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Review of the agro-ecology, phytochemistry, postharvest technology and utilization of moringa (*Moringa oleifera* Lam.)

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ABSTRACT

Purpose: This paper provides an in-depth critical review and analysis of current and recent research undertaken on the agro-ecology, photochemistry, postharvest physiology and utilization of *Moringa oleifera* Lam. **Findings:** This treatise provided a comprehensive review of current and relevant research on the horticultural practices, its agro-ecological conditions, and pre- and post-harvest operations and treatments. It showed the alignment of the biochemical production of the various phytochemicals to the ecophysiology of the plant particularly the variety and ecotypes, micro climatic and edaphic conditions, and the crop growth patterns. The detailed aggregation of the different phytochemicals and the sites of synthesis in the plant revealed that the plant produces in excess of 36 phytochemical compounds that manifest its biological efficacy in over 16 different human physiological activity and medicine. Additionally, it revealed the many approaches to the postharvest physiology of the plant parts and the extension of the shelf life and quality for processing opportunities. **Research limitations:** There were no significant limitations to the conducting of this exercise as the literature was available and accesses to communicate with authors were easily facilitated by the internet. **Directions for future research:** This is the only review which collated the findings on the agro-ecology, phytochemistry, postharvest physiology and utilization of *Moringa oleifera* Lam., and how it is linked to the world of ethno-medicine, and pharmacology. Further research is necessary to determine the efficacy of extracts from all parts of the moringa plant as potential and promising eco-friendly alternatives to common chemicals used as novel food preservatives.

INTRODUCTION

Phytochemicals are complex compounds produced by plants and used by humans as herbal medicine or as nutraceuticals for its contribution to flavor, texture, pungency, odor, or color to foods (Bridgemohan et al., 2018). However, they are not required as in the case of essential nutrients, vitamins or minerals (Fahey, 2005). *Moringa oleifera* Lam., or 'drumstick' vegetable is popular in the cultural practice of ethnomedicine due to the accumulation of many functional bioactive compounds including phenols, flavonoids, alkaloids, phytosterols, sugars, glucosinolates, ascorbic acid, minerals, and amino acids, tocopherols, polyunsaturated fatty acids, folate, tocopherols, and organic acids (Amaglo et al., 2010; Saini et al., 2014; Saini et al., 2016; Vinoth et al., 2012; Garcia et al., 2016).

It is a tropical deciduous tree (Fig. 1) that is cultivated for a variety of purposes in both the tropical and sub-tropical regions (Leone et al., 2015). All parts of the plant produce phytochemicals (Table 1), with potential applications in functional food preparations, water purification, and biodiesel production (Saini et al., 2016; Bridgemohan, 2014). Various parts of this plant such as the leaves, roots, seed, bark, fruit, flowers and immature pods act as cardiac and circulatory stimulants; possess antitumor, antipyretic, antiepileptic, anti-inflammatory, antiulcer, antispasmodic, diuretic, antihypertensive, and cholesterol-lowering, antioxidant, including antidiabetic, hepatoprotective, and antibacterial (Kasolo et al., 2010; Anwar et al., 2007; Ijarotimi et al., 2013).

The plant synthesizes these compounds in complex biochemical processes in the leaves and the phytochemical is stored in the different plant parts. However, the agro-ecological conditions under which the plant is cultivated can significantly affect the growth, development, and yield of the plant. Similarly, variations in the availability of essential plant nutrients in the soil in addition to water will influence flowering and seed production. If the plant is cultivated under extreme stress conditions such as, waterlogged, arid, shade or excessive sunlight, or nutrient deficits, then the rate of photosynthesis, partitioning of assimilates, and other metabolic processes that produce the phytochemicals are affected (Bridgemohan, 2011). The processes are undertaken after maturity and can extend and improve the phytochemical content of the plant parts.

Bamishaiye et al. (2011) investigated the proximate and anti-nutrient composition of dried leaves of *Moringa oleifera* harvested at different stages of plant maturity. In their study, leaves were harvested at three-period stages of maturity (10^{th}, 15^{th}, and 20^{th} week) after pruning. The result of the proximate analysis revealed that the 10th week had the highest carbohydrate content (55.14%). The 15th week had the highest moisture (6.3%) while the 20th week had the highest protein content (28.08%), as well as crude fiber (10.11%), ash (9.25%), fat (2.5) and pH (6.27).

The phytochemicals recorded in both aqueous and methanolic extracts of each of the different stages of leaf maturation were the same except for tannin which was present in aqueous extract but was not detected in methanolic extracts. The antinutrients included alkaloids, tannins, phenolics, saponins, flavonoids, steroids but phylobatanin and tripertenes were not obtained. Bamishaiye et al. (2011) recommended that the leaves harvested at the 20th week or late stage of maturity had a higher percentage of embedded nutrients than the two earlier stages of maturity. They also concluded that the presence of some phytochemicals like saponins and flavonoids supported the medicinal action of the plant and associated therapeutic uses and therefore could act as a nutritional and medical alternative for socially neglected populations according to Brilhante et al. (2017) and more recently (Ma et al., 2019; Oguntibeju et al., 2019).

This paper is an in-depth critical review of current and recent research conducted on the agro-ecology, phytochemistry, postharvest physiology and utilization of *Moringa oleifera* Lam., it collates the information using a meaningful and collaborative approach that provides a better and holistic view on the advances made in this field of research, and its contribution to the existing body of knowledge in moringa.

PHYTOCHEMISTRY

Moringa phytochemicals are produced by all of the morphological structures of the plant but are not phyto-nutrients. Phytochemicals are normally referred to as plant compounds that may be beneficial or detrimental, whilst phyto-nutrients may have a positive effect. Gopaul and Bridgemohan (2014) observed that *Moringa oleifera* leaf extracts functioned as a plant growth regulator (PGR) on Pak Choi seedlings.

The proximate analysis of moringa seeds (w/w%) under varying treatments of dehulling or defatted revealed that the crude protein content could reach as high as 45% and the crude fat at 38% (Table 3). This suggested that *Moringa oleifera* is an underexploited source of crop protein for use in animal feed after the oil is extracted (Bridgemohan, 2014). This was supported by Garcia et al. (2016) in a comparative analysis of the potential protein value of some agro-industrial by-products for ruminant animals. Bridgemohan and Knights (2010) in a detailed nutrient analysis of *Moringa oliefera* as a high protein supplement for animals found that the whole seeds had 12 essential amino acids in the recommended proportions for non-ruminants (Table 4). The high-fat content of the dried moringa seeds is an essential source of indigenous bio-energy which has demonstrated potential as bio-fuel and bio-diesel (Bridgemohan, 2010).

The aqueous or ethanolic extracts have demonstrated biological activity in ethno-medicine and veterinary medicine (Bridgemohan et al., 2016). Fahey (2005) reported that *Moringa oleifera* is rich in compounds containing the simple sugar, rhamnose, and unique group of compounds called glucosinolates and isothiocyanates (Table 2). It has hypotensive, anticancer, and antibacterial activity include 4-(4'-O-acetyl-a-L-rhamnopyranosyloxy) benzyl isothiocyanate (Abrams et al., 1993), 4 4-(a-L-rhamnopyranosyloxy) benzyl isothiocyanate (Abuye et al., 1999), niazimicin (Akhtar & Ahmad,1995), pterygospermin (Anderson et al., 1985), benzyl isothiocyanate (Anwar & Bhanger, 2003), and 4-(a-L-rhamnopyranosyloxy) benzyl glucosinolate (Asres,1995).

Fig. 1. *Moringa oleifera* tree.

Fig. 2. *Moringa oleifera* pods.

Table 1. Biological activities of various extracts of *Moringa oleifera* plant

Plant Parts	Extract	Biological activities	References
Foliage	Aqueous	Oxidative DNA damage protective	Chumark et al. (2008)
		Hypolipidemic and antiatherosclerotic	
		Antiproliferation and apoptosis	Sreelatha et al. (2011)
		De-regulation of nuclear factor-kappaB	Berkovich et al. (2013)
		Anti-Herpes Simplex Virus Type1 (HSV-	Kurokawa et al. (2016)
	Hydroalcoholic	Antiperoxidative and cardioprotective	Nandave et al. (2009)
	Ethanol	Antihyperglycemic and hypolipidemic	Irfan et al. (2016)
		Upregulation of TNF-α	Akanni et al. (2014)
		Hypolipidaemic	Atsukwei et al. (2014)
	Methanol	Antioxidant, anti-inflammatory and antinociceptive	Adedapo et al. (2014)
	Methanol / ethanol	Inhibit differentiation of cancer cells	Lea et al. (2012)
	Acetone	Antimicrobial and antioxidant	Ratshilivha et al. (2014)
	Isothiocyanate	Insulin resistance and hepatic gluconeogenesis	Waterman et al. (2014)
Seeds	Ethyl acetate	Antimicrobial	Emmanuel et al. (2014)

Table 2. Proximate analysis of moringa seeds (w/w%) under varying treatments (After Bridgemohan, 2014)

Proximate analysis	Whole grain	Defatted		Partial		Mean	[SD]
		Dehulled	Unhulled	Defatted	Dehulled		
Crude protein	37	45	40	34	32	36	[4.98]
Moisture	5	7	7	6	10	7	[1.30]
Crude fat	38	25	17	22	30	26	[6.90]
Crude fiber	3	3	24	16	18	13	[8.81]
Ash	4	4	4	5	5	5	[0.75]

Table 3. Amino acids [%] profile of moringa seeds under varying treatments (After Bridgemohan, 2014)

Amino acids	Whole grain	Defatted		Partial	
		Dehulled	Unhulled	Defatted	Dehulled
Aspartic acid	1.5	1.8	1.4	1.4	1.6
Threonine	0.8	0.9	0.6	0.6	0.8
Glutamic acid	7	8.5	5.7	4.2	7.4
Proline	1.7	2.1	1.5	1.3	1.8
Glycine	1.8	2.2	1.5	1.2	1.9
Alanine	1.4	1.7	1.1	1.1	1.5
Cysteine	1.5	1.8	1.2	0.9	1.5
Valine	1.3	1.6	1.1	1.1	1.4
Methionine	0.7	0.8	0.5	0.5	0.7
Isoleucine	1.1	1.4	0.9	0.9	1.2
Leucine	1.9	2.4	1.6	1.4	2.0
Lysine	0.5	0.6	0.6	0.5	0.6
Mean	1.8	2.1	1.5	1.3	1.9
[SD]	[1.37]	[0.99]	[1.44]	[1.81]	[1.28]
Total	21	26	18	15	23

Plant ecology

Moringa oleifera can be grown as shrubs for foliage and roots or as trees for pod and seeds. The plant has a wide agro-ecological amplitude (Bridgemohan, 2011). It is a tropical deciduous plant, although it is native of the sub-Himalayan mountains and can be cultivated in both the tropics and sub-tropics (Leone et al., 2015). The plant is propagated by seeds but stem cuttings are also effective at a density of 1600 – 1800 trees/ha. For vegetable foliage and animal feed/fodder production, the shrub architecture is recommended at the higher crop density.

Saini et al. (2013) found crop establishment by seeds is undesirable due to genetic variation through cross-pollination. As a tropical plant, the ideal agro-climatic conditions are warm temperatures (25–35°C), under direct sunlight, at an altitude of 500m, and on slightly acidic to alkaline soil (pH 5.0–9.0). However, it can tolerate high temperatures (up to 48 °C), frost in winter and high altitudes, and a wide variety of soil conditions. The seeds can be planted just after maturity, as the seeds do not undergo dormancy while retaining viability for up to 1 year.

Yang et al. (2006) found that the harvest season and plant leaf stage significantly influenced nutrient contents of moringa leaves. Further, higher protein, vitamin A and glucosinolates contents and AOA were obtained in hot-wet season, compared to the cool-dry season where the iron, vitamin C, and phenolic contents increased significantly.

Bridgemohan (2010) found that during the wet season, the foliage and pod/seed yield was significantly higher than the dry season, but this did not affect the seed oil yield, crude protein content or amino acid profile (Garcia et al., 2016; Bridgemohan & Knights, 2010). The dry season favored the production of mature leaves which are more nutritious than young shoots and could be quickly dried with a minimum nutrient loss under ambient conditions. The major pre-harvest factors that affect the growth and development of the pods were pruning/thinning of the branches (Goordeen, 2018), and irrigation (Yang et al., 2006), especially during the onset of flowering.

Zhang et al. (2014) studied the effects of planting density and cultivation technology on agronomic characters of *Moringa oleifera*. The results showed that the effect of different planting density on the phrenological phase was not obvious, but the increment and the characters of fruits were affected by different planting density. There were differences in the phenological phase, the increment and the characters of fruits at the fertilizing and irrigation conditions, and the growth and fertility of *Moringa oleifera* could be improved and the yield of fruit could be increased. (Bridgemohan, 2014).

Förster et al. (2015) evaluated *Moringa oleifera* ecotype variability for growth and secondary metabolite (glucosinolates, phenolic acids, and flavonoids) profile using 6 different ecotypes grown under similar environmental conditions. They found that the USA and Indian ecotypes had the best growth performance and highest secondary metabolite production. Furthermore, optimal cultivation conditions, exemplarily on sulfur fertilization and water availability for achieving high leaf and secondary metabolite yields were investigated for *Moringa oleifera*. In general, plant biomass and height decreased under water deficiency compared to normal cultivation conditions, whereas the glucosinolate content increased.

Whilst some studies about macromolecular characterization have been made, including a protein with the ability to agglutinate, proteinase inhibitors, lectins, carbohydrates and lipid contents (Olayemi & Alabi, 1994; Santos et al., 2016; Bridgemohan & Knight, 2010), the complete knowledge about what kind of metabolites are present in each organ, and their ecological and biological roles, are poorly elucidated.

Vázquez-León et al. (2017) investigated the effects of the tree age, soil physical and chemical parameters, and climatic factors, on the content of gallic acid, total phenolics, total carotenoids, and ascorbic acid and on the antiradical activity (DPPH and ABTS assays) of ethanolic extracts obtained from moringa freeze-dried leaves. They found that the bioactive compounds measured as reference and the antiradical activity from moringa leaves correlated with climatic factors (precipitation, humidity, and radiation) and with soil nutrients, principally with the K and P contents. Tree age was positively correlated with the total carotenoids contents and inversely correlated with the ascorbic acid contents. It can be seen that the variations in bioactive compounds and antiradical activity in moringa leaves are influenced by climatic factors, soil, and tree age, and will affect the antioxidant potential present in the plants during different harvest times.

Table 4. Phyto-chemical extracts of *Moringa oleifera* and use in ethno-medicine

Plant parts	Uses	Phytochemicals	References
Foliage	Mineral elements	K, Ca, Fe and Mg	Amaglo et al. (2010); Saini et al. (2014)
	Anti-inflammatory	glucosinolates, 4-O-(a-L-rhamnopyranosyloxy)-benzylglucosinolate (glucomoringin)	Amaglo et al. (2010)
		quercetin and kaempferol	Coppin et al. (2013)
		quercetin, apigenin, and kaempferol	Nouman et al. (2016)
		tetrahydrofolic acid and Formylfolic acid , carotenoids	Saini et al. (2016); Saini et al.(2014)
	Antioxidant	kaempferol, caffeoylquinic acid, zeatin, rutin, chlorogenic acid, beta-sitosterol.	Saini et al. (2014)
	Anticancer,	niazimicin	
	Hypocholesterolemic	isothiocyanate and niaziminin	
		E-luteoxanthin, 13-Z-lutein, all-E-zeaxanthin, and 15-Z-β-carotene -E-zeaxanthin, all-E-β-carotene,	Saini et al. (2014)
	Plant growth regulators	quercetin and kaempferol α-tocopherol	Gopaul & Bridgemohan (2014); Saini et al. (2014)
Roots	Antiurolithiatic	benzyl glucosinolate (glucotropaeolin	Bridgemohan et al. (2016); Amaglo et al. (2010)
Stem / shoot		glucosinolates, 4-O- (a-L-rhamnopyranosyloxy) -benzylglucosinolate (glucomoringin)	(Amaglo et al., 2010)
Pod	Crop protein	amino acids	Bridgemohan, (2008)
	Hepatoprotective	Isothiocyanates, catechin, epicatechin, ferulic acid, and vitamin C	
	Bio-energy	monounsaturated fatty acids	Bridgemohan, (2010); Saini et al. (2014)
	Crude protein	essential Amino acids	Bridgemohan (2010); Garcia et al. (2016); Amaglo et al. (2010)
	Antimicrobial,	omega-3 and omega-6, α-linolenic acid , palmitic acid	Amaglo et al. (2010)
Oil	Ulcerative colitis	oleic palmitoleic (stearic and arachidic acid, and linolenic acid	

POSTHARVEST TECHNOLOGY

Postharvest factors on phytochemical components

The major plant organs of *Moringa oleifera* that produce and store the phytochemicals are the flower seed, foliage, and roots. The edible plant parts of *Moringa oleifera* (leaves, fruits, flowers, and immature pods) form part of the traditional diet in many countries (Odee, 1998). However, the stage of maturity of plants affects the concentration of nutrients of leaves (Yu et al., 2004; Bamishaiye et al., 2011), taste and cooking as well as the amount of anti-nutrients (Sallau et al., 2012). Chodur et al. (2018) conducted studies to determine whether domesticated and wild type *Moringa oleifera* differ in myrosinase or glucosinolate levels and implied that the ultimate impact of these differences on taste affected consumption. Their assessment examined taste and measured levels of protein, glucosinolate, myrosinase content, and direct antioxidant activity of the leaves of 36 *Moringa oleifera* accessions. Taste tests highlighted differences between wild type and domesticated *Moringa oleifera*. Furthermore, there were differences in indirect antioxidant potential, but not in myrosinase activity or protein quantity. While agro-ecological conditions influenced growth and development, and the biochemical synthesis of these compounds, the retention and storage of these phytochemicals proved to be critical in maintaining the integrity, quantity, quality, and perishability of the harvested plant.

The postharvest extraction of phytochemicals (flavonols [myricetin, quercetin, and kaempferol] and phenols) in *Moringa olifera* foliage was conducted using pressurized hot water extraction (PHWE) as a "green" technology (Matshediso et al., 2015). The kaempferol and myricetin concentration decreased at 150°C, compared to quercetin which remained unchanged. Optimum extraction temperature for the flavonols and 1,1-diphenyl-2-picrylhydrazine (DPPH) radical scavenging activity was 100°C, but the total phenolic contents (TPC) increased with temperature (150°C) and then decreased.

Tetteh et al. (2019) evaluated the effects of different harvesting techniques and commonly used traditional-drying methods on the stability of glucosinolate (GS) of harvested *M*oringa *oleifera* leaves. The study revealed that sun- and oven-drying *of* leaves retained significantly higher GS contents compared to solar-and shade-drying. Further, oven-dried leaves had significantly higher levels of GS than leaves freeze-dried. Some of the processing methods like boiling, simmering and blanching affected the anti-nutritional contents of *Moringa oleifera* leaves. Sallau et al. (2012) showed that boiling reduced the cyanide content by 88.1% when compared with simmering and blanching. Similarly, boiling reduced the amounts of oxalate, phytate and trypsin inhibitors.

Harvesting methods

Moringa olifera plant parts are generally harvested manually. In view of the highly perishable nature of harvested flowers, leaves, pods and seeds, rough field handling could induce physical injuries and subsequent secondary infections to compromise postharvest quality and shelf life (Mohammed & Bridgemohan, 2019). Leaves of moringa plants grown in well-drained fertile soils under high-density planting can be harvested after 60-90 days when plants attain 1.5–2.0 m in height (Bridgemohan et al., 2019). Leaves are harvested by cutting leaf stems manually with a sharp knife at 20-45 cm above ground which ultimately results in the proliferation of new shoots. Harvesting operations can be conducted every 35-40 days thereafter. Moringa shoots intended for use as fodder can be harvested at seventy-five (75) days intervals. Under conditions of intercropping, plants can be harvested after two to four months of growth (Nouman et al., 2016).

The initial cutting can be done manually at 20cm up to 1.5m height. Ideally, harvesting procedures should be undertaken at a suitable plant height to avoid the effects of shading by overhanging companion crops. It is recommended that freshly harvested moringa leaves should not be assembled in heaps or packed tightly since the accumulation of respiratory heat could initiate deterioration, particularly when exposed to high temperatures for extended periods (Mohammed et al., 2019). In situations where moringa leaves are harvested, branches should be pruned, followed by washing in chlorinated water to remove dirt and dust. Drying must be done in the shade, preferably indoors in a clean, well-ventilated space. If leaves are dried in the sun, the vitamin content will be reduced. Leaves should be hung upside down or laid on a drying rack of string mesh to ensure good airflow. It is also important to turn or move leaves as needed to prevent rotting or molding during the drying process (Radovich & Paull, 2008; Mohammed et al., 2019).

Moringa leaves and tender pods should be harvested during the coolest time of the day, early morning or late evening to minimize moisture loss. Moringa pods are harvested depending on the variety as tender immature green (snap stage), semi-firm (fresh-cut), or dry pod state (seeds) (Bridgemohan et al., 2016; Goordeen, 2018). The semi-mature pods are harvested for the soft seeds and are less susceptible to mechanical injuries. During all harvesting and postharvest procedures in the field, and when packed and transported to the packinghouse and more so when pods are prepared for minimal processing (Fig. 2), worker hygiene and sanitation practices must be monitored and implemented consistently (Goordeen, 2019). Thus, careful supervision and proper instructions conveyed to the harvesting crew are essential to the success of the hand-harvesting operation of pods. Careful supervision includes random checks of harvesting bags or pails for trash and poor-quality pods. Packinghouse problems and buyer complaints often result from a poorly instructed and supervised harvesting crew. Pods should be removed from the plants cleanly without tearing them or causing undue damage to the pods or other plant parts. Over handling or rough handling of the pods would result in both visible and latent damages (Mohammed & Bridgemohan 2019; Goordeen, 2018).

Maturation indices

The recommended indicators of maturity and marketable quality of moringa pods include diameter, length, skin and flesh color, snapping strength, firmness and tenderness. Moringa pods with no bulge or only a slight bulge enclosing tender soft immature seeds are considered ideal maturity indices where pods are required for cooking purposes (Goordeen, 2019). However, immature ready to cook pods are susceptible to wilting. Over mature pods with bulging seeds are tough and fibrous. Uniform sizing of pods packed in crates or cartons is critical to acceptance by fresh market buyers. Additionally, pod shapes must be straight, bright green in color and typical for the cultivar.

Pre-cooling

The perishability rate of harvested moringa pods is proportional to the respiration and transpiration rate, respectively, and can be reduced by pre-cooling [14ºC] (Amuthaselvi et al., 2014; Peiris, 1997). The respiration rate increases with temperature 8.31ml/kg.h (14ºC) to 34.61ml/kg.h (28ºC) and is affected by agronomy, cultivar, production environment, and pre-harvest crop management practices. To reduce the impacts of transpiration and further deterioration in moringa pods, it is necessary to control water loss and maximize retention by harvesting at low ambient temperatures during the early mornings or late evenings (Mohammed & Bridgemohan, 2019; Goordeen, 2018).

The high build of field heat in the afternoon in the tropics is undesirable during harvesting as it increases metabolic activities of moringa pods (Bridgemohan et al., 2016; Goordeen, 2019). Accumulation undesirable field heat should be reduced immediately after harvest by pre-cooling to minimize the effects of microbial proliferation and high respiration, transpiration and ethylene production rates (Mohammed at al., 2019; Kitinoja et al., 2018). All parts of the moringa plant should be pre-cooled in the field by placing plant components in shallow, light-colored, stackable ventilated plastic crates that are either covered with broad leaves or by holding in a covered field shed or under a tree with shade to minimize water loss, respiration, and secondary infections. Pre-cooling moringa pods immersed in chlorinated water cooled at 5-7ºC for 30-40 minutes is an efficient, inexpensive, easy to apply and fast hydro-cooling technique to remove field heat as well as an effective starting point to initiate the cold chain. Limiting the time between harvesting and cooling to no more than 1 or 2 hours will help maximize shelf life. (Mohammed et al., 2019; Goordeen, 2019).

In the absence of refrigeration, alternatives such as shade, harvesting during the coolest part of the day, and drenching the produce with cold chlorinated water should be employed. Field containers packed with moringa plant parts should be cleaned with chlorinated water before packing and transport to the packinghouse and retail market display. Periodic sprinkling or spaying with chlorinated water may also initiate evaporative cooling if sufficient air circulation is present. Once the pods have been packed in cartons, air circulation must continue until the products are properly refrigerated (Kitinoja et al., 2018).

Moringa pods intended for distant fresh markets should be immediately cooled after harvest. The placement of field-warm pods in a refrigerated space, known as room cooling, is recommended only as a last resort. Room cooling may be of some benefit but is slow because it relies only on natural conduction and convection to transfer heat. Palletized and bulk containers of moringa pods may require more than 16-18 hours to cool sufficiently in cooling rooms (Mohammed et al., 2019). To promote cooling and prevent the buildup of respiration heat, the containers should be loosely stacked, leaving space between the pallets for air circulation (Thompson, 2004).

Grading and sorting

Moringa pods are sorted and graded regardless of the stage of maturity based on appearance, freshness, turgidity, and absence of blemishes. Freshness is evidenced by a distinct, audible snap when the pod is broken. The degree of seed development inside the pod indicates processing and marketing quality. Buyers and processors require a well-filled pod but harvesting flat and immature green pods must be out-graded. Dark brown pods indicate dry, over-mature pods that are unacceptable in the fresh market. Pods displaying rusty brown spots or other blemishes indicate disease, injury, or the possibility of deterioration and should be discarded (Mohammed et al., 2019).

Careful supervision of labor is the key to ensuring uniform cleaning, sizing, and packing of hand-harvested moringa pods. Growers may use a grading table or belted conveyor located at the packing shed to remove unmarketable pods. Spreading harvested pods on a conveyor belt or flat surface helps to dissipate field heat before packing, storage, and transportation (Mohammed et al., 2019).

Packaging and transport

Packaging of fresh moringa flowers, pods or leaves is one of the more important steps in the long and complicated journey from grower to consumer. Bags, crates, hampers, baskets, cartons, bulk bins, and palletized containers are convenient containers for handling, transporting, and marketing display of fresh moringa plant components. The recommended container is the shallow light-colored and well-ventilated plastic crates which must enclose the produce in convenient units for handling and distribution (Mohammed et al., 2019). The pods should fit well inside the container, with little wasted space. Packages of moringa pods commonly handled by hand are usually limited to 22-23kg. The package must protect the produce from mechanical damage and poor environmental conditions during handling and distribution. To produce buyers, torn, dented, or collapsed produce packages usually indicate a lack of care in handling the contents. Produce containers must be sturdy enough to resist damage during packaging, storage, and transportation to the market (Kitinoja et al., 2018).

Because almost all moringa contained packages are palletized, containers should have sufficient stacking strength to resist crushing in a low temperature, high humidity environment. Moringa pods packaged and destined for export markets requires containers to be extra sturdy. The packaged moringa pods must identify and provide useful information about the product such as brand, size, grade, variety, net weight, count, grower, shipper, and country of origin. It is also becoming more common to find included on the package nutritional information, recipes, and other useful information directed specifically at the consumer. In consumer marketing, package appearance has also become an important part of the point of sale displays (Kitinoja et al., 2019).

Recently, (Nayak & Khuntia, 2019) described the use of natural fiber polymer composites materials for packaging applications and advocated that *Moringa oleifera* fruit fiber (MOF) as a reinforcement and promising candidate for packaging applications. In this ongoing research, composites were fabricated by reinforcing treated *Moringa oleifera* pod fibers with polyethylene terephthalate (PET) thermoplastic polymer in order to investigate the mechanical, thermal and morphological properties. Surface treatments of fibers were conducted to obtain better compatibility with the PET matrix. Nayak and Khuntia (2019) further articulated in this novel study that the mechanical properties increased at the early stage with an increase in treated *Moringa oleifera* fiber content until optimum (20 wt% of fiber) fiber loading thereafter declined. At this fiber loading the mechanical properties obtained were 65.92 MPa of tensile strength, 98.49 MPa of flexural strength, 3.78 GPa of young's modulus and 28.09 kJ/m2 of impact strength. Thermogravimetric analysis (TGA), dynamic mechanical analysis (DMA), and scanning electron microscopy (SEM) were used for analysis. Furthermore, the TGA inferred that the thermal stability of the composites increased as compared to the neat PET matrix. It was found that composites fabricated from 20 wt.% fiber content showed superior mechanical properties as well as thermal properties as compared with other fabricated composites and can be used for packaging applications.

Storage

Fresh moringa pods are generally consumed within 2 days of harvest, more so, since immature *Moringa olifera* pods which possess a high moisture content, are thin-skinned with a cuticle that is protected with very limited amounts of wax and with high susceptibility to physical damages and subsequent secondary infection (Mohammed et al., 2019). This valuable crop has a very short shelf life (1 to 3 days at room temperature). There could also be a loss in nutritional quality due to poor postharvest handling, and different means of food preparation which influence the nutritional and functional qualities of moringa pods.

The need for preservation of moringa pods is essential due to its medicinal and therapeutic properties. Moringa pods treated with an edible coating such as gum of Arabic was considered as a cheaper alternative to cope with the perishable nature of the pods (Viyas & Mahendrakumar, 2018).

Sangeetha et al. (2017) explored the effect of time of harvest, method of harvest and pre-packaging calcium chloride treatments on shelf life and quality of *Moringa oleifera*, cv. PKM 1. Their study indicated that percentage losses in fresh weight increased significantly with increases in the storage period. The time of harvest also resulted in a significant influence on the weight loss of moringa pods. The morning harvested pods showed minimum weight loss

(10.37%) after nine days of storage under ambient conditions probably because the morning harvested pods had minimum water loss when compared to afternoon or evening harvested pods. Similar results were reported by Palada (2003) in amaranthus. Sangeetha et al. (2017) further claimed that the method of harvest also had significant effects on fresh weight losses. Harvesting of moringa pods with pedicles recorded minimum weight loss (11.25%) and decay when compared to pods without pedicles (13.31%). They attributed that the differences in decay could be related to those pods harvested without stalk and stored under ambient conditions, which, perhaps produced more decay loss as the exposed surface of stalk or scar left at the time of harvesting which created avenues for the entry of secondary pathogens. Pathak and Shrivastava (1969) and Singh and Panday (1993) have articulated similar explanations in their study with mango. The effect of postharvest treatments showed that calcium chloride (1%) treated pods recorded minimum weight loss (9.12%) when compared to untreated moringa pods (15.59%). It might be due to $CaCl_2$ that might react with water molecules and it might be acting in a manner to block the amino groups before entering into the enzymatic browning reaction. Similar results were reported by Davoodi et al. (2007) in tomato.

Freshly harvested moringa pods were subjected to three different chemical treatments, NaCl 10%, $CaCl_2$ 1%, and KMS 0.5% concentration (Viyas & Mahendrakumar, 2018). Pods were dipped in 10, 15 and 20% gum of Arabic solution, drained for two minutes followed by overnight room drying and then stored in a refrigerator at 8-10^{0}C and ambient temperature 25-30^{0}C up to 10 days. At the higher temperature, slight fungal growth was noticeable after 6 days but upon prolonged storage, after 10 days the proliferation of fungal growth was extensive making the pods unmarketable. Maximum firmness (5.85 kg/f), chlorophyll (0.14 mg/g), ascorbic acid content (78.94 mg/100g), protein content (2.13 g/100g), carbohydrate content (1.86g/100g), ash content (0.53%) were found for $CaCl_2$ 1% + coating 20% at the end of 30 days of storage under refrigerated conditions. Moringa pods coated with gum of Arabic coating was the best treatment when stored at 8-10°C and 80-85% RH in turn retained ascorbic acid, firmness, protein, crude fiber, chlorophyll, and TSS levels and maintained the lowest amount of moisture loss compared to the other treatments (Viyas & Mahendrakumar, 2018).

Other parts of the moringa plant have been studied to determine optimum quality attributes under different storage regimes. Moringa leaves for example which is also perishable should be stored under cool temperatures and high humidity to avoid excessive wilting and leaflet abscission. Moringa leaves subjected to modified atmosphere packaging (MAP) and supplemented with refrigeration at approximately 10°C (50°F) was reported by Radovitch (2009). Modified atmosphere packaging can create lower oxygen and higher carbon dioxide atmospheres during shipment and storage of horticultural commodities, potentially reducing quality loss caused by high respiration, transpiration, ethylene, and pathogen growth (Kader & Watkins, 2001). Mubvuma et al. (2013) investigated the effect of storage temperatures and the duration of moringa seed to achieve optimum germination percentages. The results of the study indicated that the management of storage temperature and storage duration of seed have the potential to improve the seed quality and germination percentage. Across all treatments, the quality of the seed improved with prolonged storage period up to three months, thereafter the quality of seed decreased with storage time unless stored under low temperatures (10°C). Good germination results were achieved after storing the seeds at a storage temperature of 25°C for a duration of 60 days.

Experiments were conducted by Tesfay and Magwaza (2017) to investigate a novel moringa leaf extract, together with commercially available edible coatings, namely, chitosan and carboxymethyl cellulose (CMC), as postharvest treatments to enhance shelf-life and improve the quality of 'Fuerte' and 'Hass' avocado fruit. Postharvest treatment included a 2% moringa extract with an emulsifier, two levels of chitosan (0.5, 1%), and CMC (0.5, 1%). Results from the study indicated that moringa extract with emulsifier and moringa containing chitosan and CMC significantly improved pod quality of both cultivars and showed that edible coatings containing moringa leaf have the potential to be commercialized as a new edible coating for future industrial application.

Katayon et al. (2006) also reported on stored *Moringa oleifera* seeds at different conditions and durations using an open container and a closed container at room temperature (28°C) and refrigerator (3°C) for durations of 1, 3 and 5 months. A comparison between turbidity removal efficiency of *Moringa oleifera* kept in refrigerator and room temperature revealed that there was no significant difference between them. *Moringa oleifera* seeds kept in a refrigerator and at room temperature for one month showed higher turbidity removal efficiency, compared to those kept for 3 and 5 months, in both types of containers. The coagulation efficiency of *Moringa oleifera* was found to be dependent on the initial turbidity of water samples. Highest turbidity removals were obtained for water with very high initial turbidity. Coagulation efficiency of *Moringa oleifera* was found independent of storage temperature and container, however, the coagulation efficiency of *Moringa oleifera* decreased as storage duration increased. Besides, *Moringa oleifera* can be used as a potential coagulant, especially for very high turbidity water.

Fotouo et al. (2016) corroborated with several authors (Rashid et al., 2008; Rahaman et al., 2009), in relation to the potential of moringa seed oil or Ben oil for biodiesel production as well as a cooking oil. There was also a consensus among them that oil quality is directly related to the physiological condition of the seeds at the time of extraction. Fotouo et al. (2016) proceeded to investigate the effect of various storage conditions and durations on moringa seed oil quantity and quality as a potential source of biodiesel. They found that moringa seed oil quality did not change significantly after 12 months of storage but after 24 months, the oil content of seed stored at 4°C in paper bags and at 20° and 30°C in aluminum bags were significantly lower than the control. The free fatty acid increased significantly after 12 months at all storage conditions and continued to increase above the recommended value (2%) at 24 months for biodiesel parent oil, except for that of seed oil stored at -19°C in aluminum bags. They deduced that the decrease in oil content and increase in free fatty acids were probably due to hydrolysis and oxidation processes accelerated by the high moisture content in the seed. The density of moringa seed oil remained unchanged throughout storage. The viscosities of oil extracted from seed stored in paper bags at -19°C and that of the oil stored at ambient temperature decreased significantly after 24 months. However, based on available literature the average oil density of less than 2mm2/s will not have a major effect on the final viscosity of the derived biodiesel. Moisture content, temperature, and storage period at which seeds are stored can influence the quality of the derived biodiesel, but seed moisture seems to be the main factor influencing the quality of the extracted oil. Seed can be stored at any of the applied conditions for six months, but if it is stored beyond this period, the use of low temperatures such as -19°C and 4°C and the use of sealed containers such as aluminum bags are recommended. Storage of the extracted oil for more than 12 months is discouraged.

In other studies, Selvi and Varadharaju (2016) examined the shelf life of moringa pods by controlled atmospheric storage. A 'Local variety' and a hybrid 'PKM 1' were selected and given a fungicidal treatment of 1% for 2-3 minutes. Respiration studies of moringa pods were conducted at three different temperatures (14, 21 and 28ºC) with the product to free volume ratios at 1:5, 1:10 and 1:20. Moringa at two different temperatures (14ºC and ambient) was stored in a specially designed PVC chamber with 3, 4 and 5% O_2 concentrations. Loss in firmness for both 'Local' and 'PKM 1' was 12.9, 13.2 and 16.9% for 14ºC with 3, 4 and 5%

O_2 concentration, respectively during 40 days of storage. The ambient stored moringa pods had a higher ascorbic acid loss of 8.2% as compared to 5.5% at 14ºC. The results were comparable with local variety also. 'PKM 1' showed a higher reduction of ascorbic acid of 54.1, 5.3 and 5.9%, respectively for 3, 4 and 5% O_2 concentrations at 14ºC in 40 days. Controlled atmosphere storage at refrigerated conditions revealed that the shelf life of moringa pods could be increased to approximately three to four times compared to ambient conditions. The best treatment for increasing the shelf life of moringa pods up to 40 days at 14°C was 4% O_2 and 5% CO_2.

Tripathi and Variyar (2018) examined the effect of radiation treatment (0.5, 1, 1.5, 2 and 2.5 kGy) and storage (10°C; 15 d) on the quality of ready to cook (RTC) moringa pods and reported an improved shelf life of 12 days for radiation treated samples at 1 kGy with suitable sensory and microbial quality. The radical scavenging activity, phenolic constituents, and isothiocyanates content were better retained in radiation processed products in comparison to control samples at the end of the intended storage duration. Their investigation also established the amenability of gamma radiation processing along with cold storage for improving the shelf life of ready-to-cook moringa pods.

Rikhotso et al. (2019) evaluated the efficacy of chitosan (CH) and carboxymethyl cellulose (CMC) incorporated with moringa leaf extracts (M) on reducing peteca spot (PS) incidence on 'Eureka' lemons. Their results showed that coating treatments and canopy position significantly affected PS incidence. Fruits coated with M + CMC, CMC, CH were less susceptible to PS development both inside and outside canopy compared to the control and M + CH coated fruit. Coating treatments significantly affected phenolic and flavonoid concentration. Moreover, coating treatments significantly reduced mass loss, ascorbic acid loss and delayed a color change of fruit.

UTILIZATION AND DEVELOPMENT OF VALUE-ADDED PRODUCTS

There are several value-added products made from various parts of the moringa tree. Included are moringa pickle, dehydrated pods, moringa flesh mesocarp powder, moringa pulp powder, moringa leaf powder, sauces, juices, dried flowers, oil and cosmetic products (Ponnuswami, 2019). Organoleptic evaluations of raw moringa plant leaves had a slight "bite", reminiscent of watercress or radish, which was more pronounced (Bridgemohan, 2014) in *Moringa oleifera* than in *Moringa stenopetala* (Bridgemohan, 2014). When cooked, the "bite" is eliminated resulting in an after taste similar to "pecany" spinach. Moringa plant flower blossoms and buds are also edible, when cooked. Moringa flowers have laxative properties if more than about 1/4 cup is eaten at one time. Very young Moringa pods are excellent eating when they are about the size of string beans. After that, they get "woody" and "stringy", and will require additional cooking time. Moringa seeds can be fried in a little oil, sometimes they "pop" just like popcorn. Add salt, and eat a few at a time, as they are intensely cleansing. The green drumsticks are used in South Asian cooking, particularly in curries. The leaves are often added in salads and stir-fries and are also cooked as a vegetable dish on their own, with added spices or topped with eggs.

Moringa leaves, flowers, and pods

Moringa leaves are dried and used in a powdered form and the pods are minimally processed and canned in a brine solution and also as pickled condiments (Price, 1985). Leaves and flowers may be dried in the shade or dehydrated and then pounded or ground and used as a food additive to improve the protein content of foods. Leaves and flowers are also used for making tea. An example of a commercial health food drink (Zija™) contains 30 g (1 oz) of moringa leaf, seed, and pod. This is reportedly the first commercially available drink from moringa. Retailing such a commercial product to the average consumer may be challenging because of high costs. However, local, prepared drink and tea products may offer the value-added opportunity for sale at farmers' formulated markets or health food stores. Young pods are consumed as a vegetable (Fig. 2). Very young pods are fibreless and can be cooked like string beans. Because the weight is low on very young pods, most commercial production involves larger, more fibrous pods that are used in soups, stews, and curries. The nutritious leaves are eaten in many dishes including soups, stews, and stir-fries. Sauteed young leaves and flowers are also eaten. The demand for home consumption of pods and leaves can generally be met by one or two backyard trees. Commercial production of mature seeds for oil occurs in India, Africa, and elsewhere. Recently, Hassan and Fetouh (2019) investigated whether moringa leaf extract (MLE) had the ability to act as postharvest preservative solution to improve the quality and longevity of gladiolus spikes. They subjected gladiolus spikes to various concentrations (0, 1, 2, 3, 4%) of MLE in vase solution and reported that all MLE concentrations significantly extended the vase life of spikes. MLE treated spikes also improved floret opening and reduced post-cutting weight loss. Furthermore, the relative water content (RWC), chlorophyll content, and membrane stability were considerably maintained while the microbial growth was suppressed in vase solution containing MLE treatments. Also, malondialdehyde (MDA) and H_2O_2 production was significantly suppressed by MLE treatments. MLE significantly increased the total phenolics and the activities of antioxidant enzymes (CAT and POX) in the florets. These ameliorative effects of MLE were more pronounced by the concentration 3% but higher level resulted in no improvement in cut gladiolus spike longevity and quality. Hassan and Fetouh (2019) concluded that MLE showed these effects via alleviation of oxidative stress induced in the cut spike, maintenance of photosynthetic pigments and water relations. Based on these findings they recommended that MLE to be applied as a useful and promising eco-friendly alternative to common chemicals used in preservative solutions for cut flowers. MLE could also be commercialized as a novel floral preservative for future floral industry application (Hassan & Fetouh, 2019).

Moringa seeds

Mahmoud (2019) transformed moringa seeds into power as a substitute for wheat flour to make cakes enriched with crude protein (7.6-17.65%), fiber (0.68-1.65%), ash (1.06-1.97), calcium (30 mg/100g) and iron (7.65mg/100g). In Africa, moringa powder is popular and used as a food supplement, whereby, 1–2 tablespoons of dried powder are added to soups and stews daily to enhance the protein content and nutritional value of food. In Africa, 25 g of moringa powder is administered to pregnant women daily to improve prenatal nutrition (Diatta, 2001).

Radovich and Paull (2008) discussed moringa oil derived from the seeds and its potential to add value to a small family farm if extraction can be optimized and if it were marketed to high-end venues as an alternative to imported olive oil. It was predicted that local and internet sales of moringa oil for cosmetic use may also have additional economic benefit based on its extraordinarily long shelf life and ability to capture the scent of added fragrances. Infusions of moringa oil with essential oils such as jasmine and lavender may also be valuable options.

Radovich and Paull (2008) also described in detail the moringa oil extraction method, composition, yield, and organoleptic attributes. The oil contains 60-75% oleic acid and is comparable to olive oil in taste and cooking quality characteristics. The high antioxidant content contributes to excellent oxidative stability and hence lower susceptibility to rancidity. Producing moringa oil on a small scale might be economically feasible if it were marketed to restaurants, hotels, and other high-end venues as a locally produced alternative to imported olive oil. If the oil is extracted through pressing, costs may be further reduced if press cake is used to replace purchased fertilizer (Radovich, 2009).

Press cake

The press cake leftover after extracting seed oil is utilized as a fertilizer and as a flocculent for water clarification. The seed cake contains positively charged compounds that are effective in settling suspended solids out of the water (flocculation) because most particles have a net negative surface charge while suspended in aqueous solution. There is international interest in using moringa-based flocculants as a locally produced, biodegradable substitute for aluminum sulfate, which is commonly used to clarify water.

Animal feed

The seed cake is normally not used as livestock feed because of the presence of anti-nutritional compounds in the mature seeds. Leaves are readily eaten by cattle, sheep, goats, pigs, chickens, and rabbits and can also be used as food for fish. Several studies demonstrated that significant proportions of traditional fodder can be replaced with moringa leaves. A study in Fiji reported significant weight gain over traditional fodder when 50% of fodder contained moringa leaves (Aregheore, 2002). In Nicaragua, cattle feed consisting of 40–50% moringa leaves is mixed with molasses, sugar cane, and grass. Moringa leaf meal can be used to substitute up to 10% of dietary protein in Nile tilapia without a significant reduction in growth. However, excessive feeding with moringa can reduce weight gain in livestock. Animals given fodder with 80% moringa in the Fijian study cited above showed lower weight gain than animals on 50% moringa fodder. Adverse effects resulting from high rates of moringa in the feed are due to excessive protein levels, and potentially anti-nutritional compounds in the leaves such as nitrate, oxalate, saponin, phytate, and isothiocyanates. Raffinose and stachyose may cause flatulence in monogastric (Foidl & Paull, 2008). Moringa biomass is reportedly low in lignin and may be valuable for ethanol production (Foidl & Paull 2008).

Medicinal uses

Most parts of the plant are used as medicine. The greatest contribution of moringa to health is its high nutritional value with the potential to target health food stores. The plant can be grown organically and this would facilitate the organic certification and greater consumer appeal. The most common direct medical use of the plant is as a poultice of the leaves and bark applied directly to wounds as an anti-microbial and to promote healing (Foidl & Paul, 2008). The anti-fungal and anti-bacterial properties of moringa extracts are well documented and are thought to be derived at least in part from 4-(α-L-rhamnopy-ranosyloxy) benzyl isothiocyanate. This compound is particularly effective against *Helicobacter pylori*, a bacterial pathogen of human beings in medically underserved areas and poor populations worldwide (Fahey, 2005). Isothiocyanates are the source of the mild horseradish smell in moringa roots and bark, which gives the tree one of its common names, “horseradish tree.” Moringa is in the same order as horseradish and other cabbage family members (*Capparales*). Isothiocyanates and related products from the cabbage family have been shown to have anti-tumor and anti-carcinogenic effects. Clinical research at Johns Hopkins University, USA, supported the traditional use of moringa to treat cancer (Fahey, 2005). The strong tradition of medical uses of moringa combined with recent scientific work supporting these tradition beliefs has resulted in increased marketing of supplements and so-called moringa “superfoods” (Radovitch & Paull 2008; Radovitch, 2009).

Utilization of waste products

Rajendran et al. (2016) conducted experiments to determine the uses of deseeded moringa pods (DMP) which is usually wasted after seed removal and subjected to environment dumping and degradation often associated with methane gas production and climate change. The nutrient analysis from their study showed that deseeded moringa pod was rich in fiber, carbohydrate and protein and the bakery products derived from DMP included fortified cookies and soup mix. Physical properties like bulk density, average size of the particle, porosity of the powder, influenced the spread potential and size of the textural characteristics such as hardness and fracturability of cookies. These physical attributes also impacted positively on organoleptic evaluations such as taste, appearance, color, flavor and overall acceptability based on a nine-point hedonic scale which actually turned out to be higher than average for the cookies and soup mix.

In other studies, Soliman et al. (2019), investigated the effectiveness of moringa seed waste as a novel green environmental absorbent for removal of industrial toxic dyes, red 60 (DR60) and Congo red (CR) from aqueous solutions. They elucidated that the absorption rate for both dyes were very high at the initial stages which eventually decreased until equilibrium was achieved. They further added that the absorption rate of the CR dye was not affected by catalyst weight, pH, or solution temperature. Maximum amounts of dyes absorbed were reported to be 170.7 and 196.8 mg/g for both CR and DR60 dyes, respectively, at 25^{0}C and pH 7. The authors concluded that the overall rate of the absorption process seemed to be controlled by a chemical process mechanism involving valence forces through the exchange or sharing of electrons between dyes and MSW absorbents. Maina et al. (2016) focused on the unexploited property of moringa seed pod (MSP) and morula nutshells (MNS) as a bio-remedial approach for removal of metals (copper, zinc, lead, manganese, cadmium, magnesium, and iron) from wastewater and borehole water. They reported that removal efficiencies were improved after treating sorbents with acids. This method was found to be simple, cheap and environmentally friendly and could be a remedial solution for water scarcity in rural areas where there are no resources to acquire expensive conventional techniques.

A study published by Otunola et al. (2013) showed that the use of moringa leaf waste (MLW) as a dietary fiber source enhanced cookie fiber content by as much as 29.54% relative to a control recipe, and 58% relative to a commercial cookie recipe. All cookies containing MLW were acceptable, scoring above 3.5 on the 7-point hedonic scale. Their investigation also highlighted that the addition of MLW fiber up to 10% in cookies was acceptable, although inclusion at 5% was found to be more acceptable. They concluded that cookies with MLW by-products have the advantage of being a good source of some of the daily requirements of dietary fiber.

CONCLUSIONS

There is an increasing rise in the use of ethno-medicinal and traditional herbs in the treatment of non-communicable, life-style, and pathogenic induced diseases in humans. The popularity of Asian homeopathic and Ayurvedic practices are based on a long successful history in the use of herbal plant treatments. *Moringa oliefera is* one of the many plants so utilized over the centuries in folklore medicine. It has attracted the attention of phytochemists and pharmacologists in the understanding of the mode of action of the active ingredients of the phytochemicals. Agronomists have investigated the crop production under both the wild and cultivated situations, and assayed the changes in the active ingredients, its biological effectiveness, biosynthesis and accumulation within the cell of the plants.

This treatise provides an in-depth assessment of the current and relevant research on the crop agronomy, its agro-ecological conditions, and pre- and post-harvest operations and treatments and utilization of value-added products. It aligned the biochemical production of the various phytochemicals to the ecophysiology of the plants particularly the variety and ecotypes, micro climatic and edaphic conditions, and the crop growth patterns. The detailed aggregation of the different phytochemicals and the sites of synthesis in the plant revealed that the plant produces in excess of 36 phytochemical compounds that manifest it biological efficacy in over 16 different physiological activity related to human health and medicine.

There are many commercial moringa products such as teas, tablets and capsules, and formulae and oils that are used in alternative medicine. However, the agronomic production and post-harvest treatments of the plant parts have been shown to influence the quality of the phytochemicals. As such, this comprehensive review aligns good agricultural practice (GAP) to optimal biosynthesis of moringa phytochemicals for its place in plant-based pharmacology.

Conflict of interest

The authors declare no conflict of interest to report.

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