African Leafy Vegetables Pre-harvest and Post-harvest constrains and Technologies for losses reduction along the field to consumer chain

Dinah Kirigia[1, 2*], Remmy Kasili[2] and Heiko Mibus[1]
[1]Geisenheim University, Institute for Urban Horticulture and Ornamental Plant Research, Von-Lade-Str. 1, 65366 Geisenheim, Germany.
[2]Jomo Kenyatta University of Agriculture and Technology, Institute for Biotechnology Research, P.O. Box 62000, Nairobi, Kenya.
***Correspondence:** dinahkarimi@gmail.com

Abstract

African indigenous leafy vegetables (ALVs) play a significant role in food security in Sub Saharan Africa (SSA). Most of the ALVs are rich in vitamins, minerals, dietary fibre, phytochemicals, anti-oxidants, medicinal properties and can withstand both biotic and abiotic stress. Currently, post-harvest losses of AVLs in SSA are more than 50% due to various constrains along "the field to consumer" chain. The constrains influences leaf nutrient value, shelf life and marketability resulting to qualitative and quantitative losses of ALVs. The major pre-harvest factors that leads to losses include; poor production conditions such as unfertile soils, drought stress, unknown mature indices, pest and diseases and poor harvesting techniques. Additionally, post-harvest constrains such as rapid physiological deterioration and microbiological decay, poor infrastructure and poor storage conditions leads to massive losses of ALVs. Post-harvest physiological changes, such as increased respiration and transpiration as well as ethylene biosynthesis highly influences post-harvest quality of vegetables. Ethylene gas is physiologically active at low concentrations and causes significant losses in product shelf life. Despite the importance of ALVs, sufficient research is not yet done to incorporate use of modern strategies and techniques for post-harvest loss reduction of ALVs. However, small scale farmers practice few traditional techniques to preserve and prolong the shelf life of ALVS including, charcoal cooling, fermentation, blanching, solar drying, sun drying and minimum processing and packaging among others. Here we review the available information on pre-harvest and post-harvest constrains of ALVs, as well as strategies and technologies to reduce losses in sub Saharan Africa.

Key words: African leafy vegetable (AVLs), post-harvest losses, Sub Saharan Africa (SSA), physiology, technologies.

Introduction

African indigenous leafy vegetables (ALVs) have been used for many centuries and play a significant role in food security and livelihood in SSA (Grivetti and Ogle, 2000). Some of the major indigenous vegetables that are consumed in the African continent include; leafy amaranths *(Amaranthus species)*, African nightshades (*Solanum species*), Spiderplant *(Cleome gynandra)*, African eggplant (*Solanum ethiopicum*), Cowpeas (*Vigna unguiculata*), Jute mallow *(Corchorus olitorius)*, Slenderleaf (*Crotalaria brevidens*), Pumpkin leaves (*Curcurbita muschata*) and African kale *(Brassica carinata)* (Schippers, 2000; Abukutsa-Onyango *et al.*, 2006). The ALVs have several advantages over the exotic vegetables; they have higher nutrient levels, medicinal and antioxidant properties, high seed production rates, short growth period and withstand both abiotic and biotic stresses (Mwai *et al.*, 2007; Odhav *et al.*, 2007; Uusiku *et al*., 2010). One hundred grams of fresh leaves in most of the ALVs contain over 100 % of the recommended daily requirements for an adult in calcium, iron, vitamin A and C, and 40 % for proteins (Mensah *et al.*, 2008; Uusiku *et al*., 2010; Kwenin *et al.*, 2011). Some members of *Solanaceae* family have been recognized for their high levels of secondary plant metabolites, although some like the alkaloids are anti-nutritive (Uusiku *et al.*, 2010).

The AVLs are mostly produced in simple farming systems like intercropping and organic farming (Kimaru *et al.*, 2015). Most of ALVs cultivars grow rapidly and may be harvested from 30 to 55 days after sowing. The ALVs are preferably harvested mainly by hand in SSA during the early hours of the day to reduce water loss (Masarirambi *et al.*, 2010). There are three main methods of harvesting ALVs. In the first method, the young entire plants can be pulled up (uprooted) in 4-6 weeks after sowing when they are about 15 to 30 cm tall (Gockowski *et al.*, 2003). The second method involves topping of the plants 10 cm above the ground to encourage lateral growth for successive harvesting. The third method involves continuous harvesting, where plants are harvested at regular intervals, either as single leaves or tender leafy branches (Onyango and Imungi, 2007). The leafy vegetables are then transported to the packing shed to avoid heat accumulation and water loss after harvesting (Acedo, 2010).

After harvesting small-scale farmers sort the vegetables, bundle and pack them in plastic crates, bamboo baskets, boxes, sacks or heap them together for ease transportation to the market (Fernando, 2006; Chen, 2007; Masarirambi *et al.*, 2010). The farmers transport the vegetables by local means, either by carrying with hands to the market, wheelbarrows or bicycles. The remaining vegetables after daily sales are stored in shades or in houses and water is sprinkled on them frequently to keep them cool (Kitinoja and Kader, 2003; Ndukwu and Manuwa, 2014). The charcoal cooling system is used by some farmers to provide cold storage for the vegetables. In some cases, the vegetables are processed as a strategy for preservation and enhancement of marketability. The most common processing methods traditionally used by small-scale farmers include, fermentation, sun drying, blanching and solar drying and minimum processing and packaging among others. (Muchoki *et al.*, 2007; Ayua and Omware, 2013; Wafula *et al.*, 2016). Production, storability, marketing and consumption of ALVs is affected by various limiting factors.

Effects of Production and Pre-harvest Constraints on African Leafy Vegetables

Production and pre-harvest factors significantly affects the quality and quantity of leafy vegetables. Previous studies have reported effects on shelf life and nutrients value of vegetables as influenced by soil nutrient, cultural practices and water supply during production (Jiang and Pearce, 2005). Crop production under stressful conditions with poor soil nutrients, water and salt stress significantly lowers the post-harvest life and decreases the nutrient levels of leafy vegetables (Jiang and Pearce, 2005; Sahou *et al*., 2014). Use of cattle and goat manure has been reported to increase crude protein and leaf biomass yields in *Cleome gynandra* and *Amaranthus hybridus* (Seeiso and Materechera, 2014). Growing of *Solanum scabrum* under drought stress and solute accumulation led to growth depression and increased electrolyte leakage as a result of membrane damage induced by oxidative stress (Assaha *et al*., 2016). Use of NPK fertilizers indicated higher antioxidants levels in *Justicia tenella* and higher phenolic contents in *Ceratotheca sesamoïdes* (Sossa-Vihotogbé *et al.*, 2013). Optimum production conditions are essential for assuring quality of ALVs.

The other production or pre-harvest factor that influences quality of ALVS is pest and diseases. Although most of ALVs can withstand both abiotic and biotic factors than the exotic vegetables, pests and diseases still remain a menace to some of the crop species and cultivars. Pests causes mechanical damages and are growth depressants to most of Agricultural crops. Damaged leafy vegetables can act as pathway to infection by disease causing pathogens and spoilage microorganisms. The free beetle is a major pest of spider plant (*Cloeme gynandra*) and causes ≥25% foliage damages (Maina *et al.*, 2015). The damaged leaves affects the physical quality of ALVs and decreases the marketability hence leads to automatic food loss. Red spider mite (*Acari Tetranychidae*) has been reported to cause severe leaf damages, reduce growth and leaf yield of African nightshade (Murungi *et al.*, 2014). Additionally, diseases such as dumping off, cankers, and various stem and root tots affects growth and yield of Leafy amaranths in wet seasons. *Alternaria* leaf spot disease of amaranths causes serious foliar damage and hence affects the quality and market of amaranths (Das, 2016). Das, 2016 also reported various pests and diseases of leafy Amaranths and their significant effects on yield and quality of the crop.

Physiological maturity of leafy vegetables is another major pre-harvest factor that influences nutrient value and shelf life. Small-scale farmers rely on relatively imprecise indicators to determine the start of harvesting of AVLs. These indicators include plant height, leaf size and color, and the times the product is ordered by customers or other chain actors, and overall production schedules (Barry *et al*., 2009). Nutritional quality of leafy vegetables have been reported to change significantly with plant age and growth conditions. The levels of antioxidants and phenolics have been reported to vary with crop age in *Ceratotheca sesamoïdes*, *Sesamum radiatum* and *Justicia tenella* (Sossa-Vihotogbé *et al.*, 2013). The contents of calcium, iron, and antioxidants has been reported to increase with plant age in leafy amaranths grown in warm temperatures (Mnkeni *et al.*, 2006).

Developing and adopting optimal nutrient and water supply during production can maximize biomass yield, nutritive value, quality and storability of ALVS. The appropriate rates of manure and fertilizer application to each specific leafy vegetable as well as mineral requirements needs to be investigated. Use of leguminous cover crops to improve soil fertility would be cheaper options for resource poor small scale farmer. There is also a need to investigate the agro-ecological areas and environmental conditions suitable for various cultivars of ALVs. Development of integrated pest management strategies as well as good cultural practices such as weeding and crop rotation would lower the infestation rates of most of the pests and diseases. Scanty information exists on effects of plant age on quality and yield of ALVs. Although ALVs can be harvested at different stages of their development, harvesting the vegetables when physiologically mature is important to ensure best nutritional value, higher yields and postharvest longevity. The Hortinlea research project seeks to determine the right physiological age of African leafy vegetables, as well to improve on the harvesting strategies. In addition, experiments to determine optimal fertilizer and water regimes as well as investigation of various pests of ALVs is going on under Hortinlea project. All these strategies aim to improve marketability, quality and to increase the shelf life of ALVs.

Factors that Influence Post-harvest Quality and Losses of African Leafy Vegetables

Quantitative and qualitative losses of leafy vegetables of mainly occur after harvesting, during transportation, processing and in storage (Masarirambi *et al.*, 2010). Post-harvest handling as well as long chains along the field to consumer is very critical in maintaining vegetable quality. A significant decline of mineral content was reported with increase in storage time and handling method in *Pterocarpus soyauxii*, *pterocarpus santalinidies*, *Gongronema latifolium*, *Corchorus olitorious* and *Amaranthis hybridus* (Nwanekezie and Obiakor-Okeke, 2014). Small scale farmers lack facilities for packaging and transportation of the vegetables to the market, and as well there is poor infrastructure in SSA. Poor post-harvest handling leads to mechanical damages, such as leaf tearing, crushing and other physical injuries. The tissue damages then leads to physiological deterioration due to oxidation of phenolic substances (Bachmann and Earles, 2000). Injuries stimulate ethylene production in vegetables leading to yellowing and sudden leaf senescence. Additionally, mechanical damage creates openings for microbial infections leading to decay and also increases water loss from the damaged tissue (Bachmann and Earles, 2000). Consumers opt not to buy the damaged vegetables and this leads to automatic losses to the farmer.

The physiological changes of the harvested organs along the field to consumer chain are also influenced by other factors such as;- post-harvest hormonal changes, nutrient degradation, chlorophyll and carotenoids degradation, microbial decay and increased transpiration and respiration rates (Bartz and Brecht, 2003; Acedo, 2010). Resource poor small scale farmers lack cold storage facilities leading to high rates of transpiration and respiration of the ALVs. This is highly influenced by high storage temperatures and relative humidity. The leafy vegetables are reported to wilt just by losing 5-10 % of fresh weight (Kanlayanarat, 2007; Acedo, 2010). Water loss through transpiration induces degradation of nutrients such as vitamin C as well as chlorophyll and carotenoids degradation (Acedo, 2010). Water losses from the harvested plant parts also increases respiration and ethylene production. Cool temperatures extend the shelf life of vegetables by reducing the rate of physiological changes, growth of spoilage microorganisms and prevents nutrient degradation (Kitinoja and Kader, 2003; Acedo, 2010). The rate of respiration and transpiration is low at cold temperatures, this reduces ethylene production and enzymatic activities hence extends the shelf life of ALVs.

Ethylene induces senescence in plants and prolonged exposure even to very low concentrations causes significant losses on fresh produce (Wills *et al*., 2000). Ethylene not only accelerates aging but also increases susceptibility of fresh produce to decay (Acedo, 2010). Chlorophyll degradation, proteolysis of soluble proteins to free amino acids and deterioration of cell membranes are the major characteristics of senescence induced by ethylene (Ferrante *et al.,* 2004; Hörtensteiner, 2006; Kanlayanarat, 2007). This yellowing of fresh vegetables as a result of chlorophyll degradation is one of postharvest factors affecting shelf life and market value of the vegetables. Production of ethylene gas by vegetables after harvesting is influenced by storage temperatures of above 10˚C, endogenous levels of sugars in the plant during harvesting, soil nutrients and water supply during production as well as plant age and cultivars (Kanlayanarat, 2007; Acedo, 2010).

Pathological decay after harvesting is another major factor that affects shelf life. The microorganisms can either be carried from the field, or from contaminated packaging materials, and favorable growth conditions along the field to consumer chain (Kanlayanarat, 2007). These conditions include wetness on the surface of leaves due to water used for washing or harvesting wet vegetables during rainy seasons. The water could be the source of pathogens or creates conducive environment for the microorganisms' growth. Storing vegetables in dirty places or near decaying plant material also leads to microbial infection (Kanlayanarat, 2007). Bacteria, fungi and enzymatic degradation are often responsible for severe losses of nutrients in ALVs due to unfavorable chemical changes. Some microbes like *Aspergillus* produce toxins that are carcinogenic, rendering ALVs and other foods unsuitable for consumption by both animals and human beings (Masarirambi *et al.*, 2010).

Post-harvest handling research on each specific leafy vegetable, including packaging seems to be scanty. Investigations of various postharvest handling and packaging would be a great mile stone in solving post-harvest losses of ALVs. Development and adaptation of ethylene gas depressants and strategies during storage and transportation would also reduce the losses and maintain the quality of ALVs. Farmers could also form unions and cooperatives and with some aid from the government, they can construct cold stores at various locations. This will increase the shelf life, enhance marketability and assure quality of ALVs. Breeding for improved varieties with prolonged shelf life, higher nutritive value, shipping and processing attributes are the current breeder's efforts on many vegetables and has a potential for enhancing quality (Fonseca, 2004; Acedo, 2010).

Post-harvest Technologies and Strategies to Improve Quality and Reduce Losses of ALVS

All forms of Post-harvest processes and techniques aim to bring benefits in terms of improving produce handling, reducing loss of nutrients, reducing food losses, increasing shelf-life and value addition to the product (Madakadze *et al.,* 2004). Small-scale farmers cannot afford refrigeration equipment's hence cool their vegetables under shades or ventilated stores, and sprinkle water on the leaves (Kitinoja and Kader, 2003; Lyatuu *et al.,* 2009; Ndukwu and Manuwa, 2014). Alternative technologies such as on-farm evaporative coolers or charcoal coolers have been explored for adoption (Lyatuu *et al.,* 2009; Ambuko *et al.,* 2013). The charcoal coolers are simple wooden structures that uses charcoal and water system to provide a cold environment for the vegetables. The charcoal coolers systems is cheap, requires no electricity and uses evaporative cooling principle to keep vegetables fresh for up to 7 days. The limitation of the method is availability of water which also remains a challenge to most rural small scale farmers.

Packaging of vegetables enhances handling and transportation, and reduces water loss from the product (Gast, 1991). Currently, packaging is mainly used for some dried ALVs products, but has limited use in the case of fresh leaf vegetables (Muchoki, 2007). The use of polyethylene and polycarbonate-bags with specific gas permeation has been used on some vegetables and leads to a modified atmosphere (MAP) inside the packages, which reduces respiration of ALVs and thus aid in retaining postharvest freshness and quality (Somjate, 2006; Acedo, 2010; Nyaura *et al.,* 2014). Although MAP packages are locally available in the market, evaluation and commercialization of their use in packaging of ALVs in the local market has not been conducted (Acedo, 2010). Use of ventilated crates and poly sacks have also been reported to reduce postharvest losses and improve quality and safety of vegetables (Adhikari, 2006). Canning technologies have been used as a preservative measure on many vegetables and can also be applied on AVLs. However canning is capital intensive and would require high initial investment, hence remains unaffordable by small scale farmers (Diamante, 2007).

Postharvest treatments such as heat treatments reduce postharvest quality loss, and new emerging postharvest technologies such as use of UV-C irradiation and electrical impulses are current research interests under Hortinlea project (Gogo *et al.,* 2016). Studies have shown the beneficial effects of postharvest treatments such as; control of insect pests, prevention of default fungal rots, and inhibition of undesired acceleration of ripening and senescence and/or promotion of the synthesis of health promoting compounds: such as carotenoids, flavonoids and dietary fibers during storage and marketing (Nicolai *et al*., 2007, Keil *et al*., 2011). These easy-to-apply postharvest treatments can prevent ALVs quality losses effectively and prolong shelf-life, storability and marketability (Gogo *et al.,* 2016).

Traditional preservation and processing technologies such as fermentation and blanching increases storability duration and quality of the vegetables. These technologies also improves food safety and prevents loss of nutrients (Muchoki *et al*., 2007; Wafula *et al.,* 2016). Food fermentation has been used for centuries as a processing technology known to increase storage duration, palatability, aroma and texture and increase the availability of proteins and vitamins. In addition, fermentation enhances food safety by reducing undesired anti-nutritional factors such as phytic acid and glucosinolates

(Habwe *et al.,* 2008; Franz *et al.,* 2014; Ifesan *et al*., 2014; Wafula *et al*., 2016). Studies have shown that the fermentation, blanching and drying of ALVs, such as cowpea leaves preserve substantial levels of nutritive compounds like the vitamins and beta-carotene (Muchoki *et al*., 2007; Wafula *et al.,* 2016).

Traditionally farmers have been practicing natural fermentation, but current studies have involved use of starter cultures in cowpeas (Wafula *et al.,* 2016). Studies have also shown successful fermentation of African kale (*Brassica carinata*) using lactic acid starter strains such as *L. plantarum* BFE 5092 and *L. fermentum* BFE 6620 (Oguntoyinbo *et al* ., 2016).

Drying is one of the food preservation methods that has been used for many centuries and is beneficial in reducing microbial decay, ensuring physiochemical stability, reducing weight and transport costs as well as improving handling and storability (Kumar *et al*., 2010). Several vegetable drying methods exist including sun drying, oven drying, solar drying, vacuum drying and freeze drying (Fellows, 2009). Leafy vegetables are held into bundles and cut into small pieces with a knife to ensure faster drying. The cut leaves are then Immersed in boiling water (blanching) or steamed for 3 minutes to minimize nutrients loss due to enzyme degradation (Fellows, 2009). Blanching is a pretreatment done on vegetables before most of processing methods or storage to destroy enzymic activity (Fellows, 2009). In addition to inactivating plant enzymes, blanching also reduces some unpleasant secondary metabolites such as oxalates. The chopped blanched leaves are then spread thinly on clean mats or flat open surface directly under the sun, oven dried or solar dried (Fellows, 2009, Masarirambi *et al.,* 2010). The dried vegetables can be stored in pots, tins, or in polythene bags and closed tightly to avoid any moisture re-entry in order to keep the leaf tissues dry (Bencini, 1991, Masarirambi *et al.,* 2010). The dried vegetables are normally soaked in water before cooking.

Although fermentation has been practiced traditionally in Africa, its potential to solve food insecurity and malnutriational crisis has not been fully exploited. Scaling up and development of fermentation, sun drying and solar drying protocols as well as of personnel training would signifantly solve postharvest losses of ALVs. This will also call for developments of proper packaging material to prevent the processed product from moisture and microbial infections to the product. Additionally, adaptation of various packaging, treatments and processing methods on ALVs will ensure quality and minimize losses in SSA. Cheaper storage options like charcoal coolers have been developed, but adaptation and knowledge about them is not widely known. This calls for improved extension services, farmers training and establishments of demonstration farms for all existing technologies and strategies for losses reduction of ALVs.

Future Prospects of ALVS Technologies

The health benefits including medicinal values and high nutrient content of ALVs has led to the global awareness about the vegetables and their utilization in solving food security crisis in SSA. This awareness has led to the awakening of researchers on all aspects of ALVs right from production to consumption. Improvement of production factors such as determining the right rates of fertilizer and water applications, identification of pests of AVLs and their control strategies are some of the current ongoing research interests under HORTINLEA program. Additionally, the HORTINLEA research project seeks to determine the right physiological age of African leafy vegetables and improve on the harvesting strategies. All these strategies aim to improve marketability, quality and to increase the shelf life of ALVs. Therefore, it is expected that more production, harvesting, postharvest handling and preservation techniques and strategies of African leafy vegetables will be revealed to reduce losses and enhance storability and quality of the vegetables.

Conclusion and Recommendations

Although ALVs have been used for many centuries as leafy vegetables, much research to explore techniques that can be used to combat post-harvest losses of the vegetables has not been done. Pre-harvest and post-harvest physiology specifically for each African leafy vegetable need to be investigated as well as the application of modern techniques in post-harvest handling of the vegetables. Adoption of such research findings by the farmers can be a great milestone in solving postharvest losses of the vegetables. Application of molecular biology techniques would also enhance the understanding on the various postharvest responses that lead to post-harvest losses of each specific vegetable crop.

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