Review
Journal of Biosystems Engineering
J. of Biosystems Eng. 40(3):238-249. (2015. 9)
http://dx.doi.org/10.5307/JBE.2015.40.3.238
eISSN : 2234-1862
pISSN : 1738-1266

Current State of Postharvest Fruit and Vegetable Management in East Africa

Collins Wakholi[1†], Byoung-Kwan Cho[1†], Changyeun Mo[2], Moon S. Kim[3]*

[1]Department of Biosystems Machinery Engineering, College of Agricultural and Life Science, Chungnam National University, 99 Daehak-ro, Yuseong-gu, Daejeon 305-764, Republic of Korea
[2]National Academy of Agricultural Science, Rural Development Administration, 310 Nongsaengmyeong-ro, Wansan-gu, Jueonju-si, Jeollabuk-do 560-500, Republic of Korea
[3]Environmental Microbiology and Food Safety Laboratory, Agricultural Research Service, US Department of Agriculture, 10300 Baltimore Avenue, Beltsville, MD 20705, USA

Received: August 9th, 2015; Revised: August 19th, 2015; Accepted: August 24th, 2015

Abstract

Purpose: Fruit and vegetable production is a fast-growing sector in East Africa, and it bears considerable local and international market potential. In an effort to analyze the challenges within this sector and suggest possible solutions, this study reviews the postharvest handling technologies commonly used with fruits and vegetables in East Africa. **Methods:** During the course of this study, small-scale farmers were identified as the most prominent producers of fruit and vegetable crops in the region. **Results:** We found that many of these small-scale farmers employed relative simple and inexpensive techniques in handling their limited volumes of produce. Several factors could be addressed to reduce postharvest losses, including weak policies, inferior infrastructure, and poor market strategies. However, the lack of basic knowledge (including demographic, scientific, and economic knowledge) among the stakeholders (e.g., researchers, farmers, governments, nongovernment organizations, and merchants) on how to develop, implement, use, and sustain the recommended handling technologies is probably the most problematic. **Conclusions:** We recommend that high priority be placed on closing the knowledge gap, which could enhance the efforts of all the stakeholders to address and reduce postharvest losses.

Keywords: East africa, Fruits, Postharvest processing, Quality loss, Vegetables

Introduction

Horticulture is one of the fastest-growing subsectors in Sub-Saharan Africa (SSA), with exports alone amounting to more than USD2 billion (4% of the world demand) in the year 2003; this amount is increasing exponentially (English et al., 2004). In keeping with this trend, the East Africa (EA) region's cultivation and consumption of horticultural products-such as fruits and vegetables-have increased rapidly in recent years. For instance, in Uganda, fresh fruit and vegetable exports increased in value by 240% between 2004 and 2005 (FIT Uganda Ltd., 2006).

The fruit and vegetable production sector in EA is dominated by small-scale farmers, and only a few medium and large-scale farmers (English et al., 2004; Mrema et al., 2008; Salami et al., 2010). The small-scale farmers mostly employ inexpensive traditional cultivation methods; the medium and large-scale producers, meanwhile, use both conventional and modified agronomic practices, and consequently reduce their costs in the process. The biggest market for fruits and vegetables produced in EA is the local burgeoning middle-class population, while the export market is much smaller but nonetheless lucrative (ACET, 2014).

This lucrative local and international fruit and vegetable market is growing quickly, and producers in the EA region are vying to exploit this market potential. However,

† C. Wakholi and B. Cho contributed equally to this work as joint first authors
***Corresponding author:** Moon S. Kim
Tel: +1-301-504-8462; **Fax:** +1-301-504-9466
E-mail: Moon.Kim@ars.usda.gov

the fruit and vegetable production sector there has been plagued by substantial losses, as reported by various researchers. Losses have ranged from 30% to 80%, representing devastating income setbacks for both farmers and governments in the region (e.g., Kader, 2002; Sudheer and Indira, 2007; Agona and Muyinza, 2008; Kitinoja et al., 2010; Kitinoja et al., 2011; ACET, 2014).

Several efforts have been made by various stakeholders to introduce strategies and measures in order to reduce these losses. Research and the implementation of technology and machinery to assist in handling and processing fruit and to improve the quality and shelf life of the produce (Kitinoja et al., 2010) have been some of the proposed postharvest loss-reduction measures. Kaminski and Christiaensen (2014) report that up to 68% of the total postharvest losses in SSA can be attributed to a lack of technology pertaining to the appropriate harvesting, handling, and storage of fruits and vegetables, so as to prevent or delay deterioration.

Efforts to develop and implement postharvest technologies and handling methods in EA in order to reduce postharvest losses have had limited success and no discernable effect, as reported by various researchers (Kitinoja, 2013; Rickman et al., 2013; Affognon et al., 2015). This finding implies that the introduced technologies could be deficient, flawed, or inappropriate or that specific sources of the losses have not yet been identified or addressed.

Therefore, the main purpose of this study is to review the technologies commonly used in EA during the most important and/or common postharvest handling stages of fruits and vegetables. Specifically, we look to assess the extent to which certain technologies and machinery are used, as well as their inherent limitations; we also look to recommend possible ways of enhancing productivity. In so doing, we can disseminate to the appropriate stakeholders information on the constraints and opportunities related to the postharvest handling of produce, with the aim of reducing the losses that this sector experiences.

Several researchers agree that a lack of appropriate knowledge is the major cause of persistent losses in the fresh fruit and vegetable sector in SSA. This lack of knowledge can pertain to the extent of the losses themselves, which technology is appropriate for a particular farming community, and general ignorance among practicing farmers (Agea et al., 2005; Mashau et al., 2012; Kitinoja, 2013; Kaminski and Christiaensen, 2014; Affognon et al., 2015). In addition, Siriphanich (2000) contends that the physiology of most tropical fruits is not well known, and so it has been difficult to develop suitable handling technologies for them. These facts point to the relevance of reviewing commonly employed postharvest technologies and handling methods for fruits and vegetables in EA, to assess their success or otherwise; from there, we can work to develop methods by which to improve them, if need be.

Background Information

East Africa facts

EA includes Uganda, Kenya, Tanzania, Rwanda, and Burundi; these countries together comprise the East African Community (EAC). The region is located between the coordinates 5°30' N 12°00' S and 28°45' E 41°50' E, in a part of the continent known as the African Great Lakes region (EAC Secretariat, 2014). The total surface area of EA is 1,817,700 km^2, and 5.6% of the total area is covered with fresh water (McCoy, 2003). Of the total land mass, 72% is dedicated to agriculture; Kenya has the most dominant commercial agricultural sector in the region, despite a large portion of the country being semi-arid (EAC Secretariat, 2014).

Estimates in 2014 indicate that the population of the region was 135.4 million, with youth (aged 15~49 years) accounting for approximately 50% of the total population. This substantially young population points to the large potential of the region in terms of available labor force, innovation, and productivity. Estimates are that the agricultural sector employs more than 75% of the population; this fact indicates that agriculture is considered the major dependable economic activity in the region (EAC Secretariat, 2014). Nevertheless, the region is considered economically underdeveloped, with a 5.9% growth rate and the average gross domestic product being USD84.7 billion (Khanna, 2013). EA is a mainly tropical region with some areas experiencing an equatorial climate. The region has fertile volcanic and alluvial soils, reliable rainfall (mean of 1,500 mm), and favorable temperatures ranging from 24 to 28°C (FAO, 1993). This favorable climate permits the cultivation of fruit and vegetable crops virtually year-round, with minimal irrigation and fertilizer inputs (Kader, 2002). The fruit and vegetable cultivation sector in this region therefore has a distinct natural advantage, compared to those of East Asia and the Middle East.

EA is home to many fruit and vegetable species, and both indigenous and foreign varieties of crops are cultivated. Crops include fruits such as citrus, mangoes, pineapple, banana (both dessert and food types), apple banana, watermelon, jackfruit, pepper, papaya, apples, avocado, and jamun, and vegetables include greens, onions, tomatoes, cucumber, pumpkins, cabbages, egg plants, carrots, and others. This produce offers a rich source of vitamins A and C, minerals, carbohydrates, and roughage (Stangeland et al., 2009), and are therefore essential for a healthy diet. Notwithstanding the relative abundance of this produce and the associated health benefits, the consumption of fruits and vegetables in the region remains below the minimum level recommended by the World Health Organization/Food and Agriculture Organization (FAO), of 400 g per day (Ruel et al., 2005; Kabunga et al., 2015). The consumption of fruit in Uganda, for instance, is far below the recommended national level of 80 g per capita per day (Ssonko et al., 2005).

State of the market

The fruits and vegetables produced in the region are normally consumed at a domestic level in fresh form, while a limited volume is consumed in processed form. Fresh fruits and vegetables are sold mostly in local markets and supermarkets, while processed products-such as packed fruit juices and fruit syrups-are widely sold in supermarkets and other major stores. Open markets remain the dominant outlets in the region for fresh fruits and vegetables (Kimaro and Msogoya, 2012; Kabunga et al., 2015), although the number of supermarkets in the cities is increasing. The major fruit and vegetable-processing companies in the region include Coca-Cola (Uganda), Britannia Foods, House of Dawda, Del Monte (Kenya), Azam juices (Tanzania), and Inyange Industries (Rwanda), among others; there are also several small-scale companies. Taking into account the exponential increase in the region in the size of the middle class and the urbanization of the population, the demand for fresh and processed fruit and vegetable products is set to increase rapidly, especially in urban and suburban areas.

The local fresh produce market has a dual nature: small-scale farmers sell their produce directly to local open markets and supermarkets, or via intermediaries (Agea et al., 2005), while the commercial (large-scale) producers sell directly to processing plants where juice, dried products, syrup, and similar products are made.

The exportation of fruits and vegetables has proved to

Table 1. Nature of the value capture opportunity for fresh fruits in East Africa

	Fresh produce	Processed produce
Exports	Market size: USD50 billion	Market size: USD15 billion
	Description - Smaller domestic fresh market, with key current fruits (bananas, pineapples, mangoes, etc.) - Several fast-growing niches (avocadoes, kiwis, berries) *Factors related to opportunity* - Cultivation of key export fruits to international quality standards - Need to improve infrastructure and production scale	*Description* - Smaller fresh market, but fast-growing - Orange and apple juices dominate; sales are largely to the EU and North America *Factors related to opportunity* - Need to develop secure supply when out of season - Opportunities to produce concentrates/juices for international market
Domestic	Market size: USD10 billion	Market size: USD1 billion (fast-growing)
	Description - Accounts for the majority of fruit volumes today - Opportunities for countries in exploiting growth in intra-regional trade and growing domestic consumer markets *Factors related to opportunity* - Need to drive volume through improved supply chain and higher production	*Description* - Characterized by two major products (juices and dried fruits), but juices are more predominant - Very fast growth expected as overall sector grows *Factors related to opportunity* - Develop fruit juice to satisfy the market - Develop secure supply of processed fruit products when out of season - Increase production of easily processed products, such as dried fruits

Source: ACET, 2014.

be an exponentially growing and lucrative sector in the region. This has rekindled interest among the youth in agriculture. In an effort to satisfy the apparently inexhaustible international demand (Organic Trade Association, 2010) for fresh and processed fruits and vegetables (mostly organic), numerous exporting firms have been established in the region, and many are offering jobs. Fruits and vegetables from EA are exported mainly to the Middle East, North Africa, and the European Union (ACET, 2014). Kenya is reportedly one of the world's leading exporters of fresh fruits and vegetables; key factors behind its success include a dynamic private sector that has benefited from structural and macro-economic reforms, and the creation of an efficient transport hub (Legge et al., 2007). Additionally, an average annual growth rate of 20% has been achieved in the horticultural sector of Uganda over the last few years (MTTI, 2007; Agona and Muyinza, 2008). Tanzania, Rwanda, and Burundi also have significant fruit and vegetable export markets. Table 1 speaks to the value for EA of opportunities in the fresh fruit market.

Postharvest loss scenario

The perishable nature of fruits and vegetables poses a formidable problem in efforts to mitigate the losses experienced worldwide by this sector. In 2013, the total worldwide production of fruits and vegetables was estimated at 486 million tons; however, 30~40% of the total production in developed countries spoils on account of a lack of proper postharvest handling. However, in developing countries, postharvest loss figures have been even more overwhelming, reportedly ranging between 30% and 60% in EA and other SSA countries (e.g., Kader, 2002; Sudheer and Indira, 2007; Agona and Muyinza, 2008; TFC, 2008; Kitinoja et al., 2011). Various other researchers have recorded abnormally high losses of up to 80% in most SSA countries (Kitinoja et al., 2010; ACET, 2014).

Reducing the postharvest loss of fresh produce is an important aspect of sustainable agricultural development efforts to increase food availability and security (Kader, 2004). However, less than 5% of the funding provided over the last 30 years for horticultural development efforts has been used to improve postharvest methods, while more than 95% has been spent on trying to increase production (Kader and Rolle, 2004). Obviously, this funding imbalance has been a major setback in efforts to limit postharvest losses. However, more attention has been paid recently to this aspect of produce production, and it is hoped that these losses can be significantly reduced by 2050, when an estimated world population of nine billion people will need to be fed. Reducing food losses is now considered an important aspect of food production, poverty alleviation, and improvements to nutrition (Affognon et al., 2015).

According to Kader (2004), there are two general causes of fruit and vegetable losses-namely, biological and environmental causes, and socioeconomic causes. Biological and environmental causes relate to storage temperature, humidity, gas concentration, and microbial load, among other factors. These factors can be easily manipulated and controlled, in the presence of available technologies; however, these technologies do entail very large initial investments. The real and core causes of postharvest losses in EA, then, are socioeconomic; they exert influence in one way or another on the biological and environmental aspects. The socioeconomic aspects include invalid marketing systems, inadequate transporting facilities, inadequate research and development capacity, weak government policies and poor policy implementation, lack of information (i.e., ignorance), lack of appropriate skills for handling the expense of postharvest technologies, and cultural diversity, *inter alia*. Consequently, among the efforts to reduce agriculture losses in the EA region, the socioeconomic causes need to be addressed first.

An investigation of postharvest fruit-handling practices in the Bagamoyo district in Tanzania (Kereth et al., 2013) found that microbial activity accounted for 63% of market losses, and physiological activity for 20%; insects and rodents, meanwhile, accounted for 17%. However, in the supply chain, mechanical damage was the major cause of loss (79%) during harvesting, while transportation and microbial damage accounted for 56% and 67%, respectively. In addition, the study found that none of the farmers interviewed had any knowledge of postharvest management and loss reduction techniques; consequently, the authors recommend that in an effort to reduce postharvest losses, the knowledge and skills levels of farmers and fruit handlers should be improved.

Various strategies and measures have been put in place to reduce these losses. One reduction measure relates to research on and the implementation of technologies and new handling techniques, with the aim of enhancing produce quality and prolonging produce shelf life (Kitinoja et al., 2010). Such action is considered essential, as up to

68% of the total postharvest losses in SSA have been ascribed to a lack of appropriate technologies for harvesting, handling, and storing produce in a manner conducive to delaying deterioration (Kaminski and Christiaensen, 2014). Alternative approaches include investment in research and development, improving the infrastructure, establishing development banks that offer financial boosts to small-scale farmers, forming cooperative groups to help form an organized market structure, and other political interventions. In Uganda, for instance, the Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) works together with two semi-autonomous institutions-namely, the National Agricultural Research Organization (NARO) and the National Agricultural Advisory Services-as well as other affiliated research institutes, to research, develop, and implement postharvest technologies that are appropriate to the local agricultural conditions (Agona and Muyinza, 2008; MAAIF, 2014).

However, regardless of these best efforts and the number of relevant studies conducted-including those on agronomy, marketing, policies, and postharvest handling-the postharvest losses experienced by the fruit and vegetable sector remain large and widespread. Therefore, the dissemination to all stakeholders of knowledge concerning appropriate postharvest technologies is crucial, if these losses are to be mitigated.

Current postharvest technologies and handling methods for fruits and vegetables in East Africa

Fruit and vegetable losses occur at various postharvest and preconsumption stages, mostly on account of various socioeconomic factors, but also because of the tender texture and high moisture content of the produce (Katende and Namirembe-Ssonkko, 2005; Kitinoja, 2013). In this section, we analyze the postharvest handling stages (i.e., harvesting, transportation, cleaning, drying, size reduction, sorting and grading, and storage) and the respective technologies involved in each. Such an analysis is considered important to detecting and quantifying losses and to suggesting possible measures by which to control the postharvest loss of fruits and vegetables.

Harvesting

The harvesting of fruits and vegetables in EA is normally done manually, using simple tools. Produce is placed in collection baskets or sisal sacks. Harvesting is typically done in the morning, when temperatures are relatively low and the produce is cool and fresh; however, when harvesting continues into the early afternoon, the rising temperatures heat up the produce in the field, thus rendering it susceptible to damage through enzymatic and microbial action (Agona and Muyinza, 2008; Kimaro and Msogoya, 2012). For these reasons, some farmers have started to harvest in the evening, when it is relatively cool, and the harvesting continues into the early night by lamplight.

Katende and Namirembe-Ssonkko (2005) conducted a study in Uganda on the possibility of employing field packing to reduce the deterioration that creates ridge blackening in okra. They found that although packing while in the field was hectic, this method presented a real-time solution to the problem of blackening. In addition, the authors suggest that using special tools to harvest okra and educating the laborers (harvesters) could mitigate the losses. They emphasize that careful and limited handling of the okra was the best way to reduce product deterioration and limit postharvest losses.

The majority of losses during harvesting are caused by a lack of skill and knowledge among the harvesting team with respect to suitable handling of the produce and how deterioration relates to temperature. Appropriate measures could be put in place to limit these losses, such as harvesting during the coolest hours of the day (Katende and Namirembe-Ssonkko, 2005), using insulated (wooden/plastic) crates, and using baskets sprayed with water to assist in cooling (Kitinoja et al., 2011; Kimaro and Msogoya, 2012). Refrigeration (for senescence-resistant fruits and vegetables) could be beneficial for large-scale farmers, especially during transporting and precooling (Kitinoja et al., 2011), but it must be done promptly. Training of the harvesters on proper fruit and vegetable handling, and how to discern the correct or required level of ripeness, is also critical.

Transportation

Transportation is done in two phases-namely, from the field to the homestead and from the home/company collection area to the market. Transportation for small-scale farmers is relatively safe, because the product is either carried to the market or simply transported on carts or bicycles, rather than on trucks (Figure 1). However, for medium-scale farmers or groups of farmers, the transportation of produce is more complicated, and the

(a) (b) (c)

Figure 1. The nature of produce transportation in EA: a) banana fruit loaded on a truck, b) orange fruit carried in a basket, and c) banana fruit loaded on a bicycle.

produce is more susceptible to mechanical and heat damage. The fruits and/or vegetables are either loaded onto trucks on wooden stacks, or simply piled onto the trucks.

Mechanical damage (fatigue) occurs during transportation because of vibrations that occur while traveling what are typically long distances, usually over untarred roads (Kimaro and Msogoya, 2012; Mashau et al., 2012). High temperatures and the buildup of gases that accelerate enzyme activity (and thus cause over-ripening or softening) and microbial activity (Agona and Muyinza, 2008) are factors that contribute to the deterioration of fruit and vegetable harvests.

Kimaro and Msogoya (2012) investigated damage to mango fruit along the various stages of the supply chain in the Morogoro region of Tanzania. They identify the vulnerable stages in the supply chain and suggest sustainable practices by which to reduce postharvest losses at wholesale markets. The authors found that approximately 6% of all losses occurred during the harvesting stage, 24% during the transportation stage, and 70% during storage and handling in the market places. They recommend certain improvements to transportation, the loading of fruit onto transport vehicles, the use of separators between the containers, and changes to storage conditions during the wholesale process.

Several measures can be implemented to reduce losses during the transportation stage, including stacking the produce on wooden or plastic racks on the truck-which allows for sufficient air circulation and reduces heat buildup-and using environment-controlled trucks (Kimaro and Msogoya, 2012; Kereth et al., 2013). In addition, government policy should prioritize road infrastructure improvements and developments. Moreover, workers need to be trained in how to load produce onto transport trucks, and how field packing could reduce mechanical damage. On stretches of poor-quality road, driving speeds should be regulated, and proper cushioning could help reduce fatigue damage.

However, most of these technologies are too expensive for the average small-scale farmer in the region (Kader, 2002), and so governments there need to make available microfinance services so that farmers or groups of farmers can afford them. Additionally, trade policies should be revised to ensure that intermediaries who use primitive transportation methods are regulated, and standard markets (i.e., with standard transportation technologies appropriate to fruits and vegetables) should be established. In Uganda, for instance, the government, together with the Food Technology and Business Incubation Center of Makerere University, is currently engaged in a project to reduce fruit price inflation and limit harvest losses during the peak harvesting seasons. A mobile processing unit (truck) from the Alvan Blanch Group (UK) is used in this project. This mobile unit travels from one growing area to another during the peak harvesting season, buying fruit from farmers, processing the fruit on site, and transporting the processed product, mostly juice and pulp, to the processing center at Makerere University (Wesonga, 2013). This unit is of great help to the fruit farmers, especially with regard to the mainly informal marketing system, as it ensures that they will realize the true value of their produce.

Cleaning

The cleaning process, which usually consists of a water bath, eliminates dirt and undesirable macro and microscopic organisms from the fruits and vegetables. This water can be warm or cool, treated or untreated, depending on the aseptic level required. Warm aseptic water produces the best results, but is more expensive because of the power needed to heat the water and the cost of the required chemical additives. Most farmers therefore use an ambient-temperature water bath to clean their produce, as it is inexpensive. Typically, for cleaning, fresh produce is tipped into plastic containers filled with water (Barbosa-Cánovas, 2003); on the other hand, large processing companies-such as Britannia or Del Monte-use more advanced and expensive cleaning techniques (including warm-water spraying) to achieve adequate aseptic levels and thus ensure food safety. Some other processing plants incorporate additional unit operations in the cleaning process, such as sorting, blanching, and precooling, in an effort to save energy and limit water consumption. Cleaning significantly reduces the microbial load in the produce and reduces its susceptibility to deterioration; it must be done thoroughly and sensibly, since the process uses expensive commodities such as water, treatment chemicals, and energy (McGlynn, 2015).

Sorting and grading

At this stage, produce is separated into predetermined categories with regard to size, shape, color, texture, degree of external/internal damage, and other characteristics. This is an important stage, as most consumers base their buying decision on these factors. Additionally, the regulatory authorities use sorting and grading techniques to certify produce engaged in trade. Most farmers, processing plants, and exporting firms in EA use human labor to sort and grade their produce; however, the human senses of sight and touch, and human judgment, are subjective, context-dependent, and inaccurate. In EA, therefore, grading and sorting pose significant challenges, and intervention is needed to ensure the quality of the sorted and graded produce.

The use of machine-based optical vision systems-including colorimetric sorters, camera-based size-sorters, and hyperspectral-image sorters-would be optimal, as these systems also facilitate the detection of fine quality aspects, such as internal damage, Brix degree, and firmness, among others. However, small-scale farmers would be hard-pressed to acquire these systems, given their high purchase cost. Therefore, in pursuit of superior quality, color, and size classifications, intervention from governments, farming groups, processing/exporting firms, and other entities is required, and farmers additionally require suitable financial and technical support.

Size reduction

Size reduction relates to the removal of unwanted parts of the produce or to attaining a desired produce size or shape. Size reduction operations increase the surface area of the produce, which in turn simplifies subsequent processing operations. The process is done just prior to further processing, such as drying, canning, juicing, pureeing, or syrup production. Most of the relevant crops in EA are sold or exported as fresh produce; only a small percentage is processed, despite the potential benefits of (and ready market for) processed fruits and vegetables. Fruit-juice production by medium and large-scale firms is the predominant process in this region, and in 2009, a growth rate of 3.7% was recorded for this sector in SSA (ACET, 2014). Most juice-processing firms employ manual methods (e.g., chopping with knives) for size reduction; they rarely use specialized chopping and/or dicing machines.

The major sources of loss during this unit operation are inaccurate approximations and the contamination of produce by workers (Mahajan et al., 2014). Therefore, training standards-such as Hazard Analysis and Critical Control Points-should be introduced to train workers on optimal produce-handling techniques.

Some farming groups in Uganda supply organically dried products to exporting companies; one of these is a farming group in Mbarara that sells dried banana chips to an exporting firm, Fruits of the Nile. The first step in preparing the banana chips is peeling and reducing the size of the fruit, which is done manually by using simple knives; from there, the fruit is dried in solar dryers (Ashden Awards, 2008). Let us look more carefully at the drying process.

Drying

The purpose of drying is to reduce the bulk and moisture content to a level such that it cannot support biochemical and microbial activity, thereby increasing the shelf life of the produce. The basic principle of drying involves the simultaneous removal of moisture from the product and the transfer of heat from the surrounding air (in motion) to the product (Krokida et al., 2003; Sagar and Kumar, 2010; Mekhilef et al., 2011). Most fruits and vegetables have a high moisture content that makes drying too impractical to employ-or, the drying process changes the physiology (e.g., loss of heat-sensitive vitamins) and/or the sensory properties of the produce (e.g., adversely affects the taste or texture). However, drying does significantly reduce the rate of deterioration and, consequently, it increases product shelf life (Sagar and Kumar, 2010).

Fruits and vegetables are dried through the use of conventional/mechanical methods, of solar energy, or even of hybrid dryers. Conventional (mechanical) dryers use fuel to increase the air temperature and reduce the relative humidity, and fans to increase the air speed. Drying conditions can be easily controlled in conventional dryers, resulting in high-quality products. In addition, the operation of these dryers is independent of the weather conditions, and the operation costs are low. However, conventional dryers are more expensive to purchase and operate than other dryer types. In some applications for which consistent product quality is essential, mechanical dryers are used (Chiewchan et al., 2012). Conventional dryer examples include light-bulb dryers, cabinet dryers, silo dryers, microwave ovens, and drum dryers, among others. These, however, are rarely used in EA.

Solar-energy-based drying methods are those most commonly used in the region; these include drying in direct sunlight, where the product is exposed directly to sunlight in the open air, and solar dryers, where the product is dried by solar energy but not in the open air. There are two types of solar drying-namely, either by direct exposure to the sun, or indirectly, by using solar-heated air to dry the product. Solar dryers use passive air circulation (natural convection), or active circulation, where the airflow is enhanced by a fan to circulate through the produce (Mekhilef et al., 2011).

Solar dryers are being implemented by several governments and nongovernment organizations in EA. For instance, working under the auspices of the Postharvest Research Program in Uganda, researchers have developed solar drying technologies, intended for dissemination to farmers and exporters; these technologies are suitable for use with pineapples, pawpaw, mangoes, apple bananas, and tomatoes. Various types of solar dryers are already available for dissemination to stakeholders; these include the Kawanda cabinet dryer, the hybrid tunnel dryer, and the portable cabinet solar dryer. In addition to these, a ginger dryer has been developed to simplify the processing of this spice for local and foreign markets. Extensions of these technologies are currently being undertaken by NARO and other collaborators-especially nongovernment organizations that deal with agribusiness, including SESAKAWA Global 2000 and the Danish International Development Agency; private sector firms; and Appropriate Technology Uganda, among others (Agona and Muyinza, 2008).

In Rwanda, Engineers Without Boarders (EWB) International, under the Johnson Space Center professional chapter (USA), are conducting various programs to assist the L'Esperance Children's Aid Orphanage in Mugonero in becoming financially independent. One of these projects is fruit-drying, for which two types of solar fruit dryers were developed; these were tested to determine which was the most appropriate for the community (EWB-JSC, 2008). In SSA, leveraging a thorough knowledge of the target community has proved successful in developing the technologies that will be used by the community (Kitinoja, 2013).

Storage

The adequate and appropriate storage of fruits and vegetables in EA remains a challenge; when it is done inadequately or inappropriately, the sector sustains significant losses (Kimaro and Msogoya, 2012). Although fresh products are often quickly sold, storage in a suitable environment is needed for fresh and processed products alike, so as to eliminate deterioration and maximize shelf life.

Fresh fruits and vegetables in EA are mostly stored in shelter shades; baskets are regularly sprayed with water, or improvised evaporative cooling containers are used. Various other local cooling methods are also employed (Katende and Namirembe-Ssonkko, 2005; Kimaro and Msogoya, 2012). Dried products are quite rare, but where available, these are mostly stored in granaries or in the usual dry-storage facilities. Some firms use conventional storage methods, and use a controlled environment (e.g., cold-room silos). However, these storage facilities are too expensive for the individual small-scale farmers that dominate fruit and vegetable production in EA; therefore, groups of farmers need to pool their resources to acquire such facilities, or the local authorities need to develop policies in support of these farmers (Agona and Muyinza, 2008; Kitinoja et al., 2011).

Cold storage and refrigeration constitute a practical approach to storing many fresh fruits and vegetables, but it could be inappropriate for some tropical fruits and vegetables, such as tomatoes, papaya, and bananas, among others. Cold conditions could cause damage to such tropical fruit and some vegetables, leading to a condition known as “chilling injury” (Siriphanich, 2000).

Typical innovative methods for storing and/or precooling fruits and vegetables are evaporative cooling and hydro cooling (Kitinoja and Kader, 2002; Kitinoja et al., 2010). A group of fruit and vegetable growers (who grow mainly mangoes, cabbages, and tomatoes) near the Mubuku irrigation scheme in Kasese, Uganda, has used this technology. The group established a simple evaporative cooling room, wherein the walls are constructed of wire mesh and charcoal and the roof is made of grass. A perforated water container is placed on the roof, and gravity induces the dripping of water from the container and into the wall matrix of the room. The wind blowing over the wet walls causes the water to evaporate from the charcoal surface, which cools the interior and the products in the room; the gases produced are carried away by the wind.

The aforementioned technologies are those most frequently used in the EA region for the postharvest handling of fruits and vegetables. Improving these methods would contribute significantly to reductions in postharvest losses in the region, ultimately leading to the advancement of the individuals concerned, as well as that of national and regional development.

Other factors to consider

There are various ways of addressing the problem of produce loss in this region-the most important of which is improving the skills and knowledge of the stakeholders with respect to the postharvest handling of fruits and vegetables. All stakeholders should be made aware of the best practices relevant to this sector and be able to implement them. Most important, however, is that appropriate government policies and regulations be established and implemented to stimulate national and regional development. The following paragraphs discuss a number of pertinent considerations relevant to improvements to the postharvest handling of fruits and vegetables in the region.

Taking into account the contribution of small-scale producers to the sector in EA, suitable land reforms and favorable land policies (e.g., agricultural land zoning implemented in Uganda, Kenya, and Rwanda) need to be developed and implemented. Furthermore, proper consideration must be given to the formation of cooperative groups, to enhance collective produce marketing and knowledge sharing. The creation of farming developmental banks could support the acquisition of suitable handling technologies and the development of cheaper postharvest handling technologies (English et al., 2004; Kitinoja et al., 2010; ACET, 2014; MAAIF, 2014).

The education of all farmers, laborers, and merchants with respect to the basic science and suitable handling of various fruits and vegetables at all postharvest stages could significantly reduce losses currently experienced in the postharvest chain. This education could be delivered by governments, nongovernment organizations, farmer groups, and others, via mass media services, community lectures, demonstration farms, and school curriculaKitinoja et al., 2011; Kitinoja, 2013; Affognon et al., 2015).

Additional considerations for curbing losses include obtaining the cooperation of farming groups-which have the interests of their members at heart-and teaching producers about all aspects related to market awareness. These strategies could help reduce losses, create jobs and, consequently, boost the income of stakeholders, thereby promoting national and regional development (e.g., Agea et al., 2005; Kimaro and Msogoya, 2012; Kereth et al., 2013; ACET, 2014).

Research and development relevant to appropriate postharvest handling techniques is a crucial factor in developing the fruit and vegetable sector. A lack of knowledge on specific products and on particular farming communities hampers research and development with regard to inexpensive, appropriate, and versatile technologies, handling methods, strategies, and policies. Consequently, this sector requires adequate investment in research and development, as appropriate knowledge is the basis of all the proposed remedial solutions (MAAIF, 2014).

The governments in the EA region need to develop and implement favorable policies to attract much-needed foreign investment that could boost production, thereby improving the standard of living in the region. Almost all the national EAC governments have already made such attempts, with Kenya enjoying success (English et al., 2004; MAAIF, 2014).

Conclusions

Using the most appropriate postharvest technologies is an effective approach to reducing the losses in the fruit and vegetable sector (Kitinoja et al., 2010; Kaminski and

Christiaensen, 2014). Although this approach has been less successful among SSA countries, it remains an important consideration. This review of the postharvest handling technologies most commonly used in EA for fruits and vegetables is an important step to determining the technologies most appropriate for the region. This review includes an assessment of cost-effectiveness, and it points to areas where improvements are needed; it also indicates the areas that require innovation. Furthermore, this review indicates that socioeconomic factors-especially those pertaining to wholly absent or inadequate knowledge on the part of the stakeholders in the sector-are the most common causes of loss in the fruit and vegetable sector. Furthermore, this review could assist in reducing the existing knowledge gap, as through it, stakeholders can be made aware of their role in the sector. This could be an important step in enabling sustainable fruit and vegetable production and income generation, and establishing food security in the region.

More community-specific research is needed to develop appropriate technologies and handling techniques that address specific problems, as has been done in Rwanda (EWB-JSC, 2008). Conversely, some researchers have proposed a general and representative approach (Kaminski and Christiaensen, 2014); however, the community-specific approach, while laborious and expensive, is more appropriate, as it takes into consideration the cultural and behavioral diversity of the SSA region.

Recommendations

This study provides a general overview of the common postharvest handling technologies and/or methods practiced in EA. However, this research is not exhaustive in presenting the details of all the technologies or methods employed, or the handling of specific products. With respect to this sector in EA, more study on specific fruit or vegetable classes, and with regard to specific communities, is required. However, this study does allude to specific factors that need to be considered and addressed by stakeholders in the region, including governments, researchers, current and prospective investors, extension services, farmers, and others, all in an effort to eliminate or reduce postharvest losses of fruits and vegetables in the region and even the whole of SSA.

As there is a vast potential for SSA countries to contribute to global food production and food security, similar reviews should be done of other agricultural products, including cereals, poultry, dairy, and other goods.

Conflict of interest

The authors have no conflicting financial or other interests.

Acknowledgements

This research was supported by the Golden Seed Project, the Ministry of Agriculture, Food and Rural Affairs (MAFRA), the Ministry of Oceans and Fisheries (MOF), the Rural Development Administration (RDA), and the Korea Forest Service (KFS).

References

ACET (African Center for Economic Transformation). 2014. The Fruit Value Capture Opportunity in Africa. Pathways to Transformation. http://acetforafrica.org/wpcontent/uploads/2014/08/ Fruit Dalberg.pdf.

Affognon, H., C. Mutungi, P. Sanginga and C. Borgemeister. 2015. Unpacking Postharvest Losses in Sub-Saharan Africa: A Meta-Analysis. World Development, 66:49-68.

Agea, J. G., E. Ssebuliba and B. Obaa. 2005. Marketing of agroforestry products in Nama sub-county, Mukono district, Uganda. *African Crop Science Conference Proceedings*. Vol. 7, No; pt. 2 of 3, pp. 537-540.

Agona. A. and H. Muyinza. 2008. An Overview of Horticulture in Uganda. Postharvest Programme NARO Uganda. Available at: http://www.egfar.org/egfar/lfm/gphi_documents/02Region_specific_documents/A_Subsaharan_Africa_(FARA)/02_Background_Documents/06_Commodities/A-2-008-003-A20_Horticulture_in_Uganda.pdf.

Aksoy, M. A. and J. C. Beghin. 2004. Global agricultural trade and developing countries. World Bank Publications.

Ashden Awards, 2008. Case study summary Fruits of the Nile, Uganda. Available at: https://www.ashden.org/files/Fruits%20of%20the%20Nile%20full.pdf.

Barbosa-Cánovas, G. V. 2003. Handling and Preservation of Fruits and Vegetables by Combined Methods for Rural Areas: Technical Manual Vol. 149. Food &

Agriculture Org.

Chiewchan, N., S. Devahastin and A. S. Mujumdar. 2012. Drying of Foods. Handbook of Food Safety Engineering, 394-411.

EAC (East African Community) Secretariat. 2014. East African Community Facts and Figures. Available at https://www.google.co.kr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0CCgQFjAC&url=http%3A%2F%2Fstatistics.eac.int%2Findex.php%3Foption%3Dcom_docman%26task%3Ddoc_download%26gid%3D144%26Itemid%3D153&ei=4gieVZmEEcKWuATJ6JXoDA&usg=AFQjCNFqgMncI0EoeWGH9iB3FrMGD_wlqQ.

English, P., S. Jaffee and J. Okello. 2004. Exporting out of Africa: the Kenya horticulture success story. In Scaling Up Poverty Reduction: *A Global Learning Process Conference*. Shanghai. May. Vol. 25.

EWB-JSC (Engineers without Borders-Johnson Space Center). 2008. 507–Project Design Compendium. EWB-JSC Rwanda. Available at: http://www.ewb-jsc.org/projects/rwanda.html.

FAO (Food and Agriculture Organization). 1993. Soil Tillage in Africa: needs and challenges. Food and Agriculture Organization (FAO) Soils Bulletin no. 69. Soil Resources Management and Conservation Service, Land and Water Dev. Division. Rome.

FIT Uganda Ltd. 2007. Study for fruits Subsector report. Available at: https://www.google.co.kr/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&cad=rja&uact=8&ved=0CBwQFjAAahUKEwjg86q3lLzHAhXkJKYKHXv5Cz0&url=http%3A%2F%2Fwww.fituganda.com%2Fmanage%2Fdownload%2Fatm%2Fmarketreports%2Fsubsectorstudyfruits.pdf&ei=tiPYVeDAC-TJmAX78q_oAw&usg=AFQjCNHAX1-_TI8HKjELTr0qTNeTT24p3Q.

Kabunga, N., S. Ghosh and J. K. Griffiths. 2015. Can Smallholder Fruit and Vegetable Production Systems Improve Household Food Security and Nutritional Status of Women?

Kader, A. A. 2002. Postharvest Biology and Technology: An Overview, In Postharvest technology of horticultural crops. University of California, Division of Agriculture and Natural Resources, Special Publication, 3311: 39-47.

Kader, A. A. 2004. Increasing food Availability by reducing postharvest losses of fresh produce. *The V International Postharvest Symposium* 682 (pp. 2169-2176).

Kader, A. A. and R. S. Rolle. 2004. The role of post-harvest management in assuring the quality and safety of horticultural produce (No. 152). Food & Agriculture Organization (FAO).

Kaminski, J. and L. Christiaensen. 2014. Post-harvest loss in sub-Saharan Africa-what do farmers say? Global Food Security, 3(3):149-158.

Katende, R. and R. Namirembe-Ssonkko. 2005. Field packing: A feasible postharvest handling method for management of ridge blackening of Okra in Uganda. *African Crop Science Conference Proceedings* (Vol. 7, No. pt. 2 of 3, pp. 615-620).

Kereth, G. A., M. Lyimo, H. A. Mbwana, R. J. Mongi and C. C. Ruhembe. 2013. Assessment of post-harvest handling practices: Knowledge and losses of fruits in Bagamoyo district of Tanzania. Food Science and Quality Management, 11:8-15.

Khanna, K. 2013. Regional Integration in Africa: A Study on the East African Community. New Delhi: Observer Research Foundation.

Kimaro, E. and T. Msogoya 2012. "Postharvest Losses of Mango Fruit (*Mangifera indica*) in Morogoro Region." Available at: http://ruforum.org/sites/default/files/Kimaro,%20E.%20%26 %20 Msogoya,%20T.pdf.

Kitinoja, L. 2013. Innovative Small-scale Postharvest Technologies for reducing losses in Horticultural Crops. Ethiopian. J. Appl. Sci. Technol. (Special Issue No.1): 9-15 (2013).

Kitinoja, L. and A. A. Kader. 2002. Small-scale postharvest handling practices: a manual for horticultural crops. University of California, Davis, Postharvest Technology Research and Information Center.

Kitinoja, L., H. A. AlHassan, S. Saran and S. K. Roy. 2010. Identification of appropriate postharvest technologies for improving market access and incomes for small horticultural farmers in Sub-Saharan Africa and South Asia.

Kitinoja, L., S. Saran, S. K. Roy and A. A. Kader. 2011. Postharvest technology for developing countries: challenges and opportunities in research, outreach and advocacy. Journal of the Science of Food and Agriculture, 91(4):597-603.

Krokida, M. K., V. T. Karathanos, Z. B. Maroulis and D. Marinos-Kouris. 2003. Drying kinetics of some vegetables. Journal of Food engineering, 59(4):391-403.

Legge, A., J. Orchard, A. Graffham, P. Greenhalgh, U. Kleih and J. MacGregor. 2007. Mapping Different Supply

Chains of Fresh Produce Exports from Africa to the UK. International Institute for Environment and Development (IIED).

MAAIF (Ministry of Agriculture, Animal industry and Fisheries). 2014. The National Agriculture Policy. Kampala, Uganda. Available at: http://www.agriculture.go.ug/userfiles/Ministry%20Policy%20statement%20FY%20201415.pdf.

Mahajan, P. V., O. J. Caleb, Z. Singh, C. B. Watkins and M. Geyer. 2014. Postharvest treatments of fresh produce. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences, 372(2017):20130309.

Mashau, M. E., J. N. Moyane and I. A. Jideani. 2012. Assessment of Post-harvest losses of fruits at Tshakhuma fruit market in Limpopo Province, South Africa. African Journal of Agricultural Research, 7(29):4145-4150.

McCoy, J. F. 2003. GEO-DATA; The World Geographical Encyclopedia.

McGlynn, W. 2015. Guidelines for the Use of Chlorine Bleach as a Sanitizer in Food Processing Operations. Oklahoma State University Food Technology Fact Sheet, FAPC-116.

Mekhilef, S., R. Saidur and A. Safari. 2011. A Review on Solar Energy Use in Industries. Renewable and Sustainable Energy Reviews, 15(4):1777-1790.

Mrema, G. C., D. Baker and D. Kahan. 2008. Agricultural mechanization in sub-Saharan Africa: time for a new look. FAO.

MTTI (Ministry of Trade Tourism and Industry). 2007. The Uganda National Export Strategy 2008-2012. Kampala, Uganda. Available at: http://www.intracen.org/Workarea/Download Asset.aspx?id=69261.

Organic Trade Association. 2010. The 2010 Organic Industry Survey. Reported by Meat Trade News Daily."USA-Organic farm sales gaining market share." Accessed August, 5, 2010.

Rickman, J., J. Moreira, M. Gummert and M. C. Wopereis. 2013. 27 Mechanizing Africa's Rice Sector. Realizing Africa's Rice Promise, 332.

Ruel, M. T., N. Minot and L. Smith. 2005. Patterns and determinants of fruit and vegetable consumption in sub-Saharan Africa: a multicountry comparison. Geneva: WHO.

Sagar, V. R. and P. S. Kumar. 2010. Recent advances in drying and dehydration of fruits and vegetables: A review. Journal of Food Science and Technology, 47(1):15-26.

Salami, A., A. B. Kamara and Z. Brixiova. 2010. Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities. Tunis, Tunisia: African Development Bank.

Siriphanich, J. 2000. November. Postharvest physiology of tropical fruit. *In the International Symposium on Tropical and Subtropical Fruits* 575 (pp. 623-633).

Ssonko, R., E. Njue, J. M. Ssebuliba and A. De Jager. 2005. Pro-Poor Horticulture in East Africa and South East Asia: The horticultural sector in Uganda, Wageningen University, A collaboration between Wageningen University Research, Makerere University, Faculty of Agriculture and East African Trade Commission.

Stangeland, T., S. F. Remberg and K. A. Lye. 2009. Total Antioxidant Activity in 35 Ugandan Fruits and Vegetables. Food Chemistry, 113(1):85-91.

Sudheer, K. P. and V. Indira. 2007. Post-harvest technology of horticultural, pp. 01-05.

TFC (Tanzania Federation of Co-operatives) Limited. 2008. Markets Information. Available at: http://ushirika.coop/content/view/20/38/1/1/.

Wesonga, N. 2013. Yumbe Fruit Farmers Get Mobile Processor. The Daily Monitor Article. Available at http://www.monitor.co.ug/News/National/Yumbe-fruit-farmers-get-mobileprocessor/-/688334/1855072/-/qt5mtjz/-/index.html.