Indian J. Agric. Res., 50 (3) 2016 : 199-205
Print ISSN:0367-8245 / Online ISSN:0976-058X

AGRICULTURAL RESEARCH COMMUNICATION CENTRE
www.arccjournals.com/www.ijarjournal.com

Moringa oleifera: A new challenge reducing heavy metal toxicity: A review

Kanitta Jiraungkoorskul and Wannee Jiraungkoorskul*

Department of Pathobiology, Faculty of Science,
Mahidol University, Bangkok-10400, Thailand.

Received: 30-12-2015 Accepted: 04-02-2016 DOI:10.18805/ijare.v0iOF.9361

ABSTRACT

Various parts of *Moringa oleifera* i.e., fruit, seed, leave, flower, bark, and root, have been used extensively in traditional medicine. One of these usages is the reducing of heavy metal toxicity. The mechanism of metal removal property by using the characteristic of its surface morphology and functional groups to uptake the heavy metal. Moreover this plant reduced the metal toxicity in living organism by its antioxidant properties. The advantage utilization of this plant is very interesting as it can easily be cultivated worldwide. Its biosorbent properties are inexpensive, availability, profitability easy of operation, effectiveness in reducing the concentration of heavy metal ions to very low levels. Besides, this plant is reported to have various chemical constituents that have the biological activities including the depletion of metal concentration and the antioxidant properties that are potential to reduce the oxidative stress induced by heavy metal.

Key words: Adsorption, Antioxidant, Heavy metal, *Moringa oleifera*, Traditional medicine.

INTRODUCTION

Nowadays, heavy metal is currently the serious pollution problem and increasingly prevalent in our daily life which should never be neglected. It has been identified in the polluted environment include cationic metals i.e., cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), manganese (Mn), mercury (Hg), nickel (Ni), zinc (Zn) whereas anionic metals are arsenic (As), boron (B), molybdenum (Mo), selenium (Se) (USDA, 2000). Natural as well as anthropogenic actions are the hundred sources of heavy metal pollution include point sources such as emission, effluent, smelting, mining, discharge from industry, vehicle exhaustion. The non-point sources are use of pesticide and municipal waste in agriculture, disposal of industry (Lone *et al.* 2008). Arsenic is used as semiconductor, animal feed additive, herbicides and wood preservative (Kumari *et al.*, 2006). Copper is used as electroplating, smelting and refining (Rai and Pal, 2002). Cadmium is used as color pigment, and rechargeable battery (Ivanova *et al.*, 2013). Chromium is used as metal alloy, color pigment, cement, rubber industry, paper and pulp mill (Akunna *et al.*, 2012). Lead is used as building material, paint and antiknock in petrol (Reddy *et al.*, 2010). Mercury is used as a whitening cosmetic, syphilis treatment and filling teeth (Jarup, 2003). Nickel is used as electroplating, stainless steel, ceramic and aircraft industry (Reddy *et al.*, 2011). The epidemiological studies of heavy metal poisoning were reported i.e., the chronic cadmium intoxication or itai-itai disease in Japan in 1947 caused a yellow discoloration of teeth or cadmium ring, lost of the sense of smell, dry mouth, anemia and impairment of bone marrow (Inaba *et al.*, 2005). The most obvious sign after exposure with arsenic was the blisters on the palms and soles, which could eventually turn gangrenous and cancerous as known as the black foot disease. The four serious incidents of arsenic outbreaks had been reported in People's Republic of China (Lian and Jian, 1994), India (Mandal *et al.*, 1999), Bangladesh (Smith *et al.*, 2000) and Taiwan (Yang *et al.* 2003). The Minamata disease was follow by the outbreak of mercury poisoning in 1956 because people who living around Minamata bay in Japan after consumed fish and progressively suffered from a weakening of muscles, loss of vision, impairment of cerebral function (Yorifuji *et al.*, 2011). In 1960 fatal incidents of lung cancer were reported from Japan due to inhalation of dust containing chromium (Rai and Pal, 2002). The US Environmental Protection Agency suggests that cadmium, copper, lead, manganese, nickel and zinc in drinking water should not exceed 0.005, 1.3, 0.015, 0.05, 0.04 and 5 mg L^{-1}, respectively (USDA, 2000; Obuseng *et al.*, 2012).

The traditional methods used for the removal of heavy metal from the wastewater are filtration (Sun *et al.*, 2009), chemical precipitation (Fu *et al.*, 2012), ion exchange (Lee *et al.*, 2007), reverse osmosis (Mohsen-Nia *et al.*, 2007), and adsorption (Kita and Skoblewski, 2010). The use of plant species for cleaning polluted soil and water named as phytoremediation, has gained increasing popularity due to the more cost-effective and fewer side effects than physical and chemical approaches (Ali *et al.*, 2013). Numerous plant species have been identified and examined for their potential in reducing different heavy metal toxicity. Among them, *Moringa oleifera*, is the new challenge of tradition medical

*Corresponding author's e-mail: pathobiologymu@gmail.com.

plant use both *in vitro* and *in vivo* for reducing metal toxic in environment and living organism.

Moringa oleifera: *M. oleifera* is known by such regional names as (Africa) mrongo, mzunze, (Bangladesh) sajina, (Cambodia) ben aile, daem mrum, (China) la mu, lat mok, la ken, (Colombia) angela, (France) moringe à graine ailée, (Ghana) yevu-ti, zingerindende, (India) segra, shajmah, sigru, (Indonesia) kalor, kelor, (Kenya) mronge, (Myanmar) daintha, dandalun, (Nepal) shobhanjan, sitachini, (Nigeria) ewe ile, bagaruwar maka, (Pakistan) soanjana, suhanjna, (Philippines) mulangai, mulangay, (Spain) árbol del ben, ángela, (Sri Lanka) murunga, (Taiwan) la mu, (Thailand) marum, (Vietnam) chum ngay, (Zimbabwe) mupulanga (Fahey, 2005; Parrotta, 2009; Paliwal *et al.*, 2011). The other common names are from the appearance of the long, slender pod which calls drumstick tree, from the spicy taste which calls horseradish tree or from the seed oil extract which calls benzoil tree (Paliwal *et al.*, 2011). *M. oleifera* is the most widely known in family of Moringaceae which has 13 species, *M. arborea, M. borziana, M. concanesis, M. drouhardii, M. hildebrandtii, M. longituba, M. oleifera, M. ovalifolia, M. peregrina, M. pygmaea, M. rivae, M. ruspoliana,* and *M. stenopetala* (Mahmood *et al.*, 2010; Paliwal *et al.*, 2011). The taxonomy of *M. oleifera* is in the Kingdom (Plantae); Subkingdom (Tracheobionta); Superdivision (Spermatophyta); Division (Magnoliophyta); Class (Magnoliopsida); Subclass (Dilieniidae); Order (Brassicales); Family (Moringaceae); Genus (Moringa); Species (*Moringa oleifera*) (USDA, 2013). The moringa tree is a small to medium size shrub, evergreen or deciduous tree common throughout the semi-arid tropical and subtropical regions of Africa, South America and Southeast Asia since its preferred dry, sandy soil habitat (Fig 1). It characterizes as fast rate growth and can be as tall as 7-12 m. and as wide

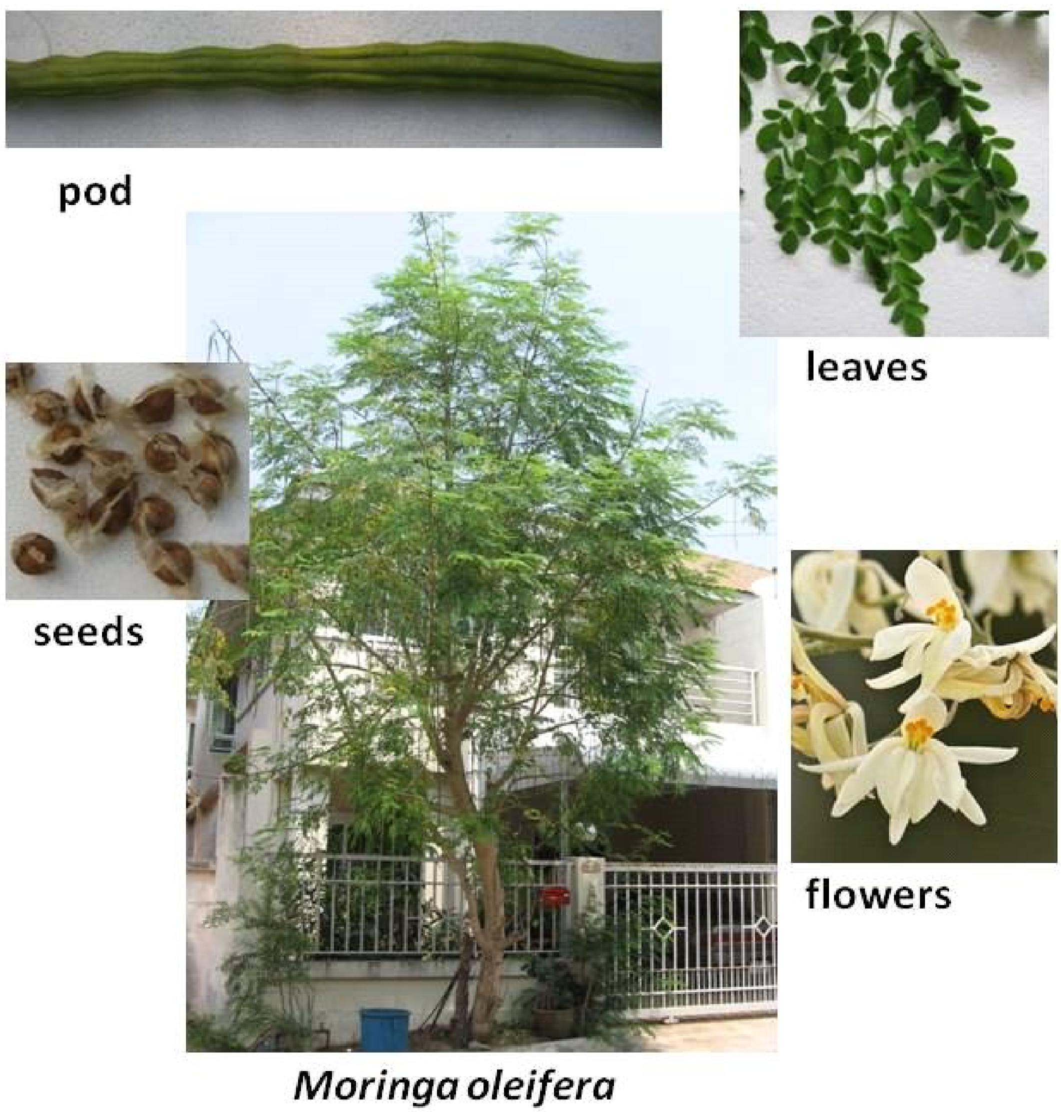

FIG 1: The general morphology of *Moringa oleifera*

as 20-40 cm. The stem is straight with a whitish-grey color, thick, soft, fissured and warty or corky, is easily peel off. The flower has pleasant fragrance and is 2-5 cm wide producing profusely in auxiliary drooping panicles of 10-25 cm long. It is white or cream color and yellow dotted at the base. The fruit is pendulous, linear, three-sided pods with nine longitudinal ridges, usually 20-60 cm long and 2.0-2.5 cm broad, containing 12-35 black seeds. The seed is about 1 cm in diameter, round shape, dark brownish with three whitish papery wings on the angles. The alternate, pinnate leaves grow mostly at the branch tips; they are 1.2 to 2.0 cm long and 0.6 to 1.0 cm wide. The leaflets are finely hairy, green and almost hairless on the upper surface, paler and hairless beneath, with red-tinged mid-veins, and are rounded or blunt-pointed at the apex and short-pointed at the base (Figure 1, Fahey, 2005; Parrotta, 2009).

***In vitro* reducing metal toxicity:** Several researches have focused on the use of various parts of *M. oleifera* in water purification and the treatment of turbid water is the best-known application (Pritchard *et al.*, 2010; Nkurunziza *et al.*, 2009). The seed contains cationic polyelectrolytes which have proved to be effective in the treatment of water, as a substitute for aluminum sulfate. Interesting in the study of natural coagulants for water contaminated with heavy metal is new and many studies have been performed in order to explore this application (Araújo *et al.*, 2013; Obuseng *et al.*, 2012). For removal of arsenic (Kumari *et al.* 2006), cadmium (Sharma *et al.*, 2006), chromium (Sharma *et al.*, 2007), lead (Reddy *et al.*, 2010), copper (Kalavathy & Miranda 2012), nickel (Marques *et al.*, 2012; Reddy *et al.*, 2011), silver (Araújo *et al.*, 2010), and zinc (Bhatti *et al.*, 2007) were reported by used several parts of *M. oleifera* plant.

Numerous studies have shown that *M. oleifera* possess effective coagulation properties. Ndabigengesere *et al*. (1995) reported that under non-reducing conditions, the coagulant proteins from *M. oleifera* seeds are 13 kDa dimeric cationic proteins with an isoelectric point pH 10-11, but under reducing conditions, the molecular weight was found to be 6.5 kDa. They suggested that the active protein is actually composed of two 6.5 kDa subunits, connected with an S-S bond that is cleaved when protein extraction occurs in reducing conditions, and that the mechanism of coagulation with *M. oleifera* consist of adsorption and charge neutralization of the colloidal charges. Agree with Gassenschmidt *et al.* (1995) who reported that the isolation from *M. oleifera* of a flocculating protein with the same molecular mass 6.5 kDa, isoelectric point above pH 10, high levels of glutamine, arginine and proline with the amino terminus blocked by pyroglutamate, and flocculant capacity comparable to a synthetic polyacrylamide cationic polymer. Scanning electron microscope has been widely used to study the morphological features of the biosorbent. *M. oleifera* bark India plant, showed the presence of asymmetric pores and open pore structure, which may provide high internal surface area and a rough structure on the surface bark, which is favorable for biosorption of heavy metal from aqueous pollutions (Reddy *et al.*, 2011). The X-ray diffraction pattern of *M. oleifera* bark showed the presence of an amount of amorphous material due to lignin and tannin. The Fourier transform infrared spectra of *M. oleifera* bark showed the presence of many functional groups, including hydroxyl group, carboxylic acid and carbonyl group (Reddy *et al.*, 2011). The change in hydroxyl group after biosorption indicated that it had been changed from multimer to monopolymer or even dissociative state which showed that the degree of hydroxyl polymerization in lignocellulose was decreased by binding of nickel. These indicated that the biosorption of metal occurs at hydroxyl, carboxyl and carbonyl functional groups present on the surface of the plant (Reddy *et al.*, 2011). The similar results were reported in the biosorption of lead by leave (Reddy *et al.* 2010), arsenic by seed (Kumari *et al.*, 2006), cadmium by seed (Sharma *et al.* 2006), copper, nickel and zinc by bark (Kalavathy and Miranda, 2012) using electron microscope, fourier transform infrared spectrophotometer, wide angle X-ray diffraction.

Obuseng *et al.* (2012) reported that the carboxylic acid and hydroxyl groups presented *M. oleifera* play a major role in the removal of heavy metal ions as observed from the significant reduction in the intensity or shift in their intensity peaks for metal-loaded by using fourier transform infrared spectrophotometer. They also reported that the trend of heavy metal removal using sonication method followed the order*:* Pb > Cu > Cd > Ni > Mn. Similarly results reported by Ravikumar and Sheeja (2013) that the percentage removals by *M. oleifera* seed India plant were Cu(95%) > Pb(93%) > Cd(76%) >Cr(70%). Sharma *et al.* (2007) also reported that the percentage removals by *M. oleifera* seed India plant were Cd(85%) >Cr(81%) > Ni(76%).

Biosorption can be defined as the ability of biological materials binding with heavy metal from wastewater. The active agents in this plant are glucosinolates and phenolics which are the functional groups that are capable of anchoring metals (Bennett *et al.*, 2003). Biosoption activity could be explained by the charge-patch mechanism due to low molecular weight and high charge density.

***In vivo* reducing metal toxicity:** The researches that regarding treatment of heavy metal are restricted mainly to some chelating agents or in combination with few antioxidants but most of the conventional metal chelating agents and antioxidants have been reported to possess toxic side effects or disadvantages i.e., headache, nausea, hypertension, hepatotoxicity, and nephrotoxicity (Flora, 2009; Ivanova *et al.*, 2013). The properties of chelating agents are capable of binding to toxic metal ions to form complex structures which are easily excreted from the body removing them from intracellular or extracellular spaces (Flora and Pachauri, 2010). Newer strategy in the therapeutic potential of medicinal plant or herb in reducing metal toxicity is increased interested. *M. oleifera* is reported to have various biological activity, including hypolipidemia (Ghasi *et al.*, 2000), regulation of thyroid hormone (Tahiliani and Kar, 2000), antihyperglycemia (Jaiswal *et al.*, 3013), antibacterial properties (Horwath and Benin, 2011), antiulcer (Choudhary *et al.*, 2013), antitumor (Sreelatha *et al.*, 2011), antiinflammation (Alhakmani *et al.*, 2013), cardioprotective (Panda *et al.*, 2013), hepatoprotective (Hamza, 2010), nephroprotective (Ouedraogo *et al.*, 2013) and neuroprotective activity (Bakre *et al.*, 2013). This article reviewed the new challenge of *M. oleifera* in relation to the treatment of heavy metal toxicity in environment and living organism.

Grabow *et al.* (1985) reported that the therapeutic efficacy of oral administration of 500 mg kg^{-1} is not toxic to human or to animal. After exposure the 100 ppm sodium arsenate in drinking water for 120 days, the therapeutic dose of seed power of *M. oleifera* India plant was fed to rat. In the blood of arsenic treated rat showed decrease of d-aminolevulinic acid dehydratase (ALAD) activity, reduced glutathione (GSH) level but increase in reactive oxygen species (ROS) in blood. In the liver was also found decrease in ALAD, but increase in d-aminolevulinic acid synthetase (ALAS) and thiobarbiturc acid reactive substances (TBARS). Activities of liver, kidney and brain superoxide dismutase (SOD) and catalase also showed a decrease on arsenic exposure. Administration of *M. oleifera* seed powder post arsenic exposure, exhibited recovery in blood ALAD activity, it restored blood GSH and ROS levels. A protection in the altered ALAD and ALAS activities of liver and TBARS level was also observed. The plant is help to deplete the amount of arsenic from blood, liver and kidneys (Gupta *et al.*, 2005).

After exposure the 150 ppm potassium dichromate in drinking water for 100 days, the 50 mg kg^{-1} of leave power of *M. oleifera* Nigeria plant was fed to rat. The chromium treated rat showed a decrease in body weight, testis weight, testis volume, testis weight/body weight ratio, plasma testosterone level, testicular enzyme glutathione peroxidase, sperm parameters i.e., sperm morphology, motility, concentration. But the treatment with moringa plant slightly prevented the chromium toxicity by enhancing the testicular morphology, improve sperm parameters, and also testosterone level (Akunna *et al.*, 2012).

The fish were fed with the supplementation with 60 mg g^{-1} fish food of leave power of *M. oleifera* Thailand plant for 28 days, and then exposed with 50% of 24h-LC_{50} of lead nitrate for 24 hours. In the non pre-moringa fed group, after lead-exposure, fish showing loss of normal gill architecture, primary and secondary lamellar disorganization, abnormal regeneration of epithelial cells, filament epithelium hyperplasia, aneurysms and lifting of the outer layer of the lamellae epithelium with the space under the epithelium. The liver was shown abundant cytoplasmatic vacuolation, some hepatocytes showing hypertrophy nuclei, and parenchyma disorganization. Renal tissue was shown glomerulus atrophy, increase number of lymphocytes in parenchyma, cloudy swelling, tubular narrowing and hyaline droplet. In contrast, the pre-moringa fed group showing slightly histopahtological change in gill, liver, and kidney. Moreover it was found numerous of mucous cells per lamella with histochemical technique (Sirimongkolvorakul *et al.*, 2012; 2013).

Chemical composition and antioxidant: Various parts of *M. oleifera* have been analyzed for chemical constituents. It is found that glucosinolates and phenolics (flavonoids, anthocyanins, proanthocyanidins, and cinnamates) are the major compounds (Araújo *et al.*, 2013). *M. oleifera* seed is reportedly containing 4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate (Bennett *et al.*, 2003) and also has proanthocyanidin and flavonoid content (Compaore *et al.*, 2011). The root has high concentrations of both 4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate and benzyl glucosinolate (Bennett *et al.*, 2003). The leaf contain 4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate and three monoacetyl isomers of this glucosinolate (Bennett *et al.*, 2003). The major phytochemical constituents in the leaves are phenolic compounds and flavonoids including quercetin and kaempferol (Verma *et al.*, 2009; Vongsak *et al.*, 2013). The bark contain only 4-(α-L-rhamnopyranosyloxy)-benzylglucosinolate (Bennett *et al.* 2003). Phytochemical analysis revealed the presence of tannins, flavonoids, steroids and alkaloids in the bark (Kumbhare *et al.*, 2012). The chemical compositions in this plant have more powerful antioxidants which are the advantage product to reduce the heavy metal toxicity.

ACKNOWLEDGMENTS

This review article was funded by the Thailand Research Fund and the Commission on Higher Education: Research Grant for Mid-Career University Faculty and in part by Mahidol University International College, Mahidol University. Thanks should be addressed to the members of the Fish Research Unit, Department of Pathobiology, Faculty of Science, Mahidol University for their technical support. Many thanks to anonymous referees and editor for their perceptive comments on, and positive criticism of this manuscript.

REFERENCES

Akunna, G.G., Ogunmodede, O.S., Saalu, C.L., Ogunlade, B., Bello, A.J. and Salawu, E.O. (2012). Ameliorative effect of *Moringa oleifera* (drumstick) leaf extracts on chromium-induced testicular toxicity in rat testes. *World J. Life Sci. Med. Res.* **2:** 20-26.

Alhakmani, F., Kumar, S. and Khan, S.A. (2013). Estimation of total phenolic content, *in-vitro* antioxidant and anti-inflammatory activity of flowers of *Moringa oleifera. Asian Pac. J. Trop. Biomed.* **3:** 623–627.

Ali, H., Khan, E. and Sajad, M.A. (2013). Phytoremediation of heavy metal - Concepts and applications. *Chemosphere* **91:** 869-881.

Araújo, C.S.T., Melo, E.I., Alves, V.N. and Coelho, N.M.M. (2010). *Moringa oleifera* Lam. seeds as a natural solid adsorbent for removal of AgI in aqueous solutions. *J. Braz. Chem. Soc.* **21:** 1727-1732.

Araújo, C.S.T., Carvalho, D.C., Rezende, H.C., Almeida, I.L.S., Coelho, L.M., Coelho, N.M.M., Marques, T.L. and Alves, V.N. (2013). Bioremediation of waters contaminated with heavy metals using *Moringa oleifera* seeds as biosorbent. *Intech* 227-255.

Bakre, A.G., Aderibigbe, A.O. and Ademowo, O.G. (2013). Studies on neuropharmacological profile of ethanol extract of *Moringa oleifera* leaves in mice. *J. Ethnopharmacol.* **149:** 783–789.

Bennett, R.N., Mellon, F.A., Foidl, N., Pratt, J.H., Dupont, M.S., Perkins, L. and Kroon, A. (2003). Profiling glucosinolates and phenolics in vegetative and reproductive tissues of the multi-purpose trees *Moringa oleifera* L. (Horseradish Tree) and *Moringa stenopetala* L. *J. Agric. Food Chem.* **51:** 3546-3553.

Bhatti, H.N., Mumtaz, B., Hanif, M.A. and Nadeem, R. (2007). Removal of Zn(II) ions from aqueous solution using *Moringa oleifera* Lam. (horseradish tree) biomass. *Process Biochem.* **42:** 547–553.

Choudhary, M.K., Bodakhe, S.H. and Gupta, S.K. (2013). Assessment of the antiulcer potential of *Moringa oleifera* root-bark extract in rats. *J. Acupunct. Meridian Stud.* **6:** 214-220.

Compaoré, W.R., Nikièma, P.A., Bassolé, H.I.N., Savadogo, A., Mouecoucou, J., Hounhouigan, D.J. and Traoré, S.A. (2011). Chemical composition and antioxidative properties of seeds of *Moringa oleifera* and pulps of *Parkia biglobosa* and *Adansonia digitata* commonly used in food fortification in Burkina Faso. *Curr. Res. J. Biol. Sci.* **3:** 64-72.

Coppin, J.P., Xu, Y., Chen, H., Pan, M.H., Ho, C.T., Juliani, R., Simon, J.E. and Wu, Q. (2013). Determination of flavonoids by LC/MS and anti-inflammatory activity in *Moringa oleifera*. *J. Func. Foods* **5:** 1892-1899.

Fahey, J.W. (2005). *Moringa oleifera*: A review of the medical evidence for its nutritional, therapeutic, and prophylactic properties. Part 1. *Trees for Life J.* **1:** 5.

Flora, S.J.S. (2009). Structural, chemical and biological aspects of antioxidants for strategies against metal and metalloid exposure. *Oxid. Med. Cell Longev.* **2:** 191-206.

Flora, S.J.S. and Pachauri, V. (2010). Chelation in metal intoxication. *Int. J. Environ. Res. Publ. Health* **7:** 2745-2788.

Fu, F., Xie, L., Tang, B., Wang, Q. and Jiang, S. (2012). Application of a novel strategy - Advanced Fenton-chemical precipitation to the treatment of strong stability chelated heavy metal containing wastewater. *Chem. Eng. J.* 189–**190:** 283-287.

Gassenschmidt, U., Jany, K.K., Tauscher, B. and Niebergall, H. (1995). Isolation and characterization of a flocculating protein from *Moringa oleifera* lam. *Biochem. Biophy. Acta* **1243:** 477-481.

Ghasi, S., Nwobodo, E. and Ofili, J.O. (2000). Hypocholesterolemic effects of crude extract of leaf of *Moringa oleifera* Lam in high-fat diet fed wistar rats. *J. Ethnopharmacol.* **69:** 21–25.

Grabow, W.O.K., Slabert, J.L., Morgan, W.S.G. and Jahn, S.A.A. (1985). Toxicity and mutagenicity evaluation of water coagulated with *Moringa oleifera* seeds preparations using fish, protozoan, bacterial, enzyme and Ames Salmonella assays. *J. Am. Water Works Assoc.* **76:** 319–321.

Gupta, R., Kannan, G.M., Sharma, M. and Flora, S.J.S. (2005). Therapeutic effects of *Moringa oleifera* on arsenic-induced toxicity in rats. *Environ. Toxicol. Pharmacol.* **20:** 456–464.

Hamza, A.A. (2010). Ameliorative effects of *Moringa oleifera* Lam seed extract on liver fibrosis in rats. *Food Chem. Toxicol.* **48:** 345–355.

Horwath, M. and Benin, V. (2011). Theoretical investigation of a reported antibiotic from the ‘‘Miracle Tree’’ *Moringa oleifera*. *Comp. Theor. Chem.* **965:** 196–201.

Inaba, T., Kobayashi, E., Suwazono, Y., Uetani, M., Oishi, M., Nakagawa, H. and Nogawa, K. (2005). Estimation of cumulative cadmium intake causing itai-itai disease. *Toxicol. Lett.* **159:** 192-201.

Ivanova, J., Gluhcheva, Y., Tsanova, D., Piskova, A., Djaleva, R., Mokresheva, S., Kamenova, D. and Mitewa, M. (2013). On the effect of chelating agents and antioxidants on cadmium-induced organ toxicity. An overview. *Eur. J. Chem.* **4:** 74-84.

Jaiswal, D., Rai, P.K., Mehta, S. Chatterji, S., Shukla, S., Rai, D.K., Sharma, G., Sharma, B., Khair, S. and Watal, G. (2013). Role of *Moringa oleifera* in regulation of diabetes-induced oxidative stress. *Asian Pac. J. Trop. Med.* **6:** 426-432.

Jarup, L. (2003). Hazards of heavy metal contamination. *Br. Med. Bull.* **68:** 167-182.

Kalavathy, M.H. and Miranda, L.R. (2012). *Moringa oleifera* - A solid phase extractant for the removal of copper, nickel and zinc from aqueous solutions. *Chem. Eng. J.* **158:** 188–199.

Kita, G. and Skoblewski, P. (2010). Biosorption of heavy metal – Modern and cheap method of polluted wastewater treatment. *Food Chem. Biotechnol.* 74: 99-105.

Kumari, P., Sharma, P., Srivastava, S. and Srivastava, M.M. (2006). Biosorption studies on shelled *Moringa oleifera* Lamarck seed powder: removal and recovery of arsenic from aqueous system. *Int. J. Min. Pro.* **78:** 131-139.

Kumbhare, M.R., Guleha, V. and Sivakumar, T. (2012). Estimation of total phenolic content, cytotoxicity and *in–vitro* antioxidant activity of stem bark of *Moringa oleifera*. *Asian Pac. J. Trop. Dis.* **2:** 144-150.

Lee, I.H., Kuan, Y.C. and Chern, J.M. (2007). Equilibrium and kinetics of heavy metal ion exchange. *J. Chin. Ins. Chem. Eng.* **38:** 71-84.

Lian, F.W. and Jian, Z.H. (1994). Chronic arsenism for drinking water in some areas of Xingjian, China. In: Nriagu, J.O. (Ed.), Arsenic in the Environment. Part II: Human Health and Ecosystem Effects. John Wiley & Sons Inc., New York, pp. 159–72.

Lone, M.I., He, Z.L., Stoffella, P.J. and Yang, X. (2008). Phytoremediation of heavy metal polluted soils and water: Progresses and perspectives. *J. Zhejiang Univ. Sci. B* **9:** 210–220.

Mahmood, K.T., Mugal, T. and Haq, I.U. (2010.) *Moringa oleifera*: A natural gift-A review. *J. Pharm. Sci. Res.* **2:**775-781.

Mandal, B.K., Biswas, B.K., Dhar, R.K., Roy Chowdhury, T., Samanta, G., Basu, G.K., Chanda, C.R., Saha, K.C., Kabir, S., Roy, S. and Chakraborti, D. (1999). Ground water arsenic contamination and suffering of people in West Bengal, India and Bangladesh: Status report up to March 1998. In: Sarkar, B. (Ed.), Metal and Genetics. Plenum Corporation, New York, pp. 41–66.

Marques, T.L., Alves, V.N., Coelho, L.M. and Coelho, N.M.M. (2012). Removal of Ni (II) from aqueous solution using *Moringa oleifera* seeds as a bioadsorbent. *Water Sci. Technol.* **68:** 1435-1440.

Mohsen-Nia, M., Montazeri, P. and Modarress, H. (2007). Removal of Cu^{2+} and Ni^{2+} from wastewater with a chelating agent and reverse osmosis processes. *Desalination* **217:** 276-281.

Ndabigengesere, A., Narasiah, S. and Talbot, B.G. (1995). Active agents and mechanism coagulation of turbid waters using *Moringa oleifera*. *Water Res.* **29:** 703-10.

Nkurunziza, T., Nduwayezu, J.B., Banadda, E.N. and Nhapi, I. (2009). The effect of turbidity levels and *Moringa oleifera* concentration on the effectiveness of coagulation in water treatment. *Water Sci. Technol.* **59:** 1551–1558.

Obuseng, V., Nareetsile, F. and Kwaambwa, H.M. (2012). A study of the removal of heavy metals from aqueous solutions by *Moringa oleifera* seeds and amine-based ligand 1,4- bis[N,N-bis(2-picoyl)amino]butane. *Anal. Chem. Acta* **730:** 87-92.

Ouedraogo, M., Lamien-Sanou, A., Ramde, N., Ouedraogo, A.S., Ouedraogo, M., Zongo, S.P., Goumbri, O., Duez, P. and Guissou, P.I. (2013). Protective effect of *Moringa oleifera* leaves against gentamicin-induced nephrotoxicity in rabbits. *Exp. Toxicol. Pathol.* **65:** 335-339.

Paliwal, R., Sharma, V. and Janmeda, P. (2011). A review on horse radish tree (*Moringa oleifera*): A multipurpose tree with high economic and commercial importance. *Asian J. Biotechnol.* **3:** 317-328.

Panda, S., Kar, A., Sharma, P. and Sharma, A. (2013). Cardioprotective potential of *N*,á-L-rhamnopyranosyl vincosamide, an indole alkaloid, isolated from the leaves of *Moringa oleifera* in isoproterenol induced cardiotoxic rats: In vivo and in vitro studies. *Bioorganic Med. Chem. Lett.* **23:** 959-962.

Parrotta, J.A. (2009). *Moringa oleifera* Lam., 1785. Enzyklopädie der Holzgewächse, Handbuch und Atlas der Dendrologie. A. Roloff, H. Weisgerber, U. Lang, B. Stimm. WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.

Pritchard, M., Craven, T., Mkandawire, T., Edmondson, A.S. and O'Neill, J.G. (2010). A comparison between *Moringa oleifera* and chemical coagulants in the purification of drinking water – An alternative sustainable solution for developing countries. *Phys. Chem. Earth* **35:** 798–805.

Rai, U.N. and Pal, A. (2002). Health hazards of heavy metals. *Ar. EnviroNews* 8(1).

Ravikumar, K. and Sheeja, A.K. (2013). Heavy metal removal from water using *Moringa oleifera* seed coagulant and double filtration. *Int. J. Sci. Eng. Res.* **4:** 10-13.

Reddy, D.H.K., Harinatha, Y., Seshaiaha, K. and Reddy, A.V.R. 2010. Biosorption of Pb(II) from aqueous solutions using chemically modified *Moringa oleifera* tree leaves. *Chem. Eng. J.* **162:** 626–634.

Reddy, D.H.K., Ramana, D.K.V., Seshaiah, K. and Reddy, A.V.R. (2011). Biosorption of Ni(II) from aqueous phase by *Moringa oleifera* bark, a low cost biosorbent. *Desalination* **268:** 150–157.

Sharma, P., Kumari, P., Srivastava, M.M. and Srivastava, S. (2006). Removal of cadmium from aqueous system by shelled *Moringa oleifera* Lam seed powder. *Bioresour. Technol.* **97:** 299–305.

Sharma, P., Kumari, P., Srivastava, M.M. and Srivastava, S. (2007). Ternary biosorption studies of Cd(II), Cr(III) and Ni(II) on shelled *Moringa oleifera* seeds. *Bioresour. Technol.* **98:** 474–477.

Sirimongkolvorakul, S., Tansatit, T., Preyavichyapugdee, N., Kosai, P., Jiraungkoorskul, K. and Jiraungkoorskul, W. (2012). Efficiency of *Moringa oleifera* dietary supplement reducing lead toxicity in *Puntius altus. J. Med. Plants Res.* **6:** 187-194.

Sirimongkolvorakul, S., Jiraungkoorskul, W., Tansatit, T., Preyavichyapugdee, N., Kosai, P. and Uakulwarwat, K. (2013). Influence of *Moringa oleifera* on histopathological changes due to lead-toxicity in red-tail tinfoil barb, *Puntius altus. Fresenius Environ. Bull.* **22:** 1946-1950.

Smith, A.H., Lingas, E.O. and Rahman, M. (2000). Contamination of drinking water of arsenic in Bangladesh. Bull. *World Health Organ*. **78:** 1093–1103.

Sreelatha, S., Jeyachitra, A. and Padma, P.R. (2011). Antiproliferation and induction of apoptosis by *Moringa oleifera* leaf extract on human cancer cells. *Food Chem. Toxicol.* **49:** 1270-1275.

Sun, L., Miznikov, E., Wang, L. and Adin, A. (2009). Nickel removal from wastewater by electroflocculation-filtration hybridization. *Desalination* **249:** 832-836.

Tahiliani, P. and Kar, A. (2000). Role of *Moringa oleifera* leaf extract in the regulation of thyroid hormone status in adult male and female rats. *Pharmacol. Res.* **41:** 319-323.

United States Department of Agriculture, USDA. (2000). Heavy metal soil contamination. Soil quality-Urban technical note No.3, pp.1-7.

United States Department of Agriculture, USDA. (20130. *Moringa oleifera* Lam. Plants Database. Natural Resources Conservation Service.

Verma, A.R., Vijayakumar, M., Mathela, C.S. and Rao, C.V. (2009). *In vitro* and *in vivo* antioxidant properties of different fractions of *Moringa oleifera* leaves. *Food Chem. Toxicol.* **47:** 2196–2201.

Vongsak, B., Sithisarn, P., Mangmool, S., Thongpraditchote, S., Wongkrajang, Y. and Grit-sanapan, W. (2013). Maximizing total phenolics, total flavonoids contents and antioxidant activity of *Moringa oleifera* leaf extract by the appropriate extraction method. *Ind. Crop Prod.* **44:** 566–571.

Yang, C.Y., Chang, C.C., Tsai, S.S., Chaung, H.Y., Ho, C.K. and Wu, T.N. (2003). Arsenic in drinking water and adverse pregnancy outcome in an arseniasis endemic area in Northeastern Taiwan. *Environ. Res.* **91:** 29–34.

Yorifuji, T., Tsuda, T., Inoue, S., Takao, S. and Harada, M. (2011). Long-term exposure to methylmercury and psychiatric symptoms in residents of Minamata, Japan. *Environ. Int.* **37:** 907-913.