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Postharvest management of fruits and vegetable: A potential for reducing poverty, hidden hunger and malnutrition in sub-Sahara Africa

Armachius James[1*] and Vumilia Zikankuba[1]

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*Corresponding author: Armachius James, Horticultural Research and Training Institute (HORTI), P.O. Box 1253, Tengeru-Arusha, Tanzania
E-mail: armachiuss@gmail.com

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Fatih Yildiz, Middle East Technical University, Turkey

Additional information is available at the end of the article

Abstract: Fruits and vegetable (FV) production is an emerging horticulture sub-sector in sub-Sahara Africa (SSA) despite the fact that, almost one-third of the produced FV is lost before reaching the plate. FV postharvest losses in SSA range from 30 to 80%, depending on a crop. Lack of postharvest management skills and technology such as temperature control to maintain the cold chain, value addition, and packaging have caused several economic and food security setbacks among them are high levels of poverty, hidden hunger and malnutrition. Globally, applications of postharvest technologies for instance; use of ethylene, 1-methylcyclopropene (1-MCP) and temperature management has proved to reduce postharvest losses of FV. Also, chemical and non-chemical methods are useful for controlling spoilage and pathogenic microbes especially on ready to eat FV products. Postharvest technologies such as controlled ripening, edible coating, temperature management, and chemical treatment methods are potential tools to reduce FV postharvest losses, increase food and nutritional security and alleviate poverty in SSA. At the same time, sanitizing chemicals and pesticides malpractice should be avoided to ensure final consumer safety.

Armachius James

ABOUT THE AUTHORS

Armachius James works as Agricultural Research Officer at Horticultural Research and Training Institute (HORTI)-Tengeru, Arusha-Tanzania, under the Ministry of agriculture, Livestock and Fisheries. He is professionally a Food and Nutrition Scientist under the department of research and development. His key research areas are horticultural crops value chain and postharvest management, postharvest physiology of fruits and vegetable and food safety.

Vumilia Zikankuba is an Agricultural research officer at Horticultural Research and Training Institute (HORTI)-Tengeru, Arusha-Tanzania, under the Ministry of agriculture. She is a Food Scientist and Technologist by professional. Her research focus area is on fruits and vegetable postharvest management, value addition, food safety and new product development.

PUBLIC INTEREST STATEMENT

Fruits and vegetable are good source of micronutrients in the diet. However, they start to deteriorate immediately after harvest due to high moisture and richness in nutrients which attract pests and spoilage microorganisms. Postharvest losses in sub-Sahara Africa are approximately over 30% mainly due to lack of postharvest management skills. At the same time, there is high rate of micronutrients deficiency, malnutrition and poverty in the region due to limited access and utilization of fruits and vegetable as the result of postharvest losses. Several postharvest technologies have been developed to improve quality, shelf life and reduce postharvest losses on fruits and vegetable. Adoption of postharvest technologies is an important step to reduce fruits and vegetable losses, thereby, contributing to poverty alleviation and reduced hidden hunger in sub-Saharan Africa. Also, sanitation procedures should be observed while pesticides malpractices strictly avoided to ensure produce quality and consumer safety.

Subjects: Agriculture & Environmental Sciences; Agriculture; Horticulture; Agriculture and Food; Food Science & Technology

Keywords: fruits; vegetables; postharvest; losses; technologies; temperature; ethylene; 1-methylcyclopropene; edible coating

1. Introduction

Postharvest losses refer to measurable quantity and quality loss of food crops at harvest, storage, transportation, processing, marketing and preparation before consumption (Buzby, Farah-Wells, & Hyman, 2014; Kiaya, 2014). It occur throughout the value chain, as a result of technical and managerial setbacks during harvest, handling, transportation, processing, packaging, marketing and distribution (FAO, 2016). Postharvest losses impact on environment and climate following unnecessary emissions of greenhouse gases produced during production, processing and transportation of fruits and vegetable (FV) which ultimately end into loss (FAO, 2016; Gustavsson, Cederberg, Sonesson, Van Otterdijk, & Meybeck, 2011; Kummu et al., 2012).

Production of FV in SSA as of 2014, is approximately at 34.22 and 31.95 million tons, respectively (FAOSTAT, 2017). At the same time, postharvest losses of FV in SSA range from 30 to 80% depending on nature of the crop, while globally postharvest losses is estimated at 30% (Ghosh, Fawcett, Sharma, & Poinern, 2016; Gustavsson et al., 2011; Kitinoja, Saran, Roy, & Kader, 2011; Niewiara, 2016; Singh, Hedayetullah, Zaman, & Meher, 2014).

However, one of the sustainable development agenda is to reduce postharvest losses to 12.3% by 2030 (Niewiara, 2016). Kitinoja et al. (2011) reported senescence, water loss, physical damage, rough handling, poor packages, poor temperature management, and lack of education as main causes of FV postharvest losses in SSA. Also, poor market infrastructure such as open and disorganized market outlets without storage facilities which are common in SSA contributes to enormous losses (Affognon, Mutungi, Sanginga, & Borgemeister, 2015; Wakholi, Cho, Mo, & Kim, 2015).

Agriculture intensification projects aim to improve income and nutrition status of households, however, increase in production without corresponding increase in postharvest management skills, storage facilities, and processing may heighten postharvest losses (Kummu et al., 2012). On the other hand, investment efforts made to save food after harvest usually cost less and are less harmful to the environment (El-Ramady, Domokos-Szabolcsy, Abdalla, Taha, & Fári, 2015). A minimum postharvest losses reduction can potentially reduce production cost (Ghosh et al., 2016; Niewiara, 2016). Application of postharvest technology on horticultural crops is an important effort for improving food and nutrition security and raised income in SSA countries (Affognon et al., 2015; Kiaya, 2014).

Empowering smallholder farmers and other stakeholders to process and store farm outputs/crops is a precondition for reducing poverty, hunger and malnutrition among youth, elders, women, men and children in SSA countries (Munesue, Masui, & Fushima, 2015). Therefore, this review puts together useful FV postharvest technologies which, if applied in SSA region may not only maintain fresh quality, nutritional value and food safety, but also will lead to increased income through increased shelf life, and reduced postharvest losses.

2. Fruits and vegetable nutritive values

FV are highly valued in human diet mainly for their minerals and vitamins content (Ara, Jahan, Abdullah, Fakhruddin, & Saha, 2015; Grubben et al., 2014). They are good sources of vitamin C, folate, β-carotene (pro-vitamin A), potassium, iron, zinc and calcium (Shetty, Magadum, & Managanvi, 2015; van Jaarsveld et al., 2014). Also, they are substantially high in antioxidants, bio-active compounds and fibers (Khandpur & Gogate, 2015; Wadhwa, Bakshi, & Makkar, 2015). Examples of antioxidants found in FV are carotenoids (β-carotene, lycopene), ascorbic acid, phenolic, polyphenols (terpenoids and flavonoids) and anthocyanins (Kongkachuichai, Charoensiri, Yakoh, Kringkasemsee,

& Insung, 2015). FV provides anti-cancer, anti-oxidative, anti-microbial and immune modulating effects apart from nutritional benefits to human health (Reynolds, Buckley, Weinstein, & Boland, 2014). Consequently, consumption of FV reduces incidence of cardiovascular diseases, cancer, and type-two diabetes in human (Cooper et al., 2015; Siegel, Ali, Srinivasiah, Nugent, & Narayan, 2014). On that regard, Food and Agriculture Organization (FAO) and the World Health Organization (WHO) of the United Nations (UN) have set average FV intake at 400 g/day per person (Rekhy & McConchie, 2014; Reynolds et al., 2014). Also, due to their bound antioxidants, pectin and carotenoids; FV are used as functional ingredients, bio-pigments and colorants in processed foods (Ahmadiani, Robbins, Collins, & Giusti, 2014; Makris & Boskou, 2014; Wrolstad & Culver, 2012).

3. FV quality and safety aspects

Quality is the combination of characteristics and properties that gives the commodity value for food and fulfills consumer's requirements (Barrett, Beaulieu, & Shewfelt, 2010). Quality focuses on the nutritional value, safety, sensory (color, taste), physical appearance (size, shape, absence of defects) and shelf life of FV (Barrett et al., 2010; Francis et al., 2012). FV quality are determined by pre-post-harvest production factors such as; location, climate, soil type, water quality, plant nutrition, use of pesticides and plant growth regulators; Postharvest handling; storage and processing (El-Ramady et al., 2015; Rehman, Alam, Malik, Ali, & Sarfraz, 2015). To producers quality is considered as high yield, resistance to diseases, ease to harvest, good appearance and few defects as well as good shipping quality, while marketers and distributors consider quality as good appearance, firmness and shelf life (Rouphael, Schwarz, Krumbein, & Colla, 2010; Zhang et al., 2014). On the other hand, consumers consider quality as good appearance, firmness, size, good flavor, convenience, nutritive value and good edible quality that defines their buying behavior (Nicolaï et al., 2014; Zhang et al., 2014).

Increased consumer awareness on food safety has led to public health concern on freshly consumed food like FV, related to food-borne illness, safe use of pesticides and ripening chemicals (Hassani et al., 2012; Martínez-Vaz, Fink, Diez-Gonzalez, & Sadowsky, 2014; Siroli, Patrignani, Serrazanetti, Gardini, & Lanciotti, 2015; Unnevehr, 2015). FV are colonized by a range of spoilage and pathogenic microorganisms (Olaimat & Holley, 2012). They get contaminated by dust, soil, and water during harvesting, handling, processing, distribution and preparation (Gil et al., 2015). Consumption of contaminated FV and their products has been linked to disease outbreaks caused by pathogens such as, *Bacillus species, Salmonella species, klebsiella species, Escherichia coli* and *Listeria monocytogens* (Caponigro et al., 2010; Eni, Oluwawemitan, & Solomon, 2010; Martínez-Vaz et al., 2014).

Safe use of pesticides and ripening chemical, detection and assessment of food adulteration are among important areas of food safety (Martínez-Vaz et al., 2014; Siroli et al., 2015). Washing and sanitizing steps before or during processing reduces the risk of chemical residues, pathogens and other contaminants on FV (São José et al., 2014). To ensure adherence to food safety Gil et al. (2015) recommended that, FV producers and all involved in the value chain should be equipped with skills and knowledge on food safety which includes; clean handling practices, personal hygiene, process hygiene and control of cross-contamination. For that reason, the differences between developed and developing countries in production, handling, processing, storage and distribution should not be an excuse to compromise FV quality and safety standards (Gil et al., 2015; Unnevehr & Ronchi, 2014).

3.1. Influence of pesticides application on FV safety

Pesticides include insecticides, herbicides, nematicides, acaricides and fungicides used to control insects, weeds, nematodes, mites and fungus, respectively (Zhang, Jiang, & Ou, 2011). They are intended to protect plant health, influence life process of plants, destroy undesirable plants, and minimize deterioration during storage and transportation (Zacharia, 2011). Pesticides are intended to control pest and diseases that could cause losses of the crop, however, their misuse can lead to adverse effect to human health and environment (Damalas & Eleftherohorinos, 2011). High application rates, wrong timing, and unfavorable environment are among other factors reported to associate with; toxic effect to plants and non-target organisms, water contamination and air pollution

(Damalas & Eleftherohorinos, 2011). de Bon et al. (2014) reported that, pesticides misuse is due to lack of skills and knowledge on application practices, disposal, dosage and the knowledge about pests and diseases. Although pesticides application level on food crops are reported to be low in Africa, the level of application on FV is exceptionally high (de Bon et al., 2014). Subsistence FV farmers in SSA have been reported to rely more on pesticides use than on other pest control methods (Karungi, Kyamanywa, Adipala, & Erbaugh, 2011). Studies in Tanzania, Kenya, Uganda, Ethiopia, Cameroon, Benin and Ghana reported pesticides malpractice, whereby; tomatoes are mostly sprayed with pesticides (de Bon et al., 2014; Karungi et al., 2011; Tilahun & Hussen, 2014). Safety implications on use of pesticides include vomiting, headache, skin irritation, respiratory diseases, poisoning and cancer to human (McCormack & Schüz, 2012). Acute poisoning remains a severe problem for human health in SSA (de Bon et al., 2014). Therefore, pesticides application threatens FV safety in SSA.

3.2. Influence of non-chemical alternatives to control pest on FV safety

Non-chemical pesticides are bio-pesticides or biochemical that occur naturally and control pests by non-toxic mechanisms (Dutta, 2015; Villaverde, Sevilla-Morán, Sandín-España, López-Goti, & Alonso-Prados, 2014). Bio-pesticides can be living organisms or their products or by products used to control plant pests (Czaja et al., 2015). These include bio-fungicides (Trichoderma), bio-herbicides (Phytopthora) and bio-insecticides (*Bacillus thuringiensis*-Bt) (Czaja et al., 2015). Bio-pesticides are excellent alternative to chemical pesticides, as they are specific to pest, low non-target organism toxicity, decompose quickly, less harmful and pose less effect to the environment (Seiber, Coats, Duke, & Gross, 2014). Plant extracts and oil from neem (*Azadiractha indica*), tobacco (*Calotropis procera*), garlic (*Allium sativum*), and dried chilies are used to control and repel some insect pests in Asian and African countries (Eze & Echezona, 2012; Khater, 2012).

Problems associated with use of chemical pesticides like environmental pollution, reduction of beneficial species not targeted, persistent toxicity in the food chain and health related problems to humans like cancer makes non-chemical pesticides preferable (Dutta, 2015; Sarwar, 2015). Sex pheromone traps are gaining popularity to control insect damage for both FV, for example, in mango and tomatoes, pheromones combination with traps are used to control fruit flies and *Tuta absoluta*, respectively (Bachmann et al., 2015; Cocco, Deliperi, Lentini, Mannu, & Delrio, 2015; Retta & Berhe, 2015). Due to their specificity and low risks, bio-pesticides are essential tool to control postharvest losses of FV.

4. Technologies and practices to reduce postharvest losses

FV are metabolically active, undergoing ripening and senescence changes, which has to be controlled in order to preserve quality and prolong shelf life (Mahajan, Caleb, Singh, Watkins, & Geyer, 2014). Application of postharvest technologies has proven quantifiable postharvest losses reduction in different part of the world and could be a strategic pathway to reduce poverty, hidden hunger and malnutrition in SSA (Affognon et al., 2015). They also, have enhanced horticultural industries to meet local and international demand of FV for nutrition and food security. The choice of technology depends on crop type, climatic conditions, affordability and ease of use (Kitinoja, 2013a; Kitinoja & Barrett, 2015). At the same time, proper postharvest handling practices should be adhered to prevent damages and bruises on FV (Kitinoja, 2013a). Postharvest technologies intend to slowdown ripening and senescence changes, thereby minimize crop spoilage and microbial growth. Some of the postharvest technologies involve use of chemical and physical methods which are efficient in reducing microbial contamination (Tripathi, Sharma, Sharma, & Alam, 2013). Physical methods include Modified Atmosphere Packaging (MAP), nano-composite package, active and intelligent packaging (Mahajan et al., 2014). Other emerging technologies are cold plasma, irradiation, ultra-sound and combined methods (Ramos, Miller, Brandão, Teixeira, & Silva, 2013).

4.1. Temperature management

Temperature is an important factor that influences the postharvest life of FV (Rudell et al., 2011). It determines FV postharvest quality and has direct influence on growth of spoilage microorganisms (Alegria et al., 2010). Therefore, pre-cooling is an important step for fresh produce pre-treatment

(Yu, Yang, & Tsai, 2013). For effective temperature management removal of field heat is achieved by several methods such as, hydro cooling, ice toping, evaporative cooling, forced air cooling and vacuum cooling that precede further processing (Kitinoja, 2013b).

On the other hand, low temperatures result into chilling injury and loss of cellular structure caused by collapsing of FV tissues (Aghdam, Sevillano, Flores, & Bodbodak, 2013). Chilling injury affects mainly tropical and subtropical FV due to their sensitivity to temperatures below 12°C (Aghdam et al., 2013). Some of the deleterious effects associated with low temperatures on FV, are failure to ripen, pitting, surface and internal discoloration, off flavors and microbial growth (Kader, 2013). However, high temperatures are implicated with heat injury and consequences on water soluble micronutrient losses such as, vitamin C and B group vitamins (Sajid, Rab, Jan, Haq, & Zamin, 2013). For instance, high temperatures due to sunlight can cause localized bleaching, sunburn and sunscald (Kader, 2013).

4.1.1. Heat treatment

Heat treatment include blanching, hot water dip, saturated water vapor, hot dry air and hot water rinse with brushing (Lurie & Pedreschi, 2014). Heat treatments can be of short (up to 1 h) or long (up to 4 days) duration at 37–55°C or less than a minute in hot water of up to a temperature of 63°C and is referred as heat conditioning method (Lurie & Pedreschi, 2014; Mahajan et al., 2014). Blanching is the pretreatment method before FV are subjected to further processing and storage (Xin, Zhang, Xu, Adhikari, & Sun, 2015). Blanching is used to inactivate deteriorating enzymes; maintain freshness color; stabilize texture and nutrients; and achieve sterilization by killing microorganisms (Xin et al., 2015). Usually, blanching involves dipping of fruits or vegetables in boiling or near to boiling water for 1–3 min, depending on their size, shape and quantity (James & Matemu, 2016; Vaclavik & Christian, 2014).

Postharvest benefits of heat treatment are linked to reduction of chilling injury, delayed ripening through inactivation of enzymes, controlling onset of fungal growth, killing of insects and other microorganisms (Lu, Charles, Vigneault, Goyette, & Raghavan, 2010; Lurie & Pedreschi, 2014). Heat treatment can be used; to preserve color of FV; to prevent development of off flavors; to firm or harden tomatoes, carrots and strawberries; and to add to prolonged shelf life of plums, peaches, carrots and grapes (Alegria et al., 2010; Mahajan et al., 2014). Example; mango fruits treated at 50°C retained overall fruit eating quality and weight as compared to untreated at five days of storage in the study conducted in South Africa (Sivakumar, Van Deventer, Terry, Polenta, & Korsten, 2012).

4.1.2. Low temperature treatment (refrigeration and freezing)

Low temperatures treatment is one of the effective methods to preserve quality and extending postharvest life of FV (Aghdam et al., 2013). Low temperatures (refrigeration and freezing) storage can keep FV quality attributes like texture, color, nutrients, aroma and flavor over a long storage period (Rawson, Tiwari, Tuohy, & Brunton, 2012). Refrigeration temperatures ranges from 1–4°C, while freezing temperatures ranges from −18 to −35°C (Grubben et al., 2014). For tropical FV of the SSA countries, low temperature conditioning is recommended before subjecting them to refrigeration or freezing temperatures (Kader, 2009, 2013; Kitinoja, 2013b). Low temperature conditioning is an alternative approach to prevent chilling injury in stored FV. The approach use intermediate temperatures prior to low temperatures storage to eliminate possibility of low temperature stress which trigger chilling injury (Aghdam et al., 2013). Therefore, it is recommended to manage FV temperatures and maintain the cold chain throughout the distribution and market operations to keep their freshness and nutritional value while prolonging shelf life (Kader, 2013; Kitinoja, 2013b).

4.2. Methods to enhance ripening

Conventional and chemical induced ripening methods are useful to accelerate ripening of FV (Islam, Mursalat, & Khan, 2016). Synthetic ripening chemicals are used to accelerating ripening of climacteric fruits like banana, mango, papaya, jackfruits and tomatoes (Mahajan et al., 2014). These chemical are also applicable to some non-climacteric fruits like pineapple to induce ripening (Paul, Pandey,

& Srivastava, 2012). Accelerated fruits ripening techniques are useful for commercial agriculture because, they lead to uniform ripening, taste, quality, early price, and market (Sugar & Basile, 2013). Example, ethylene gas is recommended to accelerate ripening of fruits and finds many application in the de-greening of citrus fruits (Conesa, Brotons, Manera, & Porras, 2014).

4.2.1. Ethylene

Ethylene (CH_2=CH_2) is a natural gaseous plant hormone, responsible for FV natural aging and ripening (Paul et al., 2012). It exhibits both beneficial and injurious effects on FV. Beneficial applications are inducing fruits ripening, improving color and aroma in tomatoes, mangoes, bananas, avocados, and de-greening of citrus fruits (Watkins & Nock, 2012). In a study conducted in Sudan, bananas treated with ethylene at fully maturity reached market color index at 2.7 days winning early market price compared to 13.75 days for untreated ones to reach the same color index (AbuGoukh, 2016).

Documented deleterious effects of ethylene on FV includes promotion of senescence, yellowing of leafy green vegetables and induced browning (Mahajan et al., 2014). Also, application of ethylene to immature FV, may produce negative effects such as poor color, poor taste, and undesirable flavors (Makky, Paschalidis, Dima, & Mangganaris, 2015).

Ethylene plays an important role by improving quality of FV, such as, uniform ripening for bananas, papaya, citrus and tomatoes (Paul et al., 2012; Sugar & Basile, 2013). Ethylene treatment on FV requires a dedicated room or chamber (Sugar & Basile, 2013). The room or on transit ripening chambers should be tight as possible, to prevent leakage of gas and need a temperature control and ventilation for uniform results (Ho, Hofman, Joyce, & Bhandari, 2016). The concentration of 0.1–1 µL/L ethylene for 24 h, is recommended for large scale commercial fruit ripening to hasten full ripening of climacteric fruits (Botondi, De Sanctis, Bartoloni, & Mencarelli, 2014). Ethylene at 0.1 ppm in air is reported to be a threshold level for triggering physiological activity in FV (Keller, Ducamp, Robert, & Keller, 2013). With newly developed ethylene testing and measuring devices, producers and transporters can detect critical ethylene concentrations to initiate control action (Janssen et al., 2014; Keller et al., 2013; Soukoulis et al., 2013). Therefore, ethylene control is vital in quality management and postharvest life of FV. Example, for effective tomatoes ripening, application of ethylene should be at fully fruit maturity, that is mature green, breaker or turning pink stage (Dhall & Singh, 2013; Khaira, Sandhu, & Singh, 2014).

4.2.2. Other ripening chemicals

Several artificial chemicals are used for commercial FV ripening, among them are; calcium carbide, ethephon (Chlorephon), ethylene gas, ethylene glycol, and propylene (Dhall & Singh, 2013). Ethephon (2-chloroethylpshonic acid) decomposes by hydrolysis to ethylene, chlorine and phosphate at pH 5 and above (Abeles, Morgan, & Saltveit, 2012). Similarly, calcium carbide produces acetylene gas when absorbs moisture (Pokhrel, 2014). Acetylene is an analogue of ethylene hormone (Asif, 2012). However, calcium carbide poses risk of explosion and carries toxic materials to consumer (Pokhrel, 2014). Therefore, use of artificial ripening agents must be carefully controlled, while community awareness on safety precaution must be observed on application of registered ones (Hossain, Akhtar, & Anwar, 2015).

Most of SSA countries have not registered any chemicals for absolute use for fruit ripening purpose (Islam et al., 2016). Thus, relevant government bodies need to relay with research and support initiatives to introduce ethylene induced ripening technologies, optimize and customize to the local conditions and extend use by the relevant stakeholders. This will help to prevent consumer exposure to hazardous chemicals and enjoy the real taste and flavor of FV.

4.3. Methods to delay ripening

Physical treatment; irradiation and edible coating; chemical treatment; nitric oxide, sulfur dioxide, gaseous treatment, ozone,1-Methylcyclopropene (1-MCP), Amenoethoxyvinyl gycine (AVG), silver nitrate, silver thio-sulfate, benzothiadiazole; controlled atmosphere packaging, modified atmosphere packaging; and emerging technologies are some of technologies which inhibit ethylene production and action during ripening and storage of FV, thereby extending shelf life (El-Ramady et al., 2015; Mahajan et al., 2014).

4.3.1. Calcium application

Calcium Chloride ($CaCl_2$) at low temperatures is used to suppress senescence, reduce chilling injury, control development of physiological disorders and increase disease resistance in stored FV (El-Ramady et al., 2015; Pinzón-Gómez, Deaquiz, & Álvarez-Herrera, 2014). The chemical prevented chilling injury in stored African eggplant as reported by Chepngeno, Owino, Kinyuru, and Nenguwo (2016). Also, tomatoes treated with Calcium Chloride were stored for 21 days without spoilage and indicated little physiochemical properties changes compared to untreated tomatoes in Nigeria, hence extended shelf life (Anyasi, Aworh, & Jideani, 2016). The extended shelf life can ensure income gain from harvested crops and making FV available and accessible to supplying micronutrient in the diet.

4.3.2. Edible coating

Edible coating is the thin layer of edible materials applied on the surface of fresh FV. It enhances the natural waxy cuticle on the surface of a produce, protecting it against spoilage microorganisms and physical damage (Dhall, 2013; Tzia, Tasios, Spiliotaki, Chranioti, & Giannou, 2016). Also, edible coating minimize moisture losses; slow down respiration, senescence and enzyme activity; preserve color, flavor and texture; protects against mechanical damage and microbial growth; thereby, retaining freshness, active volatile compounds and plant antioxidants (Mahajan et al., 2014). They are applied direct on FV surface by spraying, dipping, smearing or brushing followed by drying to create a modified barrier (Dhall, 2013). Their functions and effects depend on the type of coating materials, temperatures, alkalinity, thickness, as well as, variety of FV (Velickova, Winkelhausen, Kuzmanova, Alves, & Moldão-Martins, 2013).

Approved FV edible coatings including chitosan, cellulose, starch, gum (polysaccharides), bees and paraffin wax (lipids), mineral oils, polyvinyl acetate and several proteins based (like gelatin and soy proteins) that proves good barrier properties without residue taste or odor impairment (Dhall, 2013; Martin-Belloso & Fortuny, 2010). They are mainly used in combination and incorporated with antioxidants, antimicrobials, or nutraceuticals and functional compounds for improved shelf life, quality, stability, safety and nutrition of FV (Martin-Belloso & Fortuny, 2010). On the other hand, edible coating provides a carrier for postharvest chemicals treatment on FV and reduces the use of synthetic packaging materials, hence reduce the risks of greenhouse gases emission (Alam, Akram, Sharmin, Zafar, & Ahmad, 2014). This can provide a chance for SSA countries to use less energy and chemicals to reduce FV postharvest losses. Example, tomato surface coating with Gum Arabica had proven improved shelf life, delayed weight loss, maintained firmness and color (Ali, Maqbool, Alderson, & Zahid, 2013). Also, cucumbers and avocados coated with edible chitosan retained firmness and their quality for 14 days compared to 7 days of uncoated ones in Nigeria and South Africa, respectively (Omoba & Onyekwere, 2016; Taylor, Muller, & Minnaar, 2016). Therefore, the produce can be transported and stored for long period to marginal areas with limited access to FV and make them available to needy population.

4.3.3. 1-methylcyclopropene (1-MCP)

1-methylcyclopropene (1-MCP) delays ripening and senescence processes such as; pigment changes, de-greening, flavor and aroma development; cell wall metabolism, softening, scalding and browning (Gabioud Rebeaud & Gasser, 2015; Li et al., 2016). Nevertheless, application of 1-MCP produces negligible effects on internal quality, nutrient contents and consumer acceptability of FV (Minas, Crisosto, Holcroft, Vasilakakis, & Crisosto, 2013). It binds and block the ethylene receptors, preventing signaling, thereby inactivating senescence and ripening of some FV (Pongprasert & Srilaong, 2014). It is used as ethylene antagonistic to climacteric FV (Razzaq, Singh, Khan, Khan, & Ullah, 2016; Zhu et al., 2015). Also, 1-MCP delays ripening processes of non-climacteric FV (Li et al., 2016).

1-MCP is approved for use in more than 50 countries around the World (Mahajan et al., 2014). It is delivered as a gas in sealed environment, or powder form and can be applied either as a gas at room temperatures, by fumigation, in aqueous solution by dipping or as micro bubbles on FV surfaces (Permana & Broto, 2012; Pongprasert & Srilaong, 2014). It is used to control ripening on a wide range of FV including banana, apple, papaya, avocado, cucumber, pineapple, squash, melon, tomato, peaches, pepper, among others (Watkins, 2014). Pongprasert and Srilaong (2014), reported sustained firmness and delayed senescence for four days of ripe banana treated with 1-MCP, compared to two days of untreated ones. In South Africa, Zewter, Woldetsadik, and Workneh (2012) reported 14 days shelf life increase of 1-MCP treated bananas as compared to untreated batch. Also, 1-MCP delayed ripening of mango in a study conducted by Razzaq et al. (2016) in Western Australia. Boggala et al. (2015), reported storage of mature green tomato fruits for 35 days following application of 1-MCP in a study conducted in India. Major commercial uses of 1-MCP have been on apple fruits to maintain their crispness throughout the value chain (Gabioud Rebeaud & Gasser, 2015). Optimum conditions for the maximum effectiveness of 1-MCP depends on type of FV (Watkins, 2014). In combination with other technologies like Controlled Atmosphere (CA) storage and low temperatures, FV treated with 1-MCP can be stored for longer periods without changes in quality (Gabioud Rebeaud & Gasser, 2015; Watkins, 2014). However, when 1-MCP is applied at high doses than recommended the fruits do not ripen at all (Watkins, 2014).

4.4. Sanitizing chemicals

Several chemicals are used to sanitize surfaces and processing areas for FV to reduce, remove or kill spoilage and pathogenic microorganisms (Ramos et al., 2013). The best practice is to focus on preventing contamination of FV at the first place along the value chain. However, this is not always possible and use of techniques that reduce or eliminate microbes is important to prevent food borne outbreaks and product spoilage. Most of cleaning and sanitizing chemicals used for postharvest treatment of FV includes: chlorine (hypochlorites, chlorine dioxide), ozonation, hydrogen peroxide, trisodium phosphate, organic acids (acetic, lactic, citric and tartaric acid), electrolyzed water and calcium based solutions (Tapia et al., 2015). Depending on a crop and situation, sanitizing chemicals are applied at different recommended concentrations by dipping, rinsing or spraying on FV surfaces for a predetermined contact time (Joshi, Mahendran, Alagusundaram, Norton, & Tiwari, 2013). Sanitizing chemicals must be safe to the environment and human health, have trivial effect on produce quality, and cost effective (Joshi et al., 2013). According to Sibomana, Ziena, Schmidt, and Workneh (2017), tomato treated with Chlorine water showed a significant reduction on coliform and fungal counts on surfaces in a study conducted in South Africa.

4.5. Minimally processed FV

Minimally processed FV are prepared using non-thermal techniques to maintain freshness while keeping safety and quality right (Alegria et al., 2010). The process involves cleaning, trimming, slicing, shredding, dicing, sanitizing, packaging and many other operations depending on type and consumer requirements (Patrignani, Siroli, Serrazanetti, Gardini, & Lanciotti, 2015). They include ready to use or ready to eat products with increased functionality and consumer conveniences (Siddiqui, Chakraborty, Ayala-Zavala, & Dhua, 2011). Fresh-cut FV processing induces injury in tissues, thereby accelerating microbial growth and spoilage as the consequence (Patrignani et al., 2015; Ramos et al., 2013). Contrary to most food processing operations, minimally processed FV results in increased perishability and susceptibility to pathogenic and spoilage microorganisms (Alvarez, Ponce, Mazzucotelli, & Moreira, 2015). Therefore, need high level of sanitation, process hygiene, and knowledge of food technology and postharvest physiology (Gil, Selma, López-Gálvez, & Allende, 2009). In turn, minimally processed FV requires refrigeration throughout the chain (Alegre, Abadias, Anguera, Oliveira, & Viñas, 2010; Tian et al., 2012). Other preservation methods such as chemical preservatives, mild heat treatment, microwave processing, ionization, high hydrolytic pressure, pulse electrical field, ozone technology, oscillating magnetic field, ohmic heating, and vacuum packaging are used to complement refrigeration (Siddiqui et al., 2011). Furthermore, Modified Atmosphere Packaging (MAP), active and smart packaging, Moderate Vacuum Packaging (MVP), and Equilibrium

Modified Atmosphere Packaging (EMAP), are used to additionally maintain quality and shelf life of minimally processed FV (Ramos et al., 2013).

Shelf life of minimally processed FV is determined by; physical and mechanical damage; temperature injuries; stress induced senescence; chemical and enzymatic reactions; microbial deterioration; and packaging abusive atmosphere resulting in undesirable texture and aroma (Ramos et al., 2013). Microbiological, sensory and nutritional shelf life of minimally processed FV has an average of 7 days (Siddiqui et al., 2011).

5. Conclusions

Use of postharvest technologies such as application of ethylene and 1-MCP to enhance and delay ripening, respectively can significantly reduce FV postharvest losses throughout the value chain.

Controlled ripening is useful especially during peak seasons and on distant transportation. At the same time, maintaining the cold chain and temperature management is inevitable as most of tropical FV are sensitive to temperature and are climacteric. Also, using combined methods is more beneficial for FV postharvest losses reduction, particular with minimally processed FV. Proper use of postharvest technologies such as, controlled temperatures, sanitizing chemicals, edible coating and controlled ripening will lead to increased safety of FV and adherence to quality standards for local and international markets.

Although most of postharvest technologies are still unpopular in SSA, they are still a necessary approach to reduce FV losses, build a sustainable food and nutrition security, and alleviate poverty.

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Author details
Armachius James[1]
E-mail: armachiuss@gmail.com
Vumilia Zikankuba[1]
E-mail: zikankuba@gmail.com
[1] Horticultural Research and Training Institute (HORTI), P.O. Box 1253, Tengeru-Arusha, Tanzania.

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