Potential applications of Moringa oleifera. *A critical review*

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ABSTRACT

Moringa oleifeira is a tree from India to which many benefits for human welfare are ascribed. It grows fast, is little demanding on the soil and is cultivated throughout the inter-tropical strip. One of the main uses of its leaves and the seed press cake is in the formulation of rations for animal feeding. However, practically all the parts of the tree have diverse applications, about which there are testimonies since ancient times. This work reviews the available literature about the utilization of this plant. Different application fields of *M. oleifera* are presented in the light of the increasing scientific interest it has generated in recent years. The objective is to show the evidence contributed by the scientific literature which confirms and explains the properties and applications of *M. oleifera*, which are far from unconfirmed versions provided by popular literature and publicity.

Key words: Feeding, *Moringa oleifera*, treatment of residual waters

INTRODUCTION

Moringa oleifera, tree belonging to the Moringaceae family, is native to the southern foothills of the Himalayas and at present it is cultivated in practically all the tropical, subtropical and semiarid regions of the world. It can grow under conditions of water scarcity, but its intensive cultivation, with irrigation and fertilization, increases biomass yield until exceeding 100 tons per hectare (Foidl, Makkar and Becker, 2001). It is known by different vernacular names, such as: marango, moringa, horseradish tree, drumstick tree, ángela, asparagus tree, pearl tree, "ben" tree, tree of life, miracle tree (Fuglie, 2001). This last name is a measure of the importance of this plant to solve health problems which could otherwise be considered incurable.

For millennia, practically all the parts of *M. oleifera* have been used by mankind. The leaves, flowers, fruits and roots are appreciated for their nutritional value and may be used in human as well as animal feeding. The leaves are exceptionally rich in vitamins and different aminoacids, for which they are recommended to treat malnutrition problems in children (Fuglie, 2001). They are also used as forage, biopesticide and for biogas production (Fahey, 2005). The seeds are used in feeding, medicine, water treatment and as fertilizers (Foidl *et al*., 2001). The trunk bark is useful in the adsorption of heavy metals (Reddy, Ramana, Seshaiah and Reddy, 2011), as well as for the manufacturing of ropes and carpets (Ramachandran, Peter and Gopalakrishnan, 1980). The oil is used in the perfume and cosmetic industry as lubricant, in human feeding and biodiesel production (Rashid, Anwar, Moser, and Knothe, 2008). The seed husks serve as raw material for the production of activated carbon and anion exchangers. The plant is also used as living fence or windbreak, while the lignocellulosic biomass of the trunk and the branches may be used as construction material and to produce cellulosic pulp and ethanol (Fahey, 2005).

In spite of its ancestral usefulness, its application has been rather empirical and most of the existing information comes from the oral tradition or from general publications. Only at the end of the 20th century did this tree begin to receive the deserved attention by the scientific community. During the last two decades many reports have been published about the scientific evaluation of the processes of utilization of the plant, as well as the identification of active principles and action mechanisms, which has allowed to explain many of the previously known beneficial effects, optimize its exploitation and propose new applications. Some uses have not been scientifically confirmed yet and require future research. This review aims at presenting the evidence contributed by the scientific literature which confirm and explain the properties of *M. oleifera*; this work does not ignore the general and popular literature, although it takes these publications cautiously.

M. oleifera in animal feeding

The nutritional characteristics of *M. oleifera* are excellent, for which it is used as forage at large scale in several African countries and Nicaragua. It shows high productivity of green matter as compared with other pastures, such as alfalfa, and the highest values are reached with a planting density of one million plants per hectare (Makkar and Becker, 1996). Its leaves and the press cake from its seeds may be used in the formulation of rations for animal feeding (Pérez, Sánchez, Armengol and Reyes, 2010). The leaves may be used directly as well as after ethanol extraction. In a study conducted at the Institute of Animal Production in the Tropics and Subtropics (in Hohenheim, Germany) the aminoacid composition of the moringa leaves was proven to be comparable to that of soybean, and the index of digestible protein in the intestine (PDI) of its leaves is higher than that of several conventional protein supplements, such as coconut press cakes and cotton, peanut, sesame and sunflower seeds (Makkar and Becker, 1996).

The high levels of crude protein and PDI make the *M. oleifera* leaves a good protein supplement for highly productive cattle. On the other hand, the leaves extracted with ethanol are even better ingredients for concentrate feeds; because in addition to their high protein content, they do not have tannins, lectins, trypsin inhibitors or flatulence factors, and their saponin and phytate levels are low (Makkar and Becker, 1996). In Nicaragua good results have been obtained using mixtures of *M. oleifera* leaves with molasses and sugarcane straw (Radovich, 2011). Trials of the use of leaves from this plant in fish farming and vermiculture have also been reported (Cova, García, Castro and Medina, 2007).

The defatted *M. oleifera* press cake, due to its high protein content, is a raw material of interest for animal feeding. In a recent study, six non-traditional oil plants which grow in Cuba were compared, and *M. oleifera* turned out to be the one with the highest protein content (68,6 % of dry weight) in the press cake (Martín *et al*., 2010). The evaluation of such cake as additive in the diet of sheep has been object of recent studies. In a trial with 24 lambs, which were fed hay ad libitum and controlled quantities of soybean meal and *M. oleifera* press cake during 45 days, the addition of the cake was shown to result in better ruminal fermentation and a weight gain directly proportional to the supplied dose (Ben Salema and Makkar, 2009). The addition of this cake, which has higher content of crude protein and lower content of neutral fiber than the soybean meal, did not affect the hay ingestion or its digestibility or the nitrogen balance. On the other hand, it was shown that the proteins present in the cakes have antibiotic effect (Makkar, Francis and Becker, 2007), and that totally defatted proteins do not contain most of the secondary metabolites of plants, such as: tannins, saponins, alkaloids and trypsin and amylase inhibitors (Makkar and Becker, 1997).

M. oleifera in human feeding

Practically all the plant parts have feeding use. The fruits, leaves, flowers, roots and oil are highly appreciated for their nutritional value and are used for the elaboration of different dishes in India, Indonesia, the Philippines, Malaysia, the Caribbean and in several African countries (Foidl *et al*., 2001; Ghazali and Mohammed, 2011). The cooked fresh leaves are used in the preparation of salads, soups and sauces; they can also be consumed raw as other vegetables. The cooked flowers have a taste reminiscent of mushrooms. The young pods are very appreciated in India; they are prepared in the same way as green beans and taste similar to asparagus. When mature, the pods become ligneous and lose qualities as foodstuffs. Nevertheless, the seeds can be separated from the mature pod and used as food. The mature seeds can be prepared in a similar way to peas; and they can also be consumed fried, roasted (as peanut), in brews and sauces (Ramachandran et al., 1980). In Malaysia, the green pods are used as ingredients of local curry varieties. From the roots sauces are prepared which, due to its taste, are reminiscent of the horseradish; that is why *M. oleifera* is known in some places as horseradish tree.

The leaves of this species show high content of vitamins, provitamins and minerals (Palada and Chang, 2003). In addition, they have been proven to contain all the essential aminoacids for life, including arginine and histidine, which are generally found in proteins of animal origin and are very important for children's growth. For such reason, in the last decade the FAO promoted a program for the use of *M. oleifera* aimed at the children's population with high undernutrition rates and at the pregnant and lactating mothers (Fuglie, 2001). However, it should be stated that some Internet sources report exaggerated values to compare this plant with different fruits and vegetables regarding the nutrient content.

The *M. oleifera* oil is rich in oleic acid and tocopherols (Anwar *et al*., 2005). Except for its lower content of linoleic acid, this oil shows similar chemical composition and physical properties to olive oil. It is used in salad seasoning in Haiti and other Caribbean islands (Foidl et al., 2001), without reports of adverse effects, allergies or toxicity (Ghazali and Mohammed, 2011).

It can also be used in the improvement of the oxidative stability of other oils. During the conservation, cooking and frying of the traditional plant oils the deterioration of their nutritional qualities occurs due to collateral reactions of linoleic acid degradation (Warner and Knowlton, 1997). The oleic acid, which is more resistant to oxidation than linoleic acid, is contained in large amounts in the *M. oleifera* oil (Martín *et al*., 2010); that is why its addition to other oils allows to obtain mixtures with improved properties for culinary uses without affectations in the nutritional properties.

Medicinal uses of *M. oleifera*

In many tropical countries it is difficult to differentiate between feeding and medicinal uses of *M. oleifera*, because it is used for its nutritional qualities as well as for its medical attributes, which have been acknowledged for millennia. In India, Ayurvedic medicine contemplated the use of this plant to prevent, mitigate or cure "more than 300 diseases". The leaves, fruits, roots and seeds are useful to treat: anemia, anxiety, asthma, paralysis strokes, bronchitis, catarrh, cholera, chest congestion, conjunctivitis, sperm deficiency, milk deficit in lactating mothers, diabetes, diarrhea, erectile dysfunction, painful joints, headaches, sore throat, scurvy, sprains, pimples, lack of sexual desire in women, fever, gonorrhea, gland swelling, high blood pressure, hysteria, impurities in the blood, skin infections, sores, malaria, earache, intestinal parasitism, poisonous bites, bladder and prostate troubles, psoriasis, breathing disorders, cough, tuberculosis, abdominal tumors, ulcers, etc. (Fuglie, 2001). Its therapeutic uses are practiced in several countries, such as Bangladesh, Egypt, the Philippines, Guatemala, India, Malaysia, Myanmar, Puerto Rico, Senegal, Sri Lanka, Thailand and Venezuela, among others.

In spite of the deep roots of the moringa use in many remedies and medical treatments in different nations, not all is documented in the scientific literature. The study of the chemistry and pharmacology associated to its medical attributes is recent and still being developed. And although many of its therapeutic benefits have been tested through rigorous in vitro and in vivo studies in modern laboratories, others are still pending to be supported by clinical trials. Although the information about its healing properties is disseminated in the Internet, it is frequently based on empirical bases without making reference to the specialized literature. Besides, good part of the information is from companies which produce and/or distribute nutritional supplements and other preparations from this plant, for which its value is rather advertising. Some of the healing properties which are confirmed by scientific literature are discussed below.

Phytochemical justification of the therapeutic effects

The presence in *M. oleifera* of important phytochemicals responsible for its healing properties has been recently proven. In one of the first detailed studies about the chemical composition of this species, it was revealed to be rich in several very peculiar substances, such as glucosinolates, isothiocyanates, flavonoids, anthocyanins, proanthocyanidins and cinnamates (Benett *et al*., 2003); the distribution of phytochemicals in the different tree parts was also included.

Several of the identified compounds can be considered nutraceuticals, because they are useful in human nutrition as well as health. For example, 4-(4'-O-acetyl-α-L-ramnopiranosiloxi)-benzyl isothiocyanate, 4-(α-L-ramnopiranosiloxi)-benzyl isothiocyanate, benzyl isothiocyanate and el 4-(α-L-ramnopiranosiloxi)-benzyl glucosinolate show anticarcinogenic, hypotensive and antibacterial activity (Fahey, 2005). The high content of vitamins, minerals and other phytochemicals such as vainillin, omega fatty acids, carotenoids, ascorbates, tocopherols, β-sitosterol, octacosanoic acid, moringine, moringinine and phytoestrogens, is also an important factor in the therapeutical effects of *M. oleifera* (Fuglie, 2001; Fahey, 2005; Singh *et al*., 2009).

Antimicrobial activity

The use of *M. oleifera* for the control of diverse infections caused by microorganisms is well known, and in recent years scientific results have been generated which confirm its microbial activity. In vitro studies have proven the activity of different plant parts on pathogen microorganisms. The inhibition of the growth of *Pseudomonas aeruginosa* and *Staphylococcus aureus* by aqueous extracts from the leaves was shown by Guatemalan scientists (Cáceres *et al*., 1991). On the other hand, Chuang *et al*. (2007) showed the antifungal activity of essential oils from the leaves and alcoholic extracts from the seeds and leaves against such dermatophytes as *Trichophyton rubrum* and *Trichophyton mentagrophytes*. In addition, 44 components of the essential oils of the leaves, which can be used in the future development of pharmaceuticals for the treatment of typical skin diseases of tropical areas, could be identified.

Bacteriological studies proved the antimicrobial activity of the extracts from *M. oleifera* seeds, which flocculate Gram-positive and Gram-negative bacteria in the same way as they do with water colloids. Their bacteriostatic action consists in the disruption of the cell membrane by inhibition of essential enzymes (Suárez Entenza, and Doerries, 2003). The main ingredient responsible for such activity is 4-(4'-O-acetyl-α-L-ramnopiranosiloxi)-benzyl isothiocyanate, which has bactericide action over several pathogen species, including antibiotic-resistant *Staphylococcus*, *Streptococcus* and *Legionella isolates*. The strength of isothiocyanates as antibiotics was also shown in a study with *Helicobacter pylori*, which causes gastric and duodenal ulcers (Fahey, 2005).

In a very recent study conducted in Kenya, the microbial activity of extracts from *M. oleifera* seeds on the bacteria *Salmonella typhii*, *Vibrio cholerae* and *Escherichia coli*, which cause typhoid fever, cholera and gastroenteritis, respectively, was proven (Walter, Peter and Joseph, 2011). The authors of this review consider that this result can have a great impact, because they are natural antimicrobial agents which constitute a cheap and sustainable method for disease control and to improve the quality of life in poor communities. It should be considered that in many rural regions of underdeveloped countries, due to the high cost of chlorine and other disinfectants, no treatment is practiced on waters, which generates diseases caused by contaminant microorganisms.

Cancer prevention

The antitumor activity of remedies prepared from the leaves, flowers and roots of *M. oleifera* is acknowledged in popular medicine (Murakami *et al*., 1998). Many of the anticarcinogenic effects have been scientifically confirmed during the last years. It was recently revealed that the hydroalcoholic extracts of *M. oleifera* fruits, due to their positive effects on the hepatic cytochrome, can be used for preventing the chemical carcinogenesis. This conclusion was arrived at after a rigorous study about the genesis of skin papillomas induced by 7,12-dimetylbenzanthracene in albino rats (Bharali, Tabassum and Azad, 2003).

The effects of the extracts of this plant in cancer prevention occur due to the presence of phytochemicals which modulate the activity of enzymes, facilitating detoxification and guarantees the antitumor activity. For example, the inhibiting action of 4-(4'-O-acetyl-α-L-ramnopiranosiloxi)-benzyl isothiocyanate and niacimicin on the phorbol esters responsible for the early activation of antigens in lymphoblastoid cells has been proven (Guevara, Vargas and Sakurai, 1999). In addition, isothiocyanates isolated from the leaves inhibit the activation of the Epstein-Barr virus, in which the isothiocyanate group seems to be the decisive structural factor (Murakami *et al*., 1998).

Antioxidant activity

The accumulation of free radicals is associated to the pathogenesis of many human diseases. Antioxidants are substances capable of delaying or preventing the formation of free radicals, and their use in pharmacology is intensively studied, particularly as treatment for cerebrovascular and neurodegenerative diseases, as well as in the prevention of cancer and ischemic cardiopathy.

Plants contain antioxidant compounds –such as carotenoids, tocopherols, ascorbates and phenols- which can attenuate the oxidative damage; indirectly, by activating cell defenses, or directly, by eliminating free radicals (Ogbunugafor *et al*., 2011).

The different parts of *M. oleifera* contain more than 40 compounds with antioxidant activity. Among the compounds with this potential, because of free radical capture activity or due to metal ion chelating capacity identified in the *M. oleifera* seeds, are phenolic compounds such as kaempferol and gallic and ellagic acids (Singh *et al*., 2009).

In vitro studies showed that the extracts from *M. oleifera* leaves, fruits and seeds, due to their antioxidant properties, protect the living cells from the oxidative damage of DNA associated with ageing, cancer and degenerative diseases (Singh *et al*., 2009); such extracts were also reported to inhibit lipid peroxidation and bacterial quorum sensing, and *M. oleifera* was also proposed as an ideal candidate for the pharmaceutical, nutraceutical and functional foods industries. Another study revealed that the fraction extracted with ethyl acetate, which is rich in phenolic acids and flavonoids, shows the highest antioxidant capacity among the fractions extracted with different solvents (Verma, Vijayakumar, Mathela and Rao, 2009).

The antioxidant activity of *M. oleifera* leaves varies depending on the agroclimatic and seasonal conditions (Iqbal and Bhanger, 2006). The samples from cold regions of Pakistan showed higher antioxidant activity than those from temperate regions of that country, while the ones collected in December showed higher activity than the ones taken in June.

The extracts from *M. oleifera* seeds can be used in antioxidant therapies to decrease the genotoxicity of arsenic and other heavy metals, whose carcinogenic action mechanisms are related to oxygen reactive species. The antidote action of this plant was shown in trials with laboratory rats previously exposed to arsenic (Gupta, Dubey, Kannan and Flora, 2007). The powder from these seeds was proven to reduce the arsenic concentration and protect against the hematological activities and the oxidative stress induced by that metal, in which several phytochemicals with antioxidant and chelating capacity play a significant role. The natural coagulants of the *M. oleifera* seed, their high content of such amino acids as methionine and cistein, and such antioxidants as vitamins C and E and β-carotene are responsible for the remediation of the arsenic-induced oxidative stress (Flora and Pachauri, 2011).

Anti-inflammatory activity

Due to their high content of phenols, vitamins, omega-3 fatty acids, glutathione, sterols and isocyanates, the extracts from *M. oleifera* roots and seeds contribute directly or indirectly to the protection against inflammatory diseases (Ezeamuzle, Ambadederomo, Shode and Ekwebelem, 1996). The protecting effect of seed extracts against different inflammatory pathological conditions, including the relief of bronchial inflammations such as asthma, has been shown (Mehta and Agrawal, 2008).

In vivo experiments proved that aqueous (Ndiaye *et al*., 2002) and methanolic extracts (Ezeamuzle *et al*., 1996) from *M. oleifera* roots remarkably reduce the carrageenan-induced edema. This same anti-inflammatory activity was observed in the water- (Cáceres *et al*., 1992) and ethanol-soluble fractions (Guevara, Vargas and Uy, 1996) of the seeds. In the case of aqueous root extract, the reduction rate is similar to the one achieved with indometacin, a well-known and very strong anti-inflammatory drug (Ndiaye *et al*., 2002).

From *M. oleifera* 36 compounds have been isolated, showing anti-inflammatory activity, among them alkaloids, glucosinolates and isocyanates (Ezeamuzle *et al*., 1996; Mahajan and Mehta, 2008). Alkaloids have an activity similar to that of ephedrine and may be useful in therapy for asthma, while moringine shows bronchiole relaxation activity (Kirtikar and Basu, 1975). The seed extracts suppress several inflammatory mediators involved in chronic arthritis (Mahajan and Mehta, 2008). The moringa flavonoids increase bone density, which allows to prevent osteoporosis (Nijveldt *et al*., 2001).

Hypoglycemic and anti-hypertensive activity

In Indian traditional medicine, *M. oleifera* is used in the treatment of diabetes and blood hypertension. Popular anecdotes in African nations also report several cases of miraculous cure of diabetes and hypertension using remedies prepared from this plant. The incipient scientific research in this regard has already obtained convincing evidence from many of these cases, although the confirmation of others requires more studies. In recent years, in different countries research has been conducted aimed at evaluating the hypoglycemic, anti-diabetic and hypotensive potential of moringa using bioclinical, pharmacological and biochemical essays. In India 30 medicinal plants were studied, to which the Ayurveda, Unani and Siddha medicine systems ascribed hypoglycemic activity (Kar, Choudhary and Bandyopadhyay, 2003); the study confirmed that 24 of them caused a decrease in the blood glucose concentration of albino rats, and one of the species with higher hypoglycemic effect was *M. oleifera*.

The moringa leaves show hypoglycemic and hipotensive activity, among other biological activities (Murakami *et al*., 1998; Iqbal and Bhanger, 2006). Evidence has been obtained about their potential to alleviate diseases of the endocrine system, such as thyroid (Tahiliani and Kar, 2000) and insulin secretion disorders (Jaiswal *et al*., 2009).

Several phytochemicals obtained in the *M. oleifera* leaves and fruits have revealed their potential for diabetes and blood hypertension control. Francis, Jayaprakasam, Olson, and Nair (2004) could isolate and purify eight biologically active compounds from fruits of this plant, of which a thiocarbamate, two carbamates and phenyl glucoside stimulated the insulin secretion in pancreatic β cells of rats (Francis *et al*., 2004). On the other hand, in a study conducted by Pakistani scientists it was proven that the responsibility for the anti-hypertensive activity of moringa lies on thiocarbamate and isothiocyanate, as well as on β-sitosterol and methyl p-hydroxybenzoate (Faizi *et al*., 1998). This result coincides with a previous report which revealed the anti-hypertensive activity of the thiocarbamate glycosides isolated from *M. oleifera (Jansakul, Wun-Noi, Croft and Byrne, 1997).*

The high content of vitamins in moringa is essential in its use for diabetes treatment. Vitamin D is fundamental for the correct functioning of the pancreas and insulin secretion. The presence of β-carotene reduces the risk of blindness in diabetic patients. Vitamin B-12 is useful in the treatment of diabetic neuropathy and vitamin C prevents the accumulation of sorbitol and the glycosylation of proteins, two extremely important factors in the development of such diabetic complications as cataracts.

Adverse effects

The wide human consumption of *M. oleifera* as part of the diet and of therapeutic remedies during centuries, without reporting cases of allergies and toxicity, may seem a sufficient proof of its innocuousness. However, the accumulated knowledge would not be enough unless it was supported by scientific evidence.

Oral tests of chronic and acute toxicity in laboratory rats showed that the moringa seed does not exert any toxic effect, and rather causes a weight increase (Jahn, 1998). Toxicity has been detected on protozoa and bacteria, which is therapeutically useful and does not represent any disadvantage (Ndabigengesere *et al*., 1995). Fortunately, most tests confirm the high safety margins of the extracts from the seeds and other plant parts, for which it may be stated that the non toxicity of its seeds is scientifically proven.

M. oleifera in water treatment

The use of *M. oleifera* in water treatment to purify it is an ancient practice. In some popular literature sources this use is said to be included in the following Old Testament passage: "…Arriving at Murah, they could not drink the water because it was bitter (…) Moses pleaded with the Lord to help them, and the Lord showed them a tree to throw into the water, and the water became sweet." (Exodus 15:22-27). Independently from the attributes of moringa and the theological value of the above-mentioned biblical passage, the arguments to relate them lack scientific basis. In the same way as there is no evidence to prove that: "the tree of life, bearing twelve crops of fruit, yielding its fruit every month (…) the leaves are for the healing of the nations…" (Apocalypse 22:2-3) is another mention of moringa in the Holy Scriptures. The truth is that the seeds have been used for centuries in different regions of Asia and Africa as a natural coagulant for the clarification of turbid water (Jahn, 1988; Foidl *et al*., 2001).

Purification of drinkable water

The effectiveness of the *M. oleifera* seeds for the removal of suspended matters contained in turbid waters has been convincingly proven (Jahn, 1988; Muyibi and Evison, 1995; Ndabigengesere *et al*., 1995). In addition, it has been shown that moringa not only has coagulant properties, but also bactericide action (Folkard and Sutherland, 1996), which supports its use in water potabilization. In a study conducted in turbid waters of the Nile river, in two hours of treatments up to 99,5 % of the turbidity was reduced and 99,99 % of the bacteria were eliminated (Madsen, Schlundt and El Fadil, 1987).

Likewise, it has been indicated that the coagulant action is done by certain flocculant proteins which have been extracted from the *M. oleifera* seeds and characterized by different authors (Bhuptawat, Folkard and Chaudhari, 2007; Santos *et al*., 2009). It consists in divalent cationic proteins with a molecular mass of 13 kDa and isoelectric points between 10 and 11 (Ndabigengesere *et al*., 1995). The coagulation mechanism is linked to the adsorption and neutralization of colloidal charges.

According to the authors' opinion, the use of moringa seeds for water purification is an economically attractive choice for underdeveloped countries, taking into consideration the high cost of many chemical coagulants. In addition, some of them –such as aluminum sulfate (alum) - may have adverse effects on human health (Mendoza, Fernández, Ettiene and Díaz, 2000). The application of the seed to the water treatment generates lower mud volumes, as compared to alum (Ndabigengesere *et al*., 1995).

The required dose of seed extracts is similar to that of alum which is normally used, but if the treatment is done with purified proteins and not with the whole extract, the coagulant effect is much higher. Taking also into consideration that moringa is biodegradable, it is not toxic, and affects neither water pH nor conductivity, and the mud produced by coagulation is innocuous and little voluminous, it may be considered a viable substitute of alum. Although the non-toxicity of the seeds is confirmed, Santos *et al*. (2009) suggest to treat thermally the purified water to denaturalize the protein lectin , which is a known nutritional factor.

In addition to the studies at laboratory level successful tests have also been conducted at pilot and industrial scale (Folkard, Sutherland and Grant, 1992). However, it has not been possible to generalize the application due to the strong competition of commercial coagulants. On the other hand, the strict sanitary control existing in many countries restricts the use of new products on drinkable water. For such reason, a first step in the generalization of results could be the application of seed extracts of *M. oleifera* in the treatment of residual waters (Bhuptawat *et al*., 2007).

Residual water treatment

There are experiences about the application of *M. oleifera* in the treatment of residual water from different sources. Its use has been reported in the treatment of sewage (Bhuptawat *et al*., 2007) and industrial effluents (Ndabigengesere and Narasiah, 1998; Bhatia, Othman and Ahmad, 2007; Krishna Prasad, 2009; Morales, Méndez and Tamayo, 2009).

The evaluation at laboratory scale of an aqueous extract of moringa seeds in the treatment of sewage resulted in a decrease of the chemical oxygen demand (COD) higher than 50 %. The combination of doses of 100 mg/L of extract with 10 mg/L of alum increased the COD removal to 64 %. The simplicity of the procedure and the low cost of the extract support the treatment for its application at higher scales (Bhuptawat *et al*., 2007).

In the treatment of slaughter effluents with powder of *M. oleifera* seeds a reduction of the absorbance of 25 % for sewage was achieved, with lower quantity of suspended organic matter, and 82 % of reduction for lagoon wastewater, with higher quantity of suspended solids (Morales *et al*., 2009). The protein extractions from the seeds with saline solutions and its later use in distillery vinasse resulted in a removal of 53-64 % of the initial color (Krishna Prasad, 2009). The use of moringa defatted cake in palm oil extraction plants allowed to eliminate 95 % of the suspended solids and decrease the COD in 52,2 %. Combined with a commercial coagulant, the solid removal exceeded 99 % (Bhatia *et al*., 2007).

M. oleifera can also be useful in vector control in stagnant water. It was recently proven that seed extracts prevent the adaptation of *Aedes aegypti* to the control means used in vector control. The larvicide activity is ascribed to water soluble lectin contained in the extracts, which promotes the delay in larval growth and their mortality (Coelho *et al*., 2009).

Hard water softening

Water hardness, which consists in a high salt content, affects soap capacity as cleaning agency and causes incrustations in the pipes and equipment, creating inconveniences at industrial as well as domestic level. The process of water metal ion removal is known as softening and can be done by different methods, such as chemical precipitation, ion exchange and nanofiltration, among others. The *M. oleifera* seed has the capacity to eliminate calcium, magnesium ions and other divalent cations (Muyibi and Evison, 1995). This property was accidentally discovered in a clarification study which revealed a 60-70 % reduction of water hardness after coagulation and two hours of sedimentation (Sani, 1990). Afterwards, Muyibi and Evison (1995), in a study with four different sources of hard waters, showed that the mechanism of hardness elimination is through the adsorption of soluble ions and their later precipitation, and that removal efficiency is directly proportional to the moringa dose and independent from the water pH.

Adsorption of heavy metals

During the last decade, the use of bioabsorbents has gained acceptance for the adsorption of heavy metals, whose toxicity towards the human organism is widely acknowledged. The increasing popularity of bioabsorbents is due to the fact that the technologies currently used for the removal of toxic metals are neither effective nor economical (Reddy *et al*., 2011). They can be prepared from agricultural and agroindustrial residues, which show high adsorptive capacity due to the presence of polar functional groups which form coordination complexes with the metal ions in dissolution. In addition to its low cost, bioabsorbents show other advantages such as their high efficiency, little mud generation, high regeneration level and the possibility to recover the metal.

It was recently discovered that the moringa seeds as well as bark can be used for the adsorption of heavy metals such as cadmium, lead and nickel (Reddy *et al*., 2011). Taking into consideration the high costs of the main techniques used for the removal of toxic metals, the authors of this work consider that the discovery of the adsorptive capacity of this species is highly important for underdeveloped countries. Additionally, the *M. oleifera* bark allows a high degree of recovery of the adsorbed metals, reaching the desorption of 98 % of the nickel adsorbed from aqueous solutions (Reddy *et al*., 2011).

The effectiveness of the moringa bark powder to be used as bioabsorbent in several cycles of adsorption/desorption was confirmed in a kinetic study of adsorption and a rigorous physical-chemical characterization, using electronic microscopy, infrared spectroscopy, diffusion of X-rays and elemental analysis. The effectiveness of the material for lead removal was shown, even in the presence of other metal cations, such as Na+, K+, Ca2+ and Mg2+ (Reddy *et al*., 2011).

Non edible uses of the *M. oleifera* oil

Traditional uses

The oil shows between 22 and 40 % of the weight of *M. oleifera* seeds (Abdulkarim et al., 2005) and contains around 70 % of oleic acid (Martín *et al*., 2010). In addition to the above-discussed edible uses, its oil –commonly known as “ben oil”- receives diverse non edible uses, many of which go back to the classic civilizations of the Antiquity and are related to its particular physical and chemical properties.

This oil has the property of absorbing and retaining floral fragrances, which makes it very appropriate for the perfume and cosmetic industry. In Ancient Egypt the moringa oil was used in the preparation of perfumes, beauty lotions, holy anointing oil, skin protectors against infections, insect repellent, skin and hair humectant and conditioner (Deon, 2006). The Greek, Etruscan and Roman civilizations also used it for the same purposes (Forbes, 1955). In the modern cosmetic industry, it is used in the elaboration of soaps and perfumes (Ghazali and Mohammed, 2011), as humectants and for hair care (Kleiman, Ashley and Brown, 2008). For a long time, it was highly valued as clockwork and precision machinery lubricant (Ramachandran *et al*., 1980), and its use has also been reported in lighting because it burns without smoke.

Biodiesel production

M. oleifera, as it is a fast-growth, drought-resistant plant, with high oil yield, is an excellent choice for the sustainable production of biodiesel in countries with arid lands. In a study of the oil plants with potential for producing biodiesel in Africa, this species –with an annual yield of three tons of oil per hectare- turned out to be the second most promising one, over Jatropha curcas and surpassed only by *Croton megalocarpus* (Kibazohi and Sangwan, 2011).

Recent studies have shown the potential of moringa oil for biodiesel production (Rashid *et al*., 2008; Silva *et al*., 2010). The properties of products of the transesterification of this oil, such as: density, cinematic viscosity, lubricity, oxidative stability, cetane number and cloud point, fulfill the international standards for its use as fuel. The optimization of the alkaline transesterification conditions of the *M. oleifera* oil for biodiesel production was also reported (Rashid *et al*., 2011).

Utilization of the husks from *M. oleifera* seeds and dry pods

If the extraction of the *M. oleifera* oil and the utilization of the press cake were industrialized, large quantities of solid residues formed by the husks from seed and the fruit dry pods would be generated. A possible application of the husks is the production of activated carbon. In studies about carbonization, followed by their vapor activation, carbons were obtained with a highly developed microporous structure and a high specific area (Pollard, Thompson and McConnachie, 1995). Vapor pyrolysis has also been evaluated in only one stage, which causes the carbons to have higher adsorptive capacity than those produced by the conventional carbonization-activation method in two stages (Warhurst, McConnachie and Pollard, 1997). In both cases, the carbons showed a performance comparable with that of commercial activated carbons, and their production will represent resource saving in importing. Another possible use of the husks is the production of anion exchange resins (Orlando *et al*., 2003).

The husks as well as the dry pods of the moringa fruit are object of study by the authors of this work. It has been observed that their polysaccharide content is relatively high and glucanes represent 28 % in the husks (Martín *et al*., 2010) and 32 % in the pods (Martín and Puls, unpublished). The high content of glucanes, comparable to that of other lignocellulosic bioresources (Martín, López, Plasencia, and Hernández, 2006), promotes the interest in these materials as possible substrata for producing ethanol and other products of glucose bioconversion. For such reason it is necessary to hydrolyze the polysaccharides to obtain fermentable sugars. In preliminary trials it was proven that the glucanes present in the pods (Hernández *et al*., 2010) are more easily hydrolyzed than those of husks (Martín *et al*., 2008), which may be ascribed to the higher lignin content in the latter. If it is also taken into consideration that the pod represents 64 % of the fruit weight, the remarkable potential of this material for ethanol production is stressed.

Final considerations

The critical analysis of the available bibliography about the use of *M. oleifera* reveals that, although there are still some aspects to clarify, a considerable part of the benefits ascribed to it are scientifically confirmed. According to the authors of this paper, this species is a bioresource of high interest for its exploitation in Cuba, for which the following strategies are proposed:

- At short term: the use of leaves and fresh fruits in human and animal feeding, and in the extraction of their active principles for possible medical-pharmaceutical uses.
- At long term: the use of the dry fruits in oil production for possible feeding and non-feeding uses. This variant would generate press cakes, pods and husks.
- From the cakes proteins could be extracted for water purification and active principles for medical-pharmaceutical purposes. The remainder of the cake could be used for animal feeding.
- The pods are of interest for ethanol production, although more research is required.
- The husks could be used in activated carbon production.

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