**Moringa oleifera**: A Plant Critical for Food Security, Nutraceutical Values and Climate Change Adaptation in the Hindu-Kush Himalayan Region: A Review

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**Abstract**

*Moringa oleifera*, commonly known as miracle tree, has been suggested to be rich in its nutritional, pharmacological and immunological values in animals and humans globally. The tree is a promising option for farmers, especially in the rural areas in the Hindu-Kush Himalayan region, for the sources of food and organic fertilizers and as the tools of climate change adaptation and mitigation. The purpose of the current review is to describe the nutraceutical and immunopharmacologic values of *Moringa* and its critical role in food security and climate change situation in the Himalayan countries including Nepal, India, Pakistan, China and others. Besides, the article presents few recommendations to upgrade the practical and theoretical approaches of conservation of this plant in these countries.

**Key words:** Climate change mitigation, Food security, Immunological values, *Moringa oleifera*, Nutritional values.

The genus *Moringa* (Order: Brassicales, Family: Moringaceae) includes 13 species (Dahot 1988; Anwar et al. 2007) among which *M. oleifera* is commonly known as cabbage tree, drumstick tree, horseradish tree, bengoi tree, benzool tree, miracle tree, Shiferaw, Sheetal Chini and mother’s best friend tree. This tree has been highly popular and crucial to people of the Philippines, Sudan and the Hindu-Kush region that includes Nepal, India, Bhutan, Myanmar, Afghanistan and Pakistan. It is being grown in West, East and South Africa, tropical Asia, Latin America, the Caribbean, Florida and the Pacific Islands (Gandji et al. 2018). *M. oleifera* is a deciduous tree that grows from both direct seedling and cuttings (Omotesho et al. 2013). Its popularity is due to nutraceutical values that comprise nutritional and pharmaceutical properties and its leaves, roots, seeds, barks, flowers and pods have been used for traditional medicine to treat malaria, asthma and topical wounds (Field observation and interview with concerned people in Nepal). Thus, its nutraceutical properties in animals and men have been the essential topics because of its high values for poor, weak and ill people.

The Hindu-Kush Himalayan (HKH) region comprises high mountains, vast glaciers and the region extends about 3500km (Shrestha et al. 2015). This area is predominant for the malnutrition and hunger because it has been reported that out of global undernourished 795 million people, 52% of them are from the HKH countries (Shelley 2015). In this situation, *M. oleifera* might be an alternative option of food security in the HKH region. Therefore, the purpose of this review is to discuss its nutraceutical values and its critical role in increasing the climate change situation in the HKH region.

**FOOD INSECURITY AND MORINGA IN THE HKH REGION**

It has been evidenced that nutritional status in the HKH region is highly poor because of the food insecurity and hunger. In Nepal, six districts requiring external food and non-food items are highly food insecure and 14 districts are moderately food insecure (GoN 2017). This country carries about 60%, 53% and 48% of the food insecure people in mountains, hills and plains respectively (Rasul et al. 2018). National food (in) security data suggests that Afghanistan, Bhutan, India, Nepal, Myanmar and Pakistan have 41%, 12%, 20%, 51%, 5% and 49% food insecure people respectively (Rasul et al. 2018). Besides, the high prevalence of stunting, wasting and underweight in children less than five years old has been reported (Rasul et al. 2018). The primary underlying factors of food insecurity are high poverty, low food energy intake, lack of pure drinking water, sanitation and hygiene, lack of nutrition knowledge of women and education, replacing traditional high nutritious crops like amaranth, buckwheat, minor millet, finger millet, foxtail millet, sorghum, barley and sweet potatoes by rice, wheat and maize, changing traditional healthy diets with processed food.
and drinks and climate change and environmental degradation (Rasul et al. 2018). Thus, in the changing scenarios of HKH region, alternative cropping like *Moringa oleifera* which are invaluable in nutraceutical values and can play food security particularly for the local communities who heavily depend on gathering these vegetables from natural habitats (Joshi et al. 2007; Dangol 2002).

**NUTRACEUTICAL VALUES**

**Nutritional and non-nutritional significance**

*M. oleifera* has been a favorite food for both the poor and wealthy people in the Himalayan nation. Its fruit or seed pods or drumsticks are used as a cooked pickle or fermented pickle, fried vegetable or vegetable soup cooked in whey or yogurt or mixed in mushroom or chicken, or fish. It has been reported that *Moringa* can be used as bread, milk, spice juices, sauces and tea (Rockwood et al. 2013). It is widely reviewed that how the dried *Moringa* powder can be consumed in raw form or can be added to various food added food products like biscuit (1%), butter milk (3%), weaning food (10%), soup (10%), labneh cheese (2%) (Ravani et al. 2017). Notably, each part of this plant is rich in crucial nutrients required for body metabolism. For example, its leaves have been shown to be rich in macronutrients like proteins, carbohydrates and fats and micronutrients like vitamins and minerals such as calcium, potassium, zinc, magnesium, iron and copper (Rockwood et al. 2013; Kasolo et al. 2010; Yameogo et al. 2011; Oliveira et al. 1999; Leone et al. 2016). This plant has been shown to provide seven times more vitamin C than oranges, ten times more vitamin A than carrots, 17 times more calcium than milk, nine times more protein than yogurt, 15 times more potassium than bananas and 25 times more iron than spinach (Rockwood et al. 2013). In addition, by using rat models, the plant has been shown to be rich in stigmasterol, sitosterol and campesterol that enhanced the production of milk through stimulating estrogen hormone (Titi et al. 2013). This indicates that the plant might be involved in increasing milk in lactating mother and thus the plant has been an easy option of treating malnutrition in the developing countries.

It has been reported that the protein content is higher and is close to that of human milk, chicken egg and cow’s milk (Oliveira et al. 1999). Protein and total amino acid content have been estimated to be about 22% and 44% in leaves, 18.9% and 31% in flowers, 19% and 30% in immature pods respectively with the significant amino acids being essential to the development of bones, muscles and blood. Its value is 440mg, 2185mg, 2030mg, 45mg and 30mg per 100gm of each fresh leaf, dry leaf, leaf powder, seed and pod respectively. Iron is an essential component of hemoglobin and myoglobin. Iron content is about 26mg to 28mg in the dry leaf to leaf powder respectively. Zinc is vital in the synthesis of DNA and RNA and proper growth of sperm cells. Zinc content in the leaves of *Moringa oleifera* has been calculated as 25.5mg/100gm indicating an important source for ordinary people. Copper is an essential trace element that takes part in the absorption and utilization of iron, the metabolism of glucose and cholesterol and the formation of red blood cells. It is critical in the growth of a fetus and newly born baby. Its content is about 5.2mg in seed to 3.1mg per 100gm pods. Magnesium takes part in the proper functioning of bones, heart and blood pressure maintenance. It is approximately 448mg in the dry leaf, 368mg in 100gm leaf powder and 635mg in 100gm seeds. Potassium plays critical functions in every cell including from nervous to the cardiovascular system. Potassium is about 259mg in 100gm fresh leaves or pods, 1236mg in 100gm fresh leaves, 1324mg in 100gm dry leaf. Sulfur, a healing element, acts as pain-relieving and the muscle and skeletal anti-inflammatory. Sulfur is about 137mg in 100gm pods. These data clearly illustrate why *M. oleifera* is a boon for the malnourished people.

While various parts of *M. oleifera* are rich in metals and others, due to the surface morphology and functional groups present in the plants, they can absorb many heavy metals and help in the reduction of metal toxicity *in vitro* and *in vivo* (Jiraungkoorskul and Jiraungkoorskul 2016), suggesting their roles in reducing stress and metal toxicity-related consequences.

**Immuno-pharmacological properties**

Immunopharma cological properties involve *M. oleifera* extract or isolated bioactive compound that has a pharmacologic role in regulating or inducing and maintaining the immune system of the vertebrates. Interestingly, several antioxidants, anti-inflammatory and immunomodulatory properties of these extracts or compounds have been identified. Lots of medicinal properties like antipyretic, analgesic, antiasthmatic, antioxidant, antiurolithiatic, anti-inflammatory, anti-diabetic, antidiabetic, anti-infectious, antidiabetes, antifungal, antitumor, anticancer, antilulcer, anti-spasmos, anti-hypertensive, diuretic, cholesterol lowering,
hepatoprotective, wound-healing, activities of *M. oleifera* has been extensively reviewed by the authors from the College of Horticulture Anand Agriculture University in India (Ravani et al. 2017). Interestingly, by using in vitro and in vivo studies involving animals, *M. oleifera* leaves have been shown to be a potent source of antioxidant compounds as determined by the 2,2-diphenyl-1-picryl-hydrazyl-hydrate (DPPH) scavenging activity, superoxide scavenging activity, nitric oxide (NO) scavenging activity and lipid peroxidation inhibition assays (Sreevaltha and Padma 2009; Shih et al. 2011). It has been shown that leaf extracts can inhibit NO production by macrophage cells following treatment with bacterial lipopolysaccharide (LPS) (Coppin et al. 2013). Following induction of human macrophage by cigarette smoke and LPS, it reduced the production of tumor necrosis factor-alpha (TNF-α), interleukin (IL)-6 and IL-8 (Kooltheat et al. 2014). The reduction of serum TNF-α and IL-1 in rats following oral feeding of the extracts has been reported (Rajanandh et al. 2012). Another study found decreased gene expression of TNF-α, IL-1beta(β) and IL-6 following oral feeding of leaf concentrates (Waterman et al. 2015) indicating their role in the reduction of inflammation. Both cellular and humoral responses, detected by the enhanced number of white blood cells, percent neutrophils and serum immunoglobulins, were increased by methanolic and ethanolic extracts of *M. oleifera* leaves in cyclophosphamide-induced immunodeficient mice (Sudha et al. 2010; Gupta et al. 2010).

There are many chemicals isolated from the *M. oleifera* plants which are critical to disease prevention. For example, polyphenols like flavonoids and phenolic acids and flavonoids like myricetin, quercetin and kaempferol (Amaglo et al. 2010; Bennett et al. 2003; Siddhuraju and Becker 2003) and luteolin, apigenin, daidzein and genistein (Bajpai et al. 2010; Yang et al. 2008) have been reported. Among them, phenolic acids are antioxidant, anti-inflammatory, antimutagenic and anticancer properties (Verma et al. 2013; El-Seedi et al. 2012; Zhao and Moghadasian 2008). Other chemicals like alkaloids such as N,α-L-rhamnopyranosyl vincosamide,4-(α-L-rhamnopyranosyl) phenylacetotetilate (niazirin), pyrrolemarumine 4"-O-α-L-rhamnopyranoside, 4'-hydroxy-phenylethylamine-α-L-rhamnopyranoside (marumoside B) and its 3-O-β-D-glucopyranosyl-derivative (marumoside B) and methyl 4-((α-L-rhamnopyranosyloxy) benzylcarbamate have been recovered from their leaves (Panda et al. 2013; Sahakhipchan et al. 2011). Interestingly, their extracts like glucosinolates and isothiocyanates (Waterman et al. 2015; Waterman et al. 2014; Bennett et al. 2003; Förster et al. 2015) are required for promoting health and preventing diseases including diabetes (Dinkova-Kostova and Kostov 2012; Waterman et al. 2015) and tannins, water-soluble phenolic compounds that bind to and precipitate alkaloids, gelatin and other proteins, are anticancer, antiatherosclerotic, anti-inflammatory, anti-hepatotoxic, antimicrobial and anti-HIV replication activities (Kancheva and Kasaikina 2013; Dhakar et al. 2011). Besides, using hypertensive rat models, it has been shown that the plant is involved in antihypertension by inhibiting the secretion of IL-2 and modulating T cell calcium signaling (Attakpa et al. 2017). Its extracts also contain saponins that have hemolytic side effects, anti-cancer activities (Richter et al. 2003; Makkar and Becker 1997) and have high potential adjuvant activities and are thus, the subject of interests for immunologists and vaccinologists. Investigating new and potent adjuvant is essential because of only one approved and licensed aluminum-based adjuvants in human vaccines and due to poor understanding of their mechanisms of actions in vitro and in vivo (Ghimire 2015). In this context, *Moringa* might be a model plant for working in vaccine adjuvants.

While *M. oleifera* products and extracts are essential in immunopharmacological properties, its safety issues are critical for designing drugs and vaccines. For example, following feeding the rats with the diet containing the seed meal, these mammals have been reported to suffer from anorexia, impaired growth, stomatitis, colitis, hepatomegaly, pancreatitis, renitis, myocardiitis and atrophy of thymus and spleen. Thus, it suggests that unless the further understanding of other factors, use of *M. oleifera* as a drug or vaccine is in question (Oliveira et al. 1999).

**Alternative fodder for livestock**

Interestingly, the *Moringa* tree can supply the increasing demands of animal fodder for various wild and domestic herbivores in which it is usually believed that consumption of this plant can increase weight, milk production and prevent diseases. The diet that contains the dried form of leaves to the fish (Richter et al. 2003), laying hens (Kakengi et al. 2007), sheep (Murro et al. 2003) and cross-bred dairy cows (Sarwatt et al. 2004) has provided invaluable data although there are conflicting results regarding growth and productivity and variations among different in vitro and in vivo data. Addition of *Moringa* leaves at different levels induced improvement of the body weight and feed efficiency including decreased mortality rates and serum total cholesterol, triglyceride, LDL-cholesterol with an increased level of HDL-cholesterol in broiler chicken (Dey and De 2013). Its seed meal did not affect growth, live weight, saturated fatty acids, monounsaturated fatty acids, total unsaturated fatty acids, polyunsaturated to saturated fatty acid ratio and color although tenderness, juiciness and flavor of meat were enhanced of female Ross 308 broiler chickens aged 21 to 42 days (Ng’ambi et al. 2019).

Regarding in vivo experiments, feeding *Moringa* leaf meal to dairy cows did not increase milk production when comparing isocaloric and isoproteinic concentrates (Mendieta-Araica 2011). However, feeding *Moringa* leaves resulted in the generation of a grassy flavor and aroma in milk and higher digestibility of both crude protein and fiber, higher lactic acid concentrations with a favorable effect on silage pH compared feeding with *Elephant grass* (Pennisetum purpureum) (Mendieta-Araica 2011) indicating a crucial role of *Moringa* in influencing biochemistry and physiology of livestock.

**MORINGA TO COPE WITH THE CLIMATE CHANGE ADAPTATION**

It is widely believed that following climate change, cereal crops in the HKH region are struggling with decreasing rainfall, stream discharge, drying of springs and increased...
soil erosion. Climate change has been affecting the survival of various plants and reducing their productivity and consequently the lives of animals and humans. For example, approximately 25% decline in food productivity trend in the last thirty years from 1981 to 2012 has been reported in Kumaon Himalaya in India and the pattern of climate change and its impact on food production is increasingly experienced in the low altitudinal landscape (Tiwari and Joshi 2014). Thus, it is essential that researchers and agricultural experts search for climate change adaptation and mitigation strategies. In this situation, for HKH countries like Nepal, Moringa might be the best crop because the so-called ‘Never Die’ plant can adapt harsh weather, soil and other environmental situations (Fuglie 2000). It is a highly drought tolerant, it can survive in the temperature between 18–28 degree Celsius with an annual rainfall of 760 – 2500mm without requiring irrigation and can grow well in the dry or moist tropical or subtropical climates. In addition, it grows in any soil type (Orwa et al. 2009), however, heavy clay and waterlogged, with pH between 4.5 and 8 (optimum pH: 8.5) from less than 100masL up to 2000masL (Palada 1996; Orwa et al. 2009) suggesting its scope of cropping from high altitude of dry region to low altitude with flooded areas. Although Moringa can be attacked by several diseases and pests due to the widespread cultivation, many pests are resisted by this plant indicating its critical role in climate change adaptation (Mridha and Barakah 2017). This tree can also control soil erosion caused by flood and wind and can sequester more carbon (Amaglo 2012) playing a role in mitigating climate change. Regarding carbon sequester, the Moringa tree has been shown to absorb carbon dioxide 50 times higher compared to the Japanese cedar tree and 20 times higher than that of general vegetation (Villafuerte and Villafurte-Abonal 2009; Gandji et al. 2018).

While the agroecosystem of HKH is devastated by pesticides and inorganic fertilizers, its leaves can be a promising option to the farmers because it can be used to enhance the organic cropping by using their leaves in mulching and organic fertilizer (Mendieta-Araica et al. 2013). This is because of the significant levels of consumable biomass production and tolerance to pruning (Sánchez et al. 2006). Thus, alternatively, Moringa can be grown as food, fodder, herbal medicine, alternative crop supporters like natural fertilizer and shades, oil and to mitigating and adapting climate change consequences.

**CONCLUSION AND RECOMMENDATIONS**

M. oleifera tree is a miracle because of its broad applications for food, animal fodder, industrial and agricultural business, climate change adaptation and mitigation and laboratories of pharmacology and immunology. While the traditional medicines involving the use of Moringa is beneficial in treating many diseases, the mechanisms of action of these plant products or extracts are still not adequately understood. Regarding its immunologic and pharmacologic effects, the existing variations among in vitro and in vivo data might be because of different stages of plants, different varieties, laboratory conditions, experimental animals, animal models and extraction assays. Only understanding their immunologic and pharmacologic actions, we can understand how to design the vaccines and drugs based on Moringa. For this, graduates, researchers and faculty members from various national and international universities, government and non-government research institutes can collaborate and jointly can work for the development of knowledge regarding Moringa.

Finally, based on this review, the following recommendations can be made:

a. Documentation of different Moringa species or varieties existing in the HKH region should be done.

b. Documentation of various immunologic properties like antigen presentation, costimulation and cytokine expression of bone marrow-derived dendritic cells (BMDCs) of the biochemicals derived from the Moringa tree should be performed. It can be achieved by in vitro and in vivo models.

c. Documentation of various pharmacologic properties like anti-cancer properties and anti-diabetic properties should be performed. In vitro and in vivo models help to understand these properties.

d. The efficiency, safety and specificity of drugs or vaccine candidates of this plant should be detailed.

e. How fodder containing Moringa leaves influence the quality and quantity of milk production in dairy cattle should be further explained and evidenced.

f. An awareness program related to cropping of Moringa should be done in the areas where famine, flood and effects of climate change area experienced.

f. A common germplasm center with its cryopreservation of Moringa seed and genomes should be established in the HKH region.

**Authors’ contributions**

The authors prepared the draft and read and approved the final manuscript.

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