table 1: Overview of the geographical distribution and potential uses of *Moringa spp.*

Species	Country	Growth form	Common uses	Trivial name
M. arborea	Kenya, Somalia	Shrubs or tree	Medicinal plant	-
M. borziana	Kenya, Somalia	Herbs or small shrubs	Medicinal plant	-
M. drouhardii	Southern Madgascar	Tree	Oil, water coagulant, medicinal plant, ornamental	-
M. concanesis	Pakistan, India, Arabia	Tree	Oil, medicinal plant	-
M. hildebrandtii	Southwest Madagascar	Tree	Medicinal plant, ornamental	Hildebrandt's Moringa
M. longituba	Kenya, Southeast Ethopia, Somalia	Tree or Shrubs	Water coagulant, medicinal plant	Moringa tubiflora
M. oleifera	Most Southern Asia* (native to India)	Tree	Food source, water coagulant, oil, medicinal plant, fodder, ornamental, firewood	Horseradish, Ben-oil, Drum stick, Kelor
M. ovalifolia	Namibia, Southwest Angola	Tree	Vegetable, oil, fodder, ornamental	Phantom Tree, Ghost Tree, African Moringo
M. peregrina	Most Middle East** Red Sea, Arabia, Northeast Africa	Shrubs or small tree	Oil, medicinal plant, water coagulant, ornamental	Ben tree, wispy-needled Yasar tree, Wild drumstick tree, Yusor, Al Ban
M. pygmaea	Northern Somalia	Herbs or small shrubs	Medicinal plant	-
M. rivae	Kenya, Ethopia	Shrubs or tree	Medicinal plant	Swanjehro
M. ruspolina	Kenya, Ethopia, Somalia	Tree	Medicinal plant	
M. stenopetala	Kenya, South-west Ethopia, Somalia	Tree	Vegetable, oil, fodder, ornamental	Cabbage tree, Haleko, Shelagda, Shiferaw

*India, Bangladesh, Sri Lanka, Pakistan, Senegal, England, Egypt, Afghanistan, China, Nepal, Malaysia, Thailand, Vietnam, Indonesia, Philippines, Australia, Sierra Leone, Ghana, Nigeria, Uganda. **Israel, Jordan, Saudi Arabia, Yemen, Pakistan, Egypt, Oman, Sudan, Ethiopia, Somali, Syria (Hamza and Azmach, 2017) [85]; Olson, (1999): www.mobot.org/gradstudents/oslon/*Moringa*home.html.; Jahn *et al.* (1986) [25].

Medicinal uses different parts of *M. spp*

All plant parts of *M. spp.* are traditionally used for different purposes from centuries, but leaves are generally the most used part of this plant. Leaves are rich in protein, mineral, beta-carotene and antioxidant compounds, which are often lacking among the poor populations of underdeveloped or developing countries. Similarly, the use of Moringa's seeds concerns both nutrition and traditional medicine. Barks are boiled into the water and soaked in the alcohol to obtain drinks and infusions that is used to treat stomach ailments (ease stomach pain, ulcer and aiding digestion) and for many other diseases (Table 2).

Data presented in Table 2 depicted the vast application of *M. spp.* for health and medicinal purposes. Ayurvedic medicine says that *M. oleifera* can prevent or cure approximately 300 diseases and its leaves have been used for a long time for preventive and curative purposes (Ganguly, 2013) [18]. Also, a study in the Virudhunagar district of Tamil Nadu, India reported that Moringa is also well known among the species utilized by traditional Siddha healers (Mutheeswaran *et al.* 2011) [46]. Ancient Egyptians used oil of Moringa for its mostly cosmetic value and skin preparation in the traditional way (Mahmood, 2010) [31]; even if this species was not so popular among Greeks and Romans, but they were aware well about its medicinal properties and uses (Fahey, 2005) [14].

Anticancer properties

The most interesting property of *M. spp.* is its ability to perform many biological important functions like killing cancer cells by inducing apoptosis, depleting ATP and leading the cells to oxidative stress. This anti-cancer activity of this plant is due to the presence of glucosinolates in their seeds (Padayachee and Baijnath, 2012) [61]. Methanol crude extracts of *M. concanensis* root bark can inhibit the proliferation of hepatocellular carcinoma (Hep-G2) cells through intrinsic pathways by regulating caspase 9 and caspase 3 while reducing the mitochondrial membrane potential of the cells (Vijayarajan and Pandian, 2016) [90]. *M. oleifera* leaf extract decreased the proliferation of B16F10 melanoma cells in addition to causing roughly 22% cancerous cell death (Gismondi *et al.* 2013) [18]. Nibret and Wink (2010) [49] reported that seed oil from *M. stenopetala* inhibits the proliferation of HL-60 cells with IC50. An ethanol extract of *M. stenopetala* leaves and seeds reduced Hep-G2 activity and increased LDH leakage in a dose and time-dependent manner (Mekonnen *et al.* 2005) [36]. *M. peregrine* extracts inhibited MCF-7, Hep G2, HCT 116 (El Alfy *et al.* 2011 and El Abd and El Baroty, 2013) [12, 1]. Presently modern practitioners have used crude extracts and isolated bioactive compounds aiming towards anticancer therapy and prevention. But still, it has not been getting full recognition in modern medicine since the required proof has not been realized because neither the prevention of cancer nor the modification of relevant biomarkers of the protected state has been adequately demonstrated in human beings. Complications related to cancer and tumor therapy, cure and prevention may be resolved with this miracle plant. So, more rigorous research on the whole biomedical endorsement of Moringa as anticancer therapy is required in the near future to provide proof along with modern medicine.

Table 2: Medicinal uses of different parts of Moringa species

Species	Parts	Traditional uses	References
M. concanensis	Bark	Reduces pain, abortifacient	Patil and Patil (2005) [66]
	Leaves	External tumors	Chitravadivu *et al.* (2009) [9]
	Resin	Fire burn wounds	
	Leaves	Diarrheal, dysentery, colitis, sores, skin infection, anemia, cuts, scrapes, rashes, aging	Silver (2017) [79]
	Gum	Fevers, dysentery, asthma, dental decay	-

	Seeds	Warts	-
M. oleifera	Leaves	Cardiac stimulants, malaria, arthritis, diseases of the skin, hypertension, typhoid fevers, swellings, parasitic diseases, diabetes, cuts, contraceptive remedy, genio-urinary ailments, boost the immune system, elicit lactation, Antibacterial, antimalarial	Anwar *et al.* (2007) [4, 32]; Abe and Ohtani (2013) [2]; Yabesh *et al.* (2014) [92]; Parrotta (1993) [63]
	Oil	Gout, acute rheumatism	-
	Flowers	Tumor, inflammation, hysteria, enlargement of spleen, muscle diseases, aphrodisiac substances	Anwar *et al.* (2007) [4, 32]; Yabesh *et al.* (2014) [92]
	Roots	Toothache, anthelmintic, ant paralytic	Popoola and Obembe (2013) [67]; Sivasankari *et al.* (2014) [80]
	Bark	Aiding digestion, stomach pain, poor vision, ulcer, hypertension, joint pain, anemia, diabetes	Popoola and Obembe (2013) [67]; Yabesh *et al.* (2014) [92]
M. peregrina	Leaves	Skin rashes, paralysis	Odee *et al.* (2002) [53]
	Bark	Disinfectant to speed up wound healing	Marwah *et al.* (2007) [33]
	Pods	Infantile paralysis or convulsions	Miller *et al.* (1988) [39]
	Leaves, roots	Malaria, hypertension, stomach disorder, expel retained placenta, asthma, diabetes	Mekonnen *et al.* (1999) [37]
M. stenopetala	Leaves	Flu, diabetes and disorders associated, malaria, hypertension, expel retained placenta, stomach pain, visceral leishmanial, wound healing, common cold	Teklehaymanot and Giday (2010) [84]; Habtemariam (2016)
	Roots	Malaria, stomach pain, diabetes, Epilepsy, help during labor	Mekonnen (2002) [38]
	Bark	Cough	Teklehaymanot and Giday (2010) [84]

Nutritional aspects of *M. spp*.

Moringa trees have been used to combat malnutrition, especially among infants and nursing mothers and have been given a lot of attention as a nutrient source. It is rich in nutrition owing to the presence of varieties of essential phytochemicals present in its leaves, pods and seeds. The fact that Moringa is easily cultivable as it does not require pesticides or any other type of special treatment makes it a sustainable remedy for malnutrition. The published data on the nutrient content of this interesting plant is quite variable, both in terms of quantity of information and differences between published sources. Much of the variability is likely due to differences in soil, climate, and plant age; and processing techniques such as drying clearly impact vitamin content. The inclusion of Moringa in a diet to supplement daily nutrient needs could help to prevent many diseases (Sharma *et al.* 2012) [78]. Numerous of the research reports have shown that *M. oleifera* leaves have high protein compared to other leaves eaten as food and its flowers are a good source of fat, vitamin A, antioxidants, carotenoids and minerals like iron and potassium (Mishra *et al.* 2018) [40]. Presence of different bioactive molecules also proves their medicinal potential. One rounded tablespoon (8 g) of leaf powder will satisfy about 14% of the protein, 40% of the calcium, 23% of the iron and nearly all the vitamin A needs for a child aged 1-3 years. Six rounded spoonfuls of leaf powder will satisfy nearly all of a woman's daily iron and calcium needs during pregnancy and breast-feeding (Mishra *et al.* 2012) [41]. A research report by Rockwood *et al.* (2013) [75] confirmed that, dry leaves of *M. oleifera* contains 9 times higher proteins than yogurt, 10 times higher vitamin A than carrot, 25 times higher iron than spinach, 15 times higher potassium than bananas, 17 times higher calcium than milk and 7 times more vitamin C than an orange (Mishra *et al.* 2018) [40].

Table 3: The nutrient compositions of leaves, seeds and pods of *M. Oleifera*

Nutrients	Nutrients in plant parts (mg/100g)		
	Leaf powder	Seed	Pods
Calcium	2003	45	30
Magnesium	368	635	24
Phosphorus	204	75	110
Potassium	1324	-	259
Copper	0.57	5.20	3.1
Iron	28.2	-	5.3
Zinc	60.1	-	-

Data presented here is a result of compilation from different sources.

Protein and nutrient content in other species of Moringa

The average protein content of *M. stenopetala* seeds was found to be 42.6 g/100 g, which is higher than the 33.3 g/100 g reported for *M. oleifera* seeds grown in Brazil (Oliveira *et al.* 1999) [56], In *M. concanensis* seeds 30.1 g/100 g protein was reported in Pakistan (Manzoor *et al.* 2007) [32], and 22.1 g/100 g protein was reported in *M. peregrina* seeds grown in Saudi Arabia (Somali *et al.* 1984). The leaves of *M. peregrina* from Saudi Arabia contain 23.3% proteins (Osman and Abohassan, 2012) [60]. Raw leaves of *M. stenopetala* contain 9% crude protein on a dry matter basis (Abuye *et al.* 2003) [3]. Leaves of *M. Olefiera* contains 27.1% protein (Fuglie, 2005 and Olagbemide *et al.* 2014) [17, 55]. The mineral contents of *M. peregrine, M. stenopetala* in comparison to *M. oleifera*.

Table 3: Mineral content (mg/100 g) of various foods[a] for comparison to *M. spp.* Leaves

Sources	Ca	Fe	Mg	P	K	Na	Zn	Cu	Mn
M. peregrine leaves[b]	23.9	84.5	5.30	1.90	35.0	10.9	2.21	0.786	17.8
M. oleifera leaves[c]	19.1	107.5	3.80	30.2	9.70	192.9	60.1	6.10	81.7
M. stenopetala raw leaves dry matter[d]	793	3.08	-	65.6	453	403.5	0.53	-	8.60
Cereals									
Wheat flour, unenriched	15.0	1.17	22.0	108	107	2.00	0.70	0.144	0.682
Bread, wheat	142	3.46	48	155	184	521	1.21	0.159	1.123
Rice, white, unenriched	9.00	0.80	35	108	86	1.00	1.16	0.11	1.10
Corn, sweet, white, raw	2	0.52	37	89	270	15	0.45	0.054	0.161
Corn, yellow	7	2.71	127	210	287	35	2.21	0.314	0.485

Vegetables									
Green beans	37	1.04	25	38	209	6	0.24	0.069	0.214
Carrots	33	0.3	12	35	320	69	0.24	0.045	0.143
Spinach	58	0.8	39	28	130	130	0.38	0.093	0.639
Lettuce, green leaf	36	0.86	13	29	194	28	0.18	0.029	0.25
Soybeans, green	197	3.55	65	194	620	15	0.99	0.128	0.547

[a]USDA Nutrient database for standard references (http://www.nal.usda.gov/fnic/foodcomp/ search/). [b]Osman, and Abohassan, (2012) [60]; [c]Ogbe, and Affiku, (2011) [54]; [d]Abuye, *et al.* (2003) [3].

Ecosystem Services offered by *M. spp.*

Limited literature are available on *M. spp.* contribution to the ecosystem services. Mridha, (2015) [45] reported soil improvement when used as green manure and its seed cake used as fertilizer. Furthermore, *M. spp.* can be planted on the boundary, barrier and support, reforestation, in alley cropping that helps in erosion control and amends the soil. The rate of the Moringa tree to absorb carbon dioxide (CO_2) in comparison to Japanese cedar tree is fifty times (50x) higher; and in comparison to natural vegetation it is twenty times (20x) higher (Villafuerte *et al.* 2009; Hernandez *et al.* 2015; Potadar and Patil, 2017) [91, 23, 68]. And because of its natural capacity to improve the environment, integration of the *M. spp.* in agroforestry systems can mitigate the impacts of climate change (Kumar *et al.* 2017) [27].

Moringa seed can be useful as good as oilseeds of sunflower, soybean and cottonseeds. Oil content of soybean and cottonseed may be a leading source of edible oil with approx. 18-20% moderate oil content, and instead the seeds of Moringa containing 40% oil contents. Furthermore, oil extracted from Moringa seed is a very useful feedstock for the biodiesel production. Biodiesel derived from *M. stenopetala* seed oil is a highly acceptable substitute for petro diesel. These properties of *M. spp.* seeds can potentially contribute to tackling issues like global climate change and serves as alternative energy from renewable sources.

Bioremediation potential of *M. spp.*

During the 1990s, the properties of the *M. spp.* and its efficiency as a natural coagulant were assessed and by its uses it was found that *M. oleifera* seeds, while being biodegradable and non-toxic, can be used as a good substitute instead of coagulants such as alum mostly used in industries (Sutherland *et al.* 1994) [83]. The natural coagulant property of its different extracts and purified proteins were reported to be comparable to aluminium sulphate a mostly used coagulant, (Pritchard *et al.* 2010) [69]. Moringa's coagulating potential is because to its flocculating proteins (about 6.5 kDa) and cationic proteins (13 kDa) as isolated from the aqueous extracts of *M. oleifera* plant parts (Gassenschmidt *et al.* 1995; Ndabigengesere *et al.* 1995) [19, 48]. And continuous use of *M. oleifera* as a substitute to these chemical coagulants is also encouraged for turbid water treatments, also Moringa's flower extracts are used for disinfection of the waste water (Moura *et al.* 2011) [44]. Bio sorbents prepared by the chemical modification of leaves extracts used as a very good substitute to conventionally used adsorbents for removal of heavy metals, particularly Cu(III), Ni(II), Cd(II), and Pb(II) from the aqueous solutions (Reddy *et al.* 2010a, 2012) [72, 73]. Reddy *et al.* (2010b) [74] also demonstrated that *M. oleifera* bark can serve as an efficient bio remedier in bio sorption of Pb (II), and then concluded that the existing synthetic adsorbents such as activated carbon and ion exchange resins can be replaced by such efficient bio sorbents.

A study by Mataka *et al.* (2010) [35] investigating the potential of *M. stenopetala* and *M. oleifera* for the removal of Cd(II) ions from water indicated that the powder of *M. stenopetala* seeds, with a dose of 2.50 g/100 ml, reduces the concentration of cadmium by 53.8%. Between *M. stenopetala* and *M. oleifera*, the comparison of removal capacities indicated that *M. stenopetala* has more potential than *M. oleifera* in removing heavy metal like cadmium from water. It means that *M. stenopetala* seed powder could be used as a bio sorbent at cheap prices, for the removal of Cd from polluted water. It could be used without synthetic chemicals to remove heavy metals from water and industrial wastes. Some other studies indicated that the seed powder of *M. stenopetala* could be used to remove Cr from tannery effluent (Gatew and Mersha, 2013) [20]. Results showed that seed powder of *M. stenopetala* at a dose of 1 g/100 ml and pH of 9.5 decreased the concentration of Cr in tannery waste by 99.86%. Earlier reports indicated that *M. stenopetala* seed powder could also remove Pb from contaminated water (Mataka *et al.* 2006) [34]. These authors reported that in comparison to *M. oleifera*, *M. stenopetala* was more effective in removing heavy metals from water.

Other important uses of *M. spp.*

Moringa is used as animal fodder for a long time (Nouman *et al.* 2012, 2014) [52, 51]. It is also used as a natural coagulant of turbid water (Suarez *et al.* 2003) [82]. Actually, Moringa seed powder can be used for water purification, replacing dangerous and expensive chemicals such as aluminium sulfate (Popoola and Obembe, 2013) [67]. In addition, the *M. spp.* can be 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) [30]. Moringa leaves can also be used in the treatment of HIV infections that have been reported by local people in Nigeria (Popoola and Obembe, 2013) [67].

Conclusion

Outside India, there are some research centers focused on *M. oleifera* improvement across the world: AVDRC (Taiwan), Moringa Philippines foundation (Philippines), Moringa community (Zambia), rural development initiative (Zambia), However, urgent policy framework is required in Indian context to reap the benefits from this miracle tree. In spite of the high variability of *M. spp.* none of the institutions have its germplasm bank or any data base with either cultivated or spontaneous accessions. The divergence between genetic variability inherent to the species and the poor variability reflected in the germplasm banks must be fixed since it represents an obstacle for the progress of breeding programs of Moringa. In Northern India, *M. oleifera* pods are used frequently during the summer season but leaves and other parts are still underutilized. Benefits of this wondrous tree need to be disseminated to poor people in developing countries to combat malnutrition. Moringa can be promoted as food fortificant to enhance the nutritive value. Moringa with its multifaceted benefits seems promising in achieving the sustainable development goals for a healthy and brighter future.

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