The potential of moringa in climate change, sustainable livelihood and food security – a review

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Abstract

***Moringa oleifera* Lam. is a multipurpose plant that is being promoted as a sustainable source of bioactive phytochemicals and nutrients to reduce human and animal malnutrition. The plant offers new opportunities to small scale farmers, contributes to the production of raw materials for industries and can serve as nutritious food. The aim of this review is to stress this new development and to advocate the need for stronger policies, research and market development strategies to develop this natural resource. The re-integration of *Moringa oleifera* into the human food chain and food systems should be both lateral within Africa and vertical as product development, coupled with market development efforts, to facilitate the entry of moringa products into both the developed countries and emerging economy markets. All of this should be carried out in a way that serves the fundamental interests of all stakeholders, with the most important consideration given to the vulnerable, poor, rural communities wherein primary production occurs. A dynamic new suite of bio-products can be produced from agro-forestry systems that will at the same time contribute to the restoration of badly degraded ecosystems and agricultural site productivity. Identifying innovative policy approaches and interventions to the commercialization of *Moringa oleifera* products may enhance the endorsement of moringa as sustainable source of income for rural households and will contribute to better natural resources management. This should be done with special focus on smallholder growers to enhance sustainable agricultural systems.**

Keywords: *Moringa oleifera*, climate change, agri-chain, sustainable livelihood

INTRODUCTION

The degradation of our natural life support systems through environmental pollution and the resulting climate change is a huge burden on our planet earth. In Africa alone, emissions from poverty-driven, unsustainable use of fuel-wood for cooking are equal to about 25% of the present total US emissions. To bring two billion people out of the bottom of the pyramid of extreme poverty and fragility to a position of collective resilience, secured energy and food needs a community-level social infrastructure capable of ensuring long-term health, education with overall well-being requiring a more concerted effort.

Moringa oleifera is a tropical plant which is being actively promoted as a cheap source of antioxidants and as a sustainable solution to malnutrition. A number of partially developed value chains of useful bio-products from this multi-purpose plant have already emerged in rural markets in West Africa and beyond (Barminas et al., 1998; Freiberger et al., 1998; Sena et al., 1998; Fuglie, 2001; Amaglo et al., 2010). Indeed, moringa leaves are rich sources of vitamins and minerals with potential beneficial health effects as human and animal food (Foidl et al., 2001; Bennett et al., 2003; Fahey et al., 2001; Fahey, 2005).

In India, *Moringa oleifera* products are used extensively and represent a large combined volume of economic and value-added activities. Functional food from moringa is expected to have high free radical scavenging ability and to contribute to strong immune system development. The production and export of useful bio-products from *Moringa oleifera* can take center stage position in our national economies as well as support our old

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and dwindling cocoa industry.

The *Moringa oleifera* plant assimilates carbon dioxide twenty times more than the general vegetation according to a Japanese study as cited by Villafuerte and Villafurte-Abonal (2009). Developing this emerging *Moringa oleifera* industry could maximize benefits to sustainable rural livelihoods, enable small scale farmers to play a more meaningful role in low carbon emission as well as achieve better nutrition and reduced poverty. Growing more *Moringa oleifera* will absorb more carbon dioxide from the atmosphere, thereby limiting the world's greenhouse gas emission and slowing the progress of global warming.

GLOBAL FOOD SECURITY, BIODIVERSITY UTILIZATION AND CLIMATE CHANGE

There have been times in human history when tens of thousands of vegetables, cereals, etc. were used as food but today we rely on just a few cereals. After roughly 10,000 years of progressive agricultural civilization, 70% of the world's food supply comes from just three grains – corn, wheat and rice – and 80% of our plant-based food intake comes from just twelve plants – eight grains and four tubers (Nierenberg, 2011). Globalization, intensification and industrialization of agriculture, has been blamed for this trend where we concentrate on a very small number of species in monoculture. Thus, global agriculture is leaning too heavily on a few crops and we need to plant a wider variety of crops to build a more resilient food system.

Agriculture is part of the climate change problem, contributing about 13.5% of annual greenhouse gas emissions (with forestry contributing an additional 19%), compared with 13.1% from transportation (Villafuerte and Villafurte-Abonal, 2009). Agriculture is, however, also part of the solution, offering promising opportunities for mitigating greenhouse gas emissions through carbon sequestration, soil and land use management, and biomass production (Rabbinge, 2009). Agriculture also provides a living for more than half of the world's poorest people and so new climate-smart policies are needed to improve livelihoods of farmers, food security and access to food as well as reducing emissions of greenhouse gases. The development of moringa cultivation and industry as a new crop for the benefit of small holder farmers and environment is one of the best legacies the current generation can afford to leave for posterity.

SUSTAINABLE LIVELIHOODS, POVERTY AND CLIMATE CHANGE

Sub-Saharan Africa with a population of around 782 million people in 47 countries is home to 36 of the world's poorest countries. Two-thirds of the estimated 33 million people suffering from AIDS live in sub-Saharan Africa; the region with the highest rates of malnutrition (Kennedy, 2011). Sub-Saharan Africa is the only major region in the world that has failed to progress in terms of food security with more or less stagnant levels of production per capita in recent years (Spore, 2011a). Climate change presents a new major concern, often interacting with or aggravating existing problems. Small scale farmers in West Africa are already producing far below potential (Spore, 2011b) and since poverty is a rural phenomenon in this region, it is only agriculture that holds the key to resolving the problem. As climate change takes a firmer hold, the global population grows and market fluctuates, we need to find ways of resisting the shocks associated with these issues in order not to make an already fragile situation worse.

THE COCOA INDUSTRY, RURAL LIVELIHOOD AND CLIMATE CHANGE

Cocoa was introduced into West Africa about one hundred years ago, and by 2010 it had reached a 56 billion Euro global combined economic and value-added activity (Spore, 2011a). In 2008/2009, world cocoa production was about US$ 9 billion (ICCO, 2008). Côte d'Ivoire, with 2.4 million ha under cocoa, and Ghana (1.5 million ha) between them produce 53% of the world's cocoa (ICCO, 2008; Franzen and Borgerhoff Mulder, 2007). Cocoa is an important cash crop in both countries, contributing 7.5% of GDP in Côte d'Ivoire and 3.4% in Ghana (FAO, 2008). Half the cocoa in Ghana and Côte d'Ivoire is grown under low shade, which is a sustainable land use practice with ecological, biological and economic benefits (Asare, 2006). The cocoa sector in Ghana employs over 800,000 smallholder farm families.

The number of cocoa farm owners is estimated at 350,000. Cocoa farm sizes are relatively small ranging from 0.4 to 4.0 ha. Ghana produces high-quality cocoa that earns a premium price on the world market. It accounts for 70-100% of household incomes of cocoa farmers in Ghana (Ntiamoah and Afrane, 2008). However, by the year 2080, cocoa, which is Ghana's main export crop, may cease to grow in the country as a result of climate change (Gyan-Baffuor et al., 2007).

Worldwide, large cocoa plantations are in regions where the mean temperature ranges from 22-25°C. In the cocoa-growing areas of the Brazilian Amazon for example, temperatures are 22-30°C (Dias, 2001), while in Ghana's cocoa-growing regions they are 24-29°C (Dormon et al., 2004). The climate change (temperature and rainfall) scenarios for the semi-deciduous forest and evergreen rainforest zones of Ghana were constructed using process-based methods that rely on the General Circulation Models (GCM) in conjunction with Simple Climate Models (SCM) indicated that projected mean annual rainfall values in the semi-deciduous forest zone of Ghana will decline by -2.8, -10.9 and -18.6% in year 2020, 2050 and 2080, respectively. In the evergreen rainforest zone, mean annual rainfall will also decline by -3.1, -12.1 and -20.2%, respectively. Mean annual temperature changes will rise by 0.8, 2.5 and 5.4 and 0.6, 2.0 and 3.9°C, respectively in the semi deciduous and evergreen rainforest zones in 2020, 2050 and 2080, respectively (Anim-Kwapong and Frimpong, 2005). These projected climatic changes will exacerbate soil moisture conditions during the dry season (November to March) and aggravate the vulnerability of cocoa production to adverse climatic changes.

The Bill and Melinda Gates Foundation (BMGF) contracted the International Center for Tropical Agriculture (CIAT) to predict the impact of climate change on the cocoa-, cashew- and cotton-growing regions in Ghana and Cote d'Ivoire. The research concluded that there will be changes in suitability of growing cocoa as climate changes and this will occur in specific sites (Figure 1). There will be areas that become unsuitable for cocoa (Lagunes and Sud-Comoe in Côte d'Ivoire), where farmers will need to identify alternative crops. There will be areas that remain suitable for cocoa, but only when the farmers adapt their agronomic management to the new conditions the area will experience. There will also be areas where suitability of cocoa increases (Kwahu Plateu, between Eastern and Ashanti regions in Ghana). Finally, there will be areas where today no cocoa is grown, but which in the future will become suitable (18 Montagnes in Côte d'Ivoire). The research still found out that cocoa will continue to lose suitable area by 2050 as the temperature increases (Figure 2). Cashew will be affected positively under the predicted climates of 2050 and will gain considerable suitable area. Cotton-growing areas will become somewhat less suitable by 2050 but overall will remain satisfactory.

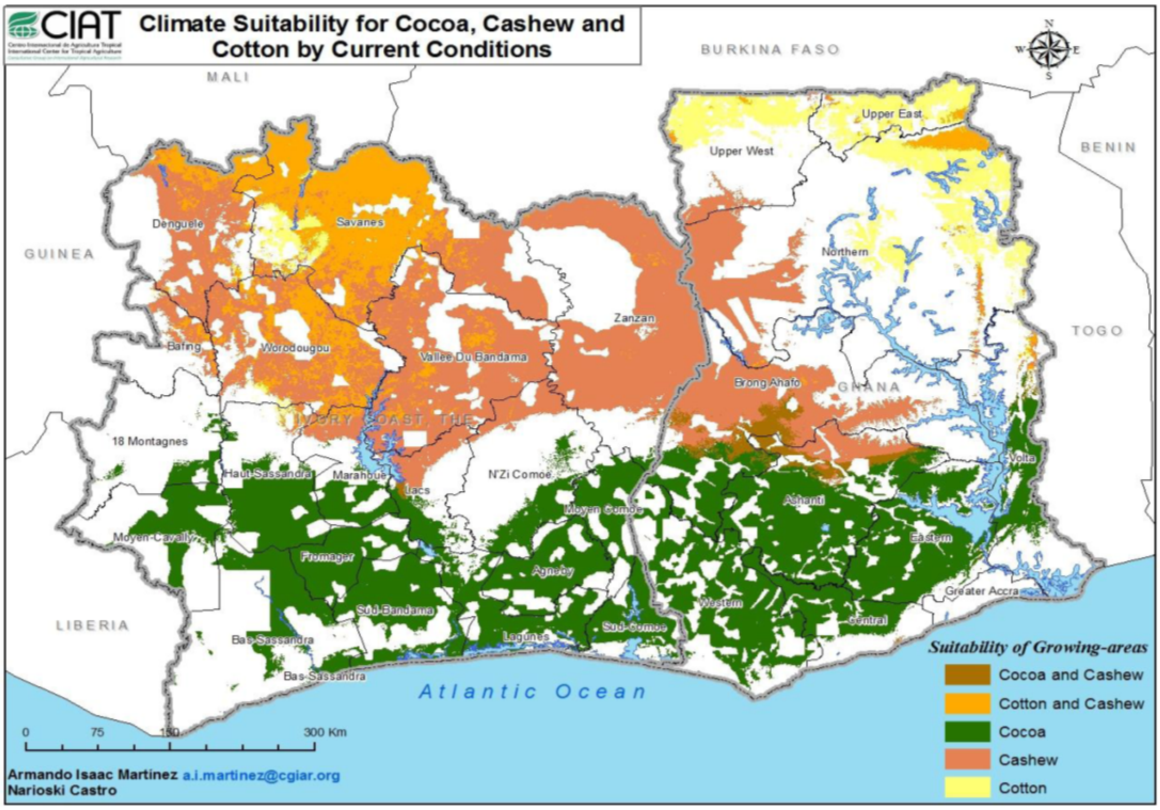

Figure 1. Current climate suitability for cocoa, cashew and cotton production in Ghana and Côte d'Ivoire. The climate suitability predictions do not include the protected areas, forest, urban and water bodies (Gyan-Baffuor et al., 2007).

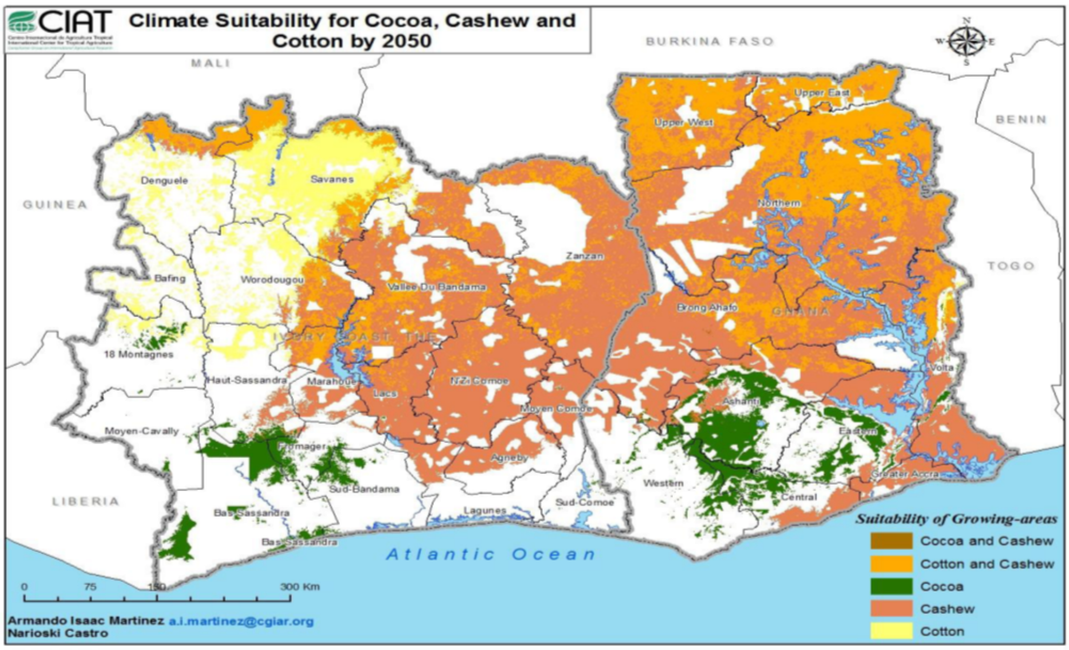

Figure 2. Climate suitability by 2050 for cocoa, cashew and cotton in Ghana and Côte d'Ivoire. The climate suitability predictions do not include the protected areas, forest, urban and water bodies (Gyan-Baffuor et al., 2007).

There are enough evidences that support the argument that the environmental impacts caused by human industry are compromising the sustainability of current economic activities, and degrading the natural life support systems, on which we and all other species depend. Climate change is expected to trigger severe consequences to smallholder poor farmers who dominate the agriculture sector in Africa. The impacts of climate change on the suitability to grow cocoa in West Africa will not only affect farmers' livelihoods and incomes, but the national economies as well. The Cocoa Research Institute of Ghana in anticipation of future climate change and taking cognizance of the debilitating effect of drought on cocoa production is continuously developing drought tolerant, high yielding and disease resistant cocoa planting materials and improved agronomic practices to sustain cocoa production and farmers' livelihoods. Farmers need to seek alternative livelihoods in view of the difficulties in cocoa production in coming years as anticipatory adaptive measures against loss of income from cocoa and livelihoods. They must devise mechanisms and adaptation strategies to reduce the impacts of climate change.

THE MORINGA PLANT AND COMMUNITY INITIATIVES

The many medicinal, nutritional, industrial, and agricultural uses of *M. oleifera* are well documented. Fahey (2005) said that the nutritional properties of *M. oleifera* are now so well known that there seems to be little doubt of the substantial health benefit to be realized by consumption of *M. oleifera* leaf powder in situations where starvation is imminent. Over 140 organizations have been involved in development initiatives aimed at introducing moringa species into communities throughout the world to help combat malnutrition, enhance the purity of water and to produce cooking and bio-diesel oil (Kwami, 2012). The World Health Organization (WHO) and other international humanitarian relief organizations such as the United Nations World Food Programme, the U.S. Agency for International Development, German Development Services and the British Overseas Development Agency have all used *M. oleifera* to combat malnutrition in many parts of the world. Religious organizations that support the use of *M. oleifera* to combat malnutrition include the Catholic Development Committee, the Church World Service, the U.S. National Council of Churches and the World Vision.

Many of these initiatives have been in rural Africa, because the climate there is ideal for *M. oleifera* cultivation and for the benefits that they can bring to developing countries and small communities (Kwami, 2012). The interest generated from the second international conference held in 2006 in Ghana on the uses of the *M. oleifera* tree, has been so great that several national moringa associations have already been formed in African countries. *M. oleifera* is well adapted to most of sub-Saharan Africa, where the world's worst rates of malnutrition and AIDS are found (Kennedy, 2011). There is growing awareness that *M. oleifera* is probably not only useful to rural communities in Africa but rather to the entire world. This growing awareness and interest has led to the spread of commercial and small-scale production of *M. oleifera* to nearly every tropical and semi-arid region of the world. There are major production sites in Africa, namely Tanzania, Kenya, Ghana, Senegal, and Malawi, while in Asia, India - Tamil Nadu is the major production site. Smaller production sites exist in New Zealand and Fiji, Nicaragua and Bolivia. In China, the Hainan Province has been growing *M. oleifera* for centuries.

MORINGA AS A VEGETABLE

The moringa tree is valued for its flowers, immature pods and leaves which can be used as vegetables. Crude protein and fat are high in the leaves, flowers and immature pods (Makkar and Becker, 1996; Sánchez-Machado et al., 2010; Amaglo et al., 2010). The dried leaves contain 30% protein and are a rich source of essential amino acids such as methionine, cystine, tryptophan, and lysine (Fuglie, 2001). The predominant minerals in *M. oleifera* tissues are potassium, calcium, iron, zinc, selenium and magnesium and are highest in the leaves (Barminas et al., 1998; Freiberger et al., 1998; Sena et al., 1998; Fuglie, 2001; Amaglo et al., 2010). Indeed, moringa leaves are rich sources of vitamins and minerals with potential beneficial health effects as human and animal food (Bennett et al., 2003; Fahey et al., 2001; Fahey, 2005; Kjaer et al., 1979; Amaglo et al., 2010).

Generally, fruits, vegetables, tea and wine are the main sources of dietary flavonoids for humans. Many flavonoids are shown to have antioxidative activity, free radical scavenging capacity, coronary heart disease prevention, and anticancer activity (Cook and Samman, 1996; Yao et al., 2004). Pal et al. (1995) reported that methanol fraction of *M. oleifera* leaf extract possesses anti-ulcer activity against induced gastric lesions in rats. On the other hand, pressed juice of the fresh leaves shows strong antibacterial activity against *Micrococcus pyogenes* var. *aureus*, *Escherichia coli*, and *Bacillus subtilis*. The flowers of *M. oleifera* are also considered to possess medicinal value as a stimulant, aphrodisiac, diuretic, and cholagogue, and have been reported to contain flavonoid pigments such as quercetin, kaempferol, rhamnetin, isoquercitrin, and kaempferitrin (Nair and Subramanian, 1962; Amaglo et al., 2010). Estrella et al. (2000) reported that *M. oleifera* leaves increase breast milk production from the third postpartum day to the fifth among mothers who delivered preterm infants. In most parts of the Philippines, women consume moringa leaves mixed in chicken or shellfish soups to enhance breast milk production. The feasibility and acceptability of introducing dried *M. oleifera* leaves into recipes as nutrients and antioxidants supplements were assessed and found feasible for even national programmes in India (Nambiar et al., 2003).

MORINGA SEED AND OIL DEVELOPMENT

The world demand and interest in dietary oils and fats, and their nutritional compositions have been increasing steadily in recent years (Gunstone, 2001). Oils and fats serve as rich source of dietary energy. They contain fatty acid components which are essential nutrients (FAO, 1978) and their functional and textural characteristics contribute to the flavor and palatability of many natural and prepared foods. This has led to a steady increase in the demand for functional ingredients obtained using "natural" processes. *M. oleifera* seed oil is therefore gaining grounds in the global vegetable oil industry as a high oleic acid type of oil. This type of oil is healthier, more stable to oxidative rancidity and useful in food systems that must have a high degree of oxidative stability.

The fruits are trilobal capsules hanging down with length of 20 to 40 cm. There are some 12 to 25 seeds fruit^{-1}. Seeds are round with dark brown color and three whitish wings. One adult moringa tree (three years) can produce 15,000 to 25,000 seeds year^{-1} and a plantation can produce 3000 kg of seeds ha^{-1}. This is equivalent to 900 kg oil ha^{-1} (i.e., 30%) and is comparable to soybean, which needs yearly cropping and yields an average of 3000 kg seeds ha^{-1} with only 20% oil yield (Mohammed et al., 2003). The dry seed contain 36% protein and have a high oleic acid (18:1) content, which is also seen in the seed oils (Amaglo et al., 2010). *Moringa oleifera* seed oil has a pleasant taste, is highly edible and desirable, especially with the current trend of replacing polyunsaturated vegetable oils with those containing high amounts of monounsaturated acids (Fuglie, 1999; Corbett, 2003). The seed oil contains all the main fatty acids found in olive oil, and therefore, can be used as a substitute to expensive olive oil.

Various extraction methods, such as traditional, mechanical and solvent extraction have been used in the extraction of *M. oleifera* seed oil. Traditionally, it is produced by boiling the seeds with water and collecting the oil from the surface of the water (Somali et al., 1984), but this method of extraction has a high level of physical exertion and is time and labor intensive. Mechanical cold-pressing involves crushing the seed in a heat-controlled process to preserve the oil's color, flavor, nutritional quality, structure of crucial fatty acids and proteins. However cold-pressing has a low efficiency and has a possibility of thermal degradation of the oil as in the traditional method. Solvent extraction method involves the counter-current flow of solvent and oil bearing materials in the extraction vessel. It is generally used to recover a component from either a solid or liquid phase. The crushed seed is brought into contact with a solvent that dissolves the oil and the solvent is thereafter separated from the oil.

Preliminary research on moringa oil quality standards has shown that there is higher market preference for cold-pressed oil. The exact requirement for moringa oil is yet to be standardized, but pressing without heat addition is preferred and is ultimately more profitable for all parties in the value chain (Kwami, 2012). So far, relatively very little has been invested in moringa oil extraction technology research and development, despite the growing demand for the oil in cosmetic and skin care products. The low efficiencies experienced when cold-pressing the seeds and the complications that arise when oil is locally manufactured using existing processing technologies, make them unsuitable for adoption by rural and small acreage farmers in rural communities. New machines and technologies are being tested for their suitability to fill in the technology gap created by this situation.

The oil from *M. oleifera* seeds has a low saturated fatty acid content (13%) and a high mono-unsaturated fatty acid content with beneficial health effects. The mono-unsaturated fatty acid chains comprise of two *ö*-9 mono-unsaturated acids, [cis-9-octadecenoic (oleic acid) and cis-11-eicosenoic acids] and one *ö*-7 mono-unsaturated acid [cis-11-octadecenoic acid (vaccenic acid)] (Vlahov et al., 2002). In addition, it has linoleic acid, linolenic acid, arachidic acid, behenic acid (C22:0), lignoceric acid (C24:0) and traces of lauric n-pentadecanoic and pentadecenoid acids (Dahot and Memon, 1985; Spangenberg et al., 1998; Tranchida et al., 2008; Amaglo et al., 2010).The high oleic acid in the oil makes it very stable, even in highly demanding applications like frying (Warner and Knowlton, 1997). With the oil being 72% oleic acid, it penetrates deep into the skin, delivering high concentrations of antioxidants, collagen, and vitamins A, C, and E. These nutrients are beneficial in reducing wrinkles, removing skin blemishes, rejuvenating and strengthening hair, and moisture retention in both skin and hair (Kwami, 2012). In Ghana, *M oleifera* seed oil is sold as an alternative to olive oil for cooking and used as cosmetic oil for infusion into body creams, soaps, and other skin care products. The Body Shop and LUSH companies in the USA launched a worldwide advertising campaign on *M. oleifera* products and are experimenting with locally produced *M. oleifera* oil in their products (Kwami, 2012).

MORINGA SEED AND WATER TREATMENT

The production of potable water involves coagulant use to remove turbidity in the form of suspended and colloidal material (Diez et al., 2002). Aluminum and iron salts are the most commonly used coagulants in water treatment. The cost and environmental side effects of these compounds has increased interest in the search and use of organic coagulants derived from plant material. Natural biodegradable coagulants offer advantages to inorganic or synthetic organic polymers, which are associated with human pathological processes (Jahn, 1986, 1988; Olsen, 1987; Sutherland et al., 1994; Muyibi and Evison, 1995; Okuda et al., 2001a). *M oleifera* (MO) seed extracts have been shown to have large effects on turbidity removal (92-99% reduction) (Jahn, 1986; Muyibi and Evison, 1995). Water treated with MO seed extract produces less sludge volume compared to aluminum (Ndabigengesere and Narasiah, 1998). An additional benefit of using coagulants derived from MO is that edible and other useful products may be extracted before the coagulant is fractionated. Residual solids may be used as animal feed and fertilizer, while the shell of the seed may be activated and used as an adsorbent or in mushroom cultivation. The coagulant is thus obtained at extremely low or zero net cost and has been recommended for water treatment in African and South Asian countries (Okuda et al., 1999).

Several reports have described the main water-extractable component in *M. oleifera* seed as proteinaceous. It was described as a water-soluble protein with a net positive charge (Nkhata, 2001), as dimeric cationic proteins with molecular mass of 12-14 kDa and isoelectric point (pI) between 10 and 11 (Ndabigengesere et al., 1995). Others reported a molecular mass of 6.5 kDa and a pI greater than 10 (Gassenschmidt et al., 1995). On the other hand, Okuda et al. (2001b) reported that the active component from an aqueous salt extraction was not a protein, polysaccharide nor lipid, but rather an organic polyelectrolyte with molecular weight of about 3.0 kDa. A simple, scalable purification method and a convenient coagulation activity assay have been developed, which allow the straightforward comparison of the characteristics and coagulation properties of water and salt and MO extracts relative to aluminum. In addition, MO extract has antimicrobial properties against some gram-positive and gram-negative bacteria (Mandloi et al., 2004).

Moringa oleifera seed, maize (*Zea mays*) and chitosan were used in direct filtration of Bilaoli lake water and evaluated for their efficiency in removing turbidity and microorganisms from water. The experiments with these natural coagulants gave filtered water turbidity less than or almost equal to 1 NTU and thereby met the turbidity criteria for drinking water as per WHO guidelines. Bilaoli lake water had low ionic strength and low turbidity, which represents one of the most difficult raw waters to treat, but natural coagulants in direct filtration achieved good filtrate quality (Mandloi et al., 2004).

MORINGA AND CLIMATE CHANGE

Introduction of this plant into a farm, which has a biodiverse environment can be beneficial for both the owner of the farm and the surrounding eco-system. One practical step to compensate for the several unpreventable carbon dioxide emissions is to plant trees. This is because trees take carbon dioxide out of the atmosphere and they release oxygen in return. The type of trees planted will have a great influence on the environmental outcome. According to a Japanese study as cited by Villafuerte and Villafurte-Abonal (2009), the rate of absorption or assimilation of carbon dioxide by the *M. oleifera* tree is twenty times (20×) higher than that of general vegetation and fifty times (50×) higher when compared to the Japanese cedar tree.

The *M. oleifera* tree, therefore, will be a useful tool in the prevention of global warming as one *M. oleifera* tree will be equivalent to the effectiveness of fifty Japanese cedar trees in absorbing carbon dioxide (Villafuerte and Villafurte-Abonal, 2009). For example, if we would expand *M. oleifera* from 100,000 ha worldwide to 1,000,000 ha, that would equate to five gigatonnes of carbon dioxide being sequestered. *M. oleifera* is thus a multipurpose plant that is difficult to overlook in today's battle with climate change. It is a fast growing tree and well adapted to growing in adverse conditions with at least 400 mm of rain annum^{-1}, conditions under which many other plants would not be able to grow. Moringa presents itself as an easy plant for agri-business, poverty mitigation and a climate smart plant choice to be developed for the benefit of present and future generations.

CONCLUSIONS

The *M. oleifera* plant is truly multipurpose and offers new opportunities to small scale farmers and contributes to the development of raw materials but will need strong policies, research and market development strategies in order to realize its full potential. The integration of *M. oleifera* into the human food chain and food systems should be both lateral within Africa and vertical with regard to product development, coupled with market development efforts, to facilitate the entry of *M. oleifera* products into both the developed countries and emerging economy markets. All of this should be carried out in a way that serves the fundamental interests of all stakeholders, with the most important consideration given to the vulnerable, poor, rural communities where primary production occurs. A dynamic new suite of bio-products can be produced from agroforestry systems that will at the same time contribute to the restoration of badly degraded ecosystems and agricultural sites.

Cluster models of public-private partnerships have become an important tool in developing innovations that improve the competitiveness of local agri-chains. This model should guarantee the availability of certified *M. oleifera* products at affordable prices which is a major concern for consumers of *M. oleifera* products. Identifying innovative policy approaches and interventions to the commercialization of *M. oleifera* products that endorse moringa as source of sustainable rural household incomes will result in enhanced natural resources management with focus on smallholder growers in sustainable agricultural systems.

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