



Postharvest Spoilage and Management of Fruits and Vegetables: A Perspective on Small-Holder Agricultural Systems of the Tropics

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ABSTRACT

Fruits and vegetables are important components of human diets all over the world. They are noted for their high moisture contents, and for providing good measures of amino acids, minerals and vitamins to their consumers. They are reported to afford their best benefits especially when consumed fresh. However, damages incurred during harvesting or handling, physiological changes and pathological attacks during storage are known to reduce their shelf-lives, affect their nutrient quality and possible health benefits. Herein we reviewed available literature on the subject matter from 1997-2018; and information obtained from local growers or grocers of agro-produce in southeast Nigeria.. Bacteria and fungi represent the highest numbers of incidents of post-harvest microbial diseases on agro-produce which often times are predisposed by abrasions due to poor harvesting and handling techniques and/or poor storage facilities especially at village level farmsteads, farm-families and marketing chains. Microbes-induced rots and deteriorations usually begin around wound sites and are exacerbated by moisture and insect migration into store houses. Between 10-50 % agricultural produce losses and food wastages are reported to occur post-harvest. Losses are more severe in the developing than developed economies and the warm humid agro-ecology coupled with poor storage structures which characterize tropical agricultural landscapes amongst other factors have been implicated for these huge losses. Simple techniques of curing harvested tubers, avoidance of wounds on produce, wrapping leafy vegetables with old newspapers, avoiding direct sun rays on produce, not packing fruits and vegetables tightly during shipment and storage; and fumigating storehouses with bio-pesticides (tropical plant extracts) are some of the post-harvest practices to prolong shelf-lives of agro-commodities compatible with low-input agriculture. These low input techniques of handling and storing agro-produce after harvesting are hereby discussed.

INTRODUCTION

1.1 Why store agricultural produce?

Agricultural productions are seasonal, and require certain time lags to produce crops. We store agricultural produce for use at a later date usually during off-seasons or in places far removed from areas with competitive advantage to produce such crops. However, in order to grow, develop and build their own protoplasm, pathogenic microorganisms have been man's greatest rival competing with and depriving him of stored food calories and nutrient-rich produce (Amadioha, 2012; Amadioha and Enyiukwu, 2019a). Ensuring global food security hence is one of the greatest challenges facing humanity especially in this 21st century; and worldwide fungi and bacteria pose the largest number of crop destroying pathogens both in the field and storage with fruits and vegetables being the worst hit (Ajibade and Amusa, 2001; Meyer *et al.*, 2016; Kasso and Bekele, 2018).

Phyto-pathogenic fungi, bacteria and oomycetes are agents of rots and deterioration of stored agro-produce leading to postharvest losses and wasted foods around the world (Enyiukwu *et al.*, 2014a; Kasso and Bekele, 2018). Association of yams, cassava, potato, wheat, cowpea, soybean, tomato and water melon for instance with *Rhizopus spp.*, *Mucor sp.*, *Curvularia sp.*, *Aspergillus sp.*, *Erwinia sp.* and *Fusarium sp.* resulted in rots and storage deterioration of these crops in Nigeria and around the world (Mahovic and Bartz, 2019; Mohammed, 2013; Enyiukwu *et al.*, 2014b). During pathogenesis, hyphae of these pathogens elaborate from their spores, conidia or chlamydospores, combining armies of enzymes and/or mechanical pressure to compromise and overcome host cuticle and defense mechanisms; to colonize and ramify the susceptible tissues (Amadioha 1994a, b).

In thus doing, these pathogens deprive the host plant of calories and other vital growth factors and use same to build their own protoplasm (Qi *et al.*, 2013; Markson *et al.*, 2014; Amadioha and Enyiukwu, 2019b). In Nigeria, postharvest studies conducted on Sweet, Irish and Hausa potatoes as well as tomato and cowpea showed that losses of protein, lipids, depletion of starch granules, and reduction of minerals such as calcium, phosphorus, potassium, magnesium, zinc and iron attend these pathogenic attacks on susceptible agro-produce in the country (Amadioha, 2004; Markson *et al.*, 2014 Nwaneri, 2017; Amadioha and Enyiukwu, 2019a, b).

Because of the increasing human population the world over, there is need therefore not only to increase food production or at least sustain current production rate but more importantly to reduce to barest minimum postharvest wastages at the current production scale. In developing countries such as ours, crop yields are generally low due amongst other factors to high on-farm pest and microbial disease attacks; with some of these

diseases continuing their ravages in stored produce. Postharvest food spoilages are therefore tremendously threatening to food security (Madrid, 2011; Kumar and Bekele, 2016) and have been adjudged the greatest form of losses encountered in farming concerns (Enyiukwu *et al.*, 2014b). So far it is reported that in the developing countries the bulk of research efforts on agriculture (95 %) is directed at pre-harvest field studies whilst only few research attempts (5 %) are geared at postharvest studies (Madrid, 2011)

1.2 Objectives of this study

Therefore, this article examined the postharvest spoilages and management techniques of fast perishing agricultural commodities (fruits and vegetables) in typical smallholder agricultural systems of remote tropical locations with a view to presenting compatible techniques and methods that can help enhance shelf-lives of produce and hence food security and safety in rural settings.

2.0 METHODOLOGY

2.1 Data generation and papers consideration

Apriori data generated from searches on the subject matter from literature conducted in the databases of ResearchGate, Google and Google Scholar based on the methodology adopted by Mgbeahurike *et al.* (2017; 2018) and Enyiukwu (2019) was used in this study. The search terms included top-rate bacterial and fungal microbes of field crops, tunes of post-harvest losses in cereals, tubers, fruits and vegetable; global and local estimates of losses of post-harvest produce, post-harvest microbial spoilage, storage forms of post-harvest produce, post-harvest management of cereals, tubers, fruits and vegetable; in the humid topics. Published papers and other useful materials on some URLs from 1997-2018 were considered for inclusion for review in this work. However, papers and other materials not written in English or written in English prior to the period designated for consideration of materials for review for this work were excluded from considerations. In addition to these, information obtained from the interaction of the lead researcher with 20 growers and marketers of grocers at the farm-gates and weekly Ndoru and Ariam markets respectively in Ikwuano Local Government Area (LGA) of Abia state, Nigeria during the wet (April-September) and dry (October-December) seasons of 2018 were also incorporated into the review (Appendix 1).

3.0 DISCUSSION

3.1 Environmental influences on storability of agro-produce

Temperature and relative humidity are the two most important parameters that determine the storage life and produce quality (Tan, 2016). Agro-produce are living things which are actively respiring and transpiring, losing water in the process. Proper control of these two factors elongates the shelf-lives and quality of produce. By lowering storage temperature and increasing relative humidity around postharvest produce, their rate of respiration, water loss, ethylene production and microbial development on them are reduced. Therefore temperature and humidity play active roles in the attainment of safe moisture content for stored produce. Safe moisture content varies with agro-produce and is attained when equilibrium is struck between the humidity surrounding atmospheric air and the moisture content of the specific produce. At the safe moisture content, the produce could store better and longer and the danger of shrinkage, insect damage and attacks of noxious spoilage bacteria and moulds becomes negligible (TSGC, 2019).

However, due to poor handling of agro-produce during harvesting, they suffer abrasions and bruises. The consequence being increased rate of respiration of the bruised produce leading to increased output of water vapour. This condition is exacerbated by high ambient temperatures which in concert with high relative humidity around stored produce encourage microbial growth and development (Tan, 2016).. As a result of increased rate of respiration and lowered tissue defense mechanisms of the affected produce to microbial attacks, mouldiness and spoilage begin to set in; and this could be worsened by surface moisture accumulation on produce (TSGC, 2019). Control of postharvest agro-produce spoilage and wastages usually involves the careful alteration of the physics of the store atmosphere to seriously disadvantage or disfavour development of spoilage-inducing microorganisms (Tan, 2016).

3.2 Qualitative impacts of microbial attacks on agro-produce: A brief highlight

Besides quantitative deteriorations, qualitative losses on produce such as anthracnose of banana, mango, guava, avocado and papaya on the other hand, could render agro-produce unsightly and thus reduce their marketable values (FRM, 2015). Some microbial pathogens associated with rots and spoilage of agro-produce include *Aspergillus spp.*, *Penicillium spp.*, *Botrydipodia spp.*, *Fusarium spp.*, etc.; in some instances these pathogens especially those of fungal origin produce toxins (mycotoxins) such as ochratoxin A, aflatoxins, T-2 toxins, H-2 toxin, vomitoxin (DON), zearalenone, and ergot which contaminate agro-produce and when such contaminated produce is consumed they interfere with functions of enzymes and hormones, impede organs such as kidney, liver and the central nervous system (CNS). Mycotoxins have been ascribed as cause of various cancers, allergies, immune-dysfunction and even death in humans (Shephard, 2008; Enyiukwu et al.,

2014b; 2018). In stored oily products attacks from postharvest moulds alter their taste making them rancid, of reduced value and poor marketability in international trade due to their accumulation of free fatty acids (FFAs) (Enyiukwu et al., 2014b). Insect infestations on the other hand, damage stored produce and increase their respiration rate, creating hotspots and building up moisture-spots in stores which in the end add to and make worse pathogenic attacks and deterioration of stored agro-produce (www.ento.psu.edu/extension/t..).

Given the enormous nature of microbes-induced postharvest agro-losses and their effects, the pertinent question now therefore is how do we consciously checkmate losses due to microbial attacks on stored produce and reduce wasted foods? Two scientific principles to this effect have been advanced which involve to:

- ✚ Kill the spoilage causing moulds out-rightly or
- ✚ Actively suppress their activity.

The later could be done through altering the environment of storage to disfavour the metabolism of the moulds and bacteria; and this could be achieved through:

- Low temperature storage involving refrigeration of agro-produce at 11-14°C where costs permit (Tan, 2016).
- Reduction of moisture content of produce to some safe levels through sun or air-drying so that the produce keeps well for 1 week to up to 1 year (www.knowledgebank.irri.org/n; TSGC, 2019).
- Addition of preservatives which are synthetic or chemicals of plant origin that ward-off microbes and/or prevent their proliferation and eventual spoilage of agro-produce. However care must be taken in adopting this method since some of these substances are potentially hazardous to human health. Plant protection experts or their trained extension agents must be involved in training farmers in this regard (Enyiukwu et al., 2014a, b, c).
- Processing agro-produce quickly into other products or food-forms in the crop's value chain that have inherent ability to store better and longer (www.ug.edu.gh/iast/node/5).

3.3 Quantitative Post-harvest microbial deteriorations: A grouping

Spoilage refers to deterioration in agricultural produce which makes it to lose nutritional value, taste bad, rotten or mouldy and thus becomes a carrier of potentially hazardous and disease causing biota or toxins. It may also refer to a loss in quality, vigour, colour and consistency of agro-produce due to pathogenic or non pathogenic factors (Garcha, 2018). Other factors which predispose or constitute spoilage of agro-produce

include physical damages during harvesting, threshing, storage or shipment, physiological damage such as sprouting and pathological deteriorations and contaminations with microbial toxins (FFTC, 2018; Enyiukwu *et al.*, 2018):

3.3.1 Physical damage of agro-produce during threshing, storage and transit

Physical damage could cause or contribute considerably to postharvest losses in stored produce or predispose them to enhanced physiological degradation. Physical damage may result from rough harvesting, or rough

threshing of grains or due to poor handling of produce in storage, transit or value chain lines. It may occur as well from impacts of extremes of temperature on produce. For example temperatures below 12°C cause chilling injury in tubers whereas temperature range of 30-45°C may cause black heart characterized by discolouration at the center of the tuber (Fig. 1) and mahogany browning in potato due to asphyxiation from too low oxygen or too high carbon dioxide (CO₂) tension in the soil or store environment. In some cases it may occur in tubers growing in waterlogged areas for the same reasons (Ephytia, 2019).

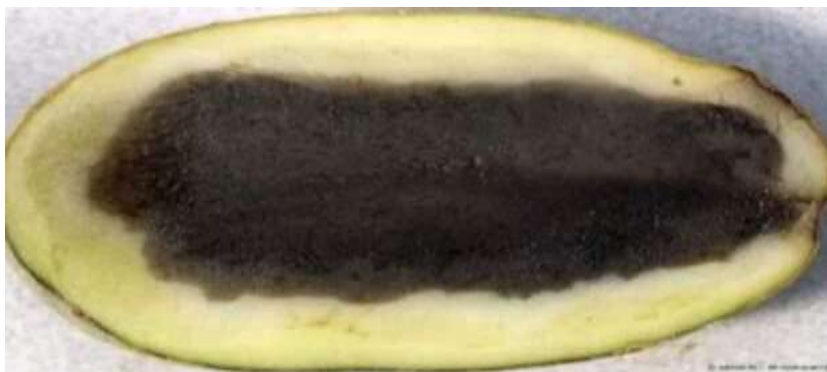


Figure 1: Black heart of Irish potato

Source: www.ephytia.inra.fr/en/G/21136/Potato-Black-heart

3.3.2 Physiological damage of agro-produce during storage and transit

This may be as a result of metabolic losses in the form of wilting or respiration. It may also be due to sprouting particularly in tubers such as yam. In any case sprouting reduces the marketability of produce. Cassava for example suffers from serious postharvest physiological deterioration (PPD) commonly known as vascular streaking which occurs some hours (within 24-48 h) after harvesting and can result in loss of 40-60 % total expected economic value of the tubers. This internal blue-black discoloration usually starts at sites of damage

especially around the central vascular bundles near to sites of damage of the root tuber and spreads to the adjacent storage parenchyma, and subsequently making the starch stored therein to undergo structural changes (Fig. 2); and thus unpalatable and unmarketable (Njoku, 2009).. Other forms of physiological changes in quality may occur frequently in all root crops in storage due to changes in starch-sugar equilibrium. In general low temperatures increase the sugar content of tubers leading to sweetening and may tend also to increase the rate of sprouting. Though sweetening is welcome in sweet potatoes or yams, in most other tubers it is reported to be undesirable.



Figure 2: Longitudinal section of cassava tuber showing vascular streaking

Photo: DN Enyiukwu

3.3.3 Pathological deteriorations of agro-produce during storage and transit

The most serious cause of postharvest losses in agro-produce is probably pathogenic attacks though however, they may be predisposed by physical or physiological damages (Okigbo, 2004; Kumar and Kalita, 2017; Kasso and Bekele, 2018). Most microbes that participate in postharvest losses are low grade, wound requiring organisms that attack produce at sites of injury incurred

during harvesting, post-harvest handling, transit or storage especially vegetables, fruits and tubers (Fig. 3). Less frequently though, the pattern of attack may also involve pre-harvest systemic infection which blossoms during protracted storage especially where there are uncured postharvest wounds and abrasions in tubers (Okigbo, 2003; 2004; Enyiukwu *et al.*, 2014b). In most cases attack leads to fermentation, tuber softening and discharge of offensive odour, hardening or making its matrix brittle (Amadioha and Markson, 2007; Njoku, 2009; Markson *et al.*, 2014; Nwaner, 2017).



Figure 3: Microbes-rotted sweet potato tuber (A) and its transverse sections (B) and transverse section of microbes rotted cassava tuber (C) **Photo:** DN Enyiukwu

3.4 Financial estimates of microbes-induced postharvest produce losses in crops

Fruits and vegetables represent the most perishable agricultural commodities and in addition to decimations suffered from pests and diseases attacks in the field; postharvest losses are reported to be very severe in these classes of produce especially in the warm humid tropics owing to lack of adequate storage facilities and poor produce handling techniques (Salau and Shehu, 2015; Kumar and Kalita, 2017; Kasso and Bekele, 2018). Globally, besides the possibility of total crop failure (100%) in severe cases due to plant diseases occasioned by microbial attacks in the field, growers suffer tremendous postharvest losses ranging from 5-70 % of actual yield of several agricultural crops (Madrid, 2011; Begum *et al.*, 2008; 2013).

In fruits and vegetables losses up to 25 % and 40 % respectively have been documented (Olayemi *et al.*, 2012; Kasso and Bekele, 2018). In most Asian

countries postharvest losses of agricultural produce are comparatively high; ranging from 10-50 %; peaking in high-moisture containing produce such as fruits and vegetables. In India losses of 20-35 % of tomato produced in that country occurred postharvest. Out of the 17 million MT of vegetables produced in Japan in 1991, 10 % was reportedly lost during postharvest handling and distribution (Madrid, 2011; FFTC, 2019). FFTC (2019) further noted that as much as 32 % loss of Chinese cabbage and radish both major constituents of Korean diets are lost postharvest per annum in both Japan and Taiwan. Also, in Thailand losses due to fruit rot of 60 % for mango, tomato and cabbage; 50 % for head lettuce and cauliflower; 30 % for bell flower and 17 % for Chinese cabbage have been reported (FFTC, 2019). The USA, Canada, New Zealand and Australia are not left out, in these economies on the average, 52 % fruits and vegetables and 38 % grains among other commodities are lost or wasted every year from farm-gates to dining tables (Fig. 4).

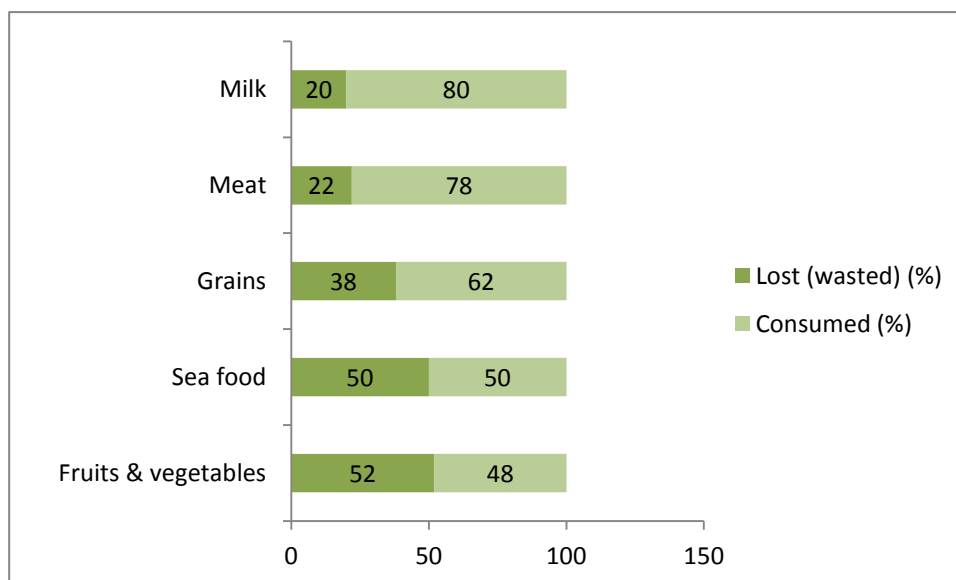


Figure 4: Estimates of foods spoilt, lost or wasted annually in USA, Canada, Australia and New Land
Source: Plumer (2012)

Diverse ranges of agricultural produce including corms, tubers and fish are reported to be lost or wasted after harvest on annual basis in SSA (Oluyemi *et al.*, 2012; Enyiukwu *et al.*, 2014b). Surveys conducted in Nigeria on postharvest wastages in yam, cassava, maize, plantain and vegetables by Oluyemi *et al.* (2012) revealed loss profiles of 33 %, 27 %, 20.33 %, 27.0 % and 33.0 % respectively. A similar study in Sokoto State, Nigeria by Salau and Shehu (2015) showed that 43 % of vegetables produces in the State were lost to microbial maceration and degradation encouraged by poor harvesting, handling and storage of produce. Out of the 134 million Mt of sweet potato produced around the world, 34 million MT were reportedly estimated to be lost to postharvest spoilages. Yam another important tuber crop in tropical Africa according to this source recorded a loss profile of 5 million Mt out of a total global production figure of 19 million MT (Enyiukwu *et al.*, 2014b).

Estimates by the Imperial College London (2012) suggest that each year fungal diseases alone destroy not less than 125 million MT of protein-calorie providing food crops such as rice, wheat, maize, potatoes and soybean; and thus dispossess 600 million people around the world of valuable sources of energy and growth factors. In three (3) cereal crops (rice, wheat and maize) alone global agriculture is reported to lose not less than USD 60 billion to fungal diseases on annual basis (Imperial College, 2012). Similarly, bacterial diseases are not left out in the hunt to dispossess men of food and their economic investment in agriculture. For instance, *R. solanacearum* is an extremely damaging pathogen having wide geographic distribution and host range. Estimates suggest that USD 1 billion is lost each year around the world due to attacks by the pathogen complex in susceptible crops (Manifield *et al.*, 2012).

Worldwide statistics in money terms, for postharvest losses in fruits and vegetables reveal that growers of horticultural crops lose not less than USD 625 million per annum (Pandy and Pandy, 2012). In Latin America alone, it is estimated that microbes-induced postharvest losses of major crops totaled about 38 million MT per annum. Estimates further showed that postharvest losses of agricultural produce in India and Latin America amounted to USD 66 million per year. In the EU countries, the postharvest losses in fruits and vegetables have been estimated at a whopping 4.0 billion EUR every year (Madrid, 2011). In the USA, a report at the Washington Post by Plumer (2012) noted that the country loses, wastes or spoils fruits and vegetables, sea foods, grains and other commodities estimated at USD 165 billion every year due in part to postharvest handling practices and high aesthetic standards or requirements for foods especially fruits and vegetables. Africa south of the Sahara with its high ambient temperatures and relative humidity coupled with poor storage and transit systems is not left out of huge post-harvest food wastages, Total post-harvest losses in perishable agro-produce ranging 20-40 % estimated to amount to about 4 billion dollars loss of revenue to growers has been documented in the sub-region (Hailu and Derberi, 2015).

The possibility of these postharvest losses and wasted foods increasing or worsening in the foreseeable future is high especially in southern Asia and tropical sub-Saharan Africa (Sadiku and Sadiku, 2011; Enyiukwu *et al.*, 2014b). Experts suggest that these losses occurred largely because of inappropriate storage at traditional village level storage systems, poor produce handling and marketing infrastructure (Hailu and Derberi, 2015; FFTC, 2019). The reason for this is to a large extent, due to microbial spoilage or deteriorations of moisture-rich fresh agro-produce stored in these

systems in locations characterized by high environmental temperatures and humidity; which without doubt have been made worse by climate change effects from heightened values of these parameters (Salami and Salami, 2011; Enyiukwu *et al.*, 2014b, c; FFTC, 2019). As a way of assessing impacts of low-input storage materials in a trial, replacing conventional traditional bamboo baskets commonly used in packaging in some Asian settings with improved rubber crates was found to significantly reduce postharvest spoilage and wastage of head lettuce during shipment from Chang Mai to Bangkok from 35.8 % to 12.6 % (FFTC, 2019).

4.0 Postharvest storage and management of loss-prone agricultural produce in the tropics

4.1 General management of physical damages

Ensure you avoid poorly drained or water-logged soils when planting tuber crops or during tuber crops development (Mahovic and Bartz, 2019). Make sure you do not harvest potato tubers during very hot weather (over 30°C), and ensure you shade-dry them (other tubers inclusive) quickly to avoid moisture condensation on them. It is recommended that during transit or storage adequate ventilation of tubers should be maintained. Also, tubers should not be packed too tightly in enclosed containers during shipment so as to avoid abrasions (Ephytia, 2019). In fruits such as tomato, eggplant and mango, do not pack ripe fruits in enclosed containers and ensure harvesting and storage only in cool dry weather (Personal communications, 2018).

4.2 General management of Postharvest Physiological Diseases (PPDs)

In High-tech societies, vacuum packaging is used to delay onset of PPDs, however, this is impractical given our peculiar circumstances. Conventional breeding or even biotechnology-assisted breeding is used to breed varieties whose roots store longer without developing vascular streaking (Njoku, 2009). In smallholder farming systems, it is advisable not to harvest cassava right after a heavy rain (Njoku, 2009). Harvest only what is needed for food or processing, ensuring you avoid wounding the cassava roots and store the harvested roots in cool dry well ventilated places preferably under tree shade or underground trenches with the tubers still attached to their stems (Personal communication, 2018; Magsasaka, 2016).

4.2 General management of pathological diseases

Several management options are open for use by growers against microbial deteriorations in agricultural produce. These range from good agronomic practices, chemical control, applying botanical measures and using bio-agents to manipulate storage environments to disfavor pathogenic infection, growth and development.

These approaches have been well reviewed by Enyiukwu *et al.* (2014a).

5.0 Specific management of postharvest microbes induced diseases of stored produce

5.1 Fruits and vegetables

5.1.1 *Rhizopus* soft rot of tomato

Vegetables are plant organs high in moisture content and consist of succulent tissues which may be eaten raw or cooked as part of the main dish. Their nutritional profiles are high supplying essential vitamins and minerals in diets (Afolabi *et al.*, 2012). Because of their high content of moisture, vegetables are very highly perishable, and hence do not keep well in store after harvest. In fact it is estimated that one-third (1/3) of all perishable agro-produce is lost or wasted between farm-gates and usage at kitchens (www.msugreenalliance.wordpress.com/2017...).

Many vegetables including tomato are attacked by *Rhizopus* soft rot caused by the fungus *Rhizopus stolonifer* in stores, transit or market. The fungus is necrotrophic. It secretes pectolytic enzymes which breakdown the cellulose cell wall of the mature cells of the fruit tissues, invades and kills them first before feeding on them. Infected host tissues become discoloured and liquefied (Nelson, 2009). Mycelia of the fungus can be seen on the fruit a few days on the fruit post-infection even without a hand lens. The organism requires an optimum temperature of 25°C and relative humidity (RH) range of 75-85% to unleash attacks on susceptible tomato varieties. Generally, the organism is a wound requiring parasite and usually overwinters unfavourable conditions as zygospores that may survive for many months. The intensity of attacks of the pathogen on tomato fruits varies with cultivar of the crop, temperature, relative humidity, amount of inoculum present and the amount of wounding at harvest, threshing or storage. Usually losses are greater in a few days and decreases with time (Mahovic and Bartz, 2019).

Management of *Rhizopus* soft rot:

It is pertinent to note that resistant varieties to this disease and several other post-harvest fungi or bacteria-induced diseases of vegetables thus far are unavailable (Mahovic and Bartz, 2019). Generally, in managing fungal or bacterial soft rot, it is essential you avoid wounding the fleshy fruit of tomato during harvesting, handling, transit or marketing (Nelson, 2009). In the event this happened, the wounded fruits should be discarded or ensure that they are consumed immediately or better still be processed by dehydration. Do not harvest tomato fruits in wet weather, because dampness of fruit will encourage susceptibility to fungal rot pathogens and development of soft rots (Mahovic and Bartz, 2019).

In urban or sub-urban settings, sound fruits should be stored in storage facilities free of crevices, roof-leaks, debris, rodents and insects. Disinfect all such facilities to ensure freedom from insects and pest before storage and after sale of all existing stocks of produce. Ensure also that no weight is placed over the fruits during transit or storage. Before storage, wrap fruits with paper impregnated with specific synthetic or botanical fungicides such as Botran 75W (Dicloran 75W). Lastly, do not store fruits for a very long time (Mahovic and Bartz, 2019) especially when narrow spectrum fungicides with low residual activity is used as preservative. Make sure that such tomato fruits are converted to other longer storing forms in the crop's value chains.

In local farm-settings store only sound fruits in bamboo baskets impregnated with *Tectonia* or banana leaves to cushion the fruits against shock, prevent abrasions and absorb undue moisture (Personal communication, 2019). In smallholder households the ground or whole fruits dehydrated by boiling and preserved with few pints of vegetable oil store well at room temperature for up to 1-2 month (Personal communication, 2019).

5.1.2 Storage spoilage of onion bulbs

Sprouting is one of the major constraints limiting storage life of onion bulbs. After prolonged storage periods mature onion bulbs begin to sprout either during transit, marketing or in store. This generally, reduces the market acceptability and value of the bulbs. Traditionally, onions are stored in simple structures, insulated from undue temperature and humidity build-up through maximum allowance of air circulation. This is achieved by keeping the depth of the pile at minimum, orienting the store house to allow maximum passage of prevailing wind and stacking the bulbs on a mesh of wood or cane with an air space below or in jute bags. The maximum length of storage depends on the agronomic practices adopted by the farmer in the field, cultivar, store condition, and bulbs quality before storage (Wani and Taskeen-un-Nisa, 2011; Nischnitz et al., 2013).

Longer storing cultivars are generally characterized by high dry matter contents, high refractive index, low water loss rate, strong pungency and hence less liable to microbes incited rots. Onions can be stored at relative humidity of 70-80% and 0°C for 8-9 months. Higher temperatures progressively decrease the shelf-life of this valuable spice. At room temperature in the tropics most cultivars desiccate highly and rot uneconomically. Attacks by insects and mites on bulbs seem exclusive to fields, however, the nematode *Ditylenchus dipsaci* which has infected the crop in the field could continue systemic degradation of stored bulbs causing them to be puffy and light weight. Fungi such as *Alternaria spp.*, *Sclerotium spp.*, *Fusarium spp.*, *Rhizopus spp.*, *Pernorospora spp.*, *Botrytis spp.* and *Colletotrichum spp.* among others have been found to be associated with onion rots (Awurum et al., 2016). Neck

rot caused by *B. allii* and *B. aclada* is commonly recognized as the most widely distributed storage disease pathogen of onion bulbs. Infection occurs in the field when the crop blooms and is carried over to the stores. The fungus causes softening of the scales which take on water soaked appearance. Neck rot prevail severely when moist conditions precedes harvest and while onion is being dried in the field. Excessive late applications of nitrogen fertilizers and irrigation (i.e. post bulb initiation) have been reported to exacerbate the disease (Nischnitz et al., 2013; Awurum et al., 2016).

Massive storage losses in onion have been reported in many countries including India. *Aspergillus niger* has been documented as the cause of black mould rot of stored onions. The fungus is widespread in distribution in onion growing locations, and has been reported as one of the most destructive diseases of the crop in storage (Wani and Taskeen-un-Nisa, 2011). Evidence of its presence is huge masses of black powdery spores on both the exterior and between bulb scales of infected samples. High N-fertilizers predisposes the crop to the disease. Downy mildew caused by *Perenospora destructor* is also associated with the rot of onions in storage. The disease is systemic and infected bulbs are soft and shriveled or may sprout prematurely (Awurum et al., 2016). Basal stem rot on the other hand is a wound requiring disease of onion caused by *F. oxysporum f.sp cepae*. This fungus is soil-borne, and the attendant disease on the crop is exacerbated by high storage temperature and relative humidity. Similarly *Sclerotium cepivorum* another soil-borne disease of the crop is systemic and late infection leads to high storage decays in the crop (Awurum et al., 2016). Bacterial pathogens such as *Erwinia carotovora ssp carotovora*, *Pseudomonas cepacia* and *Bacillus coagulans* are also reported to cause varying degrees of rot of the produce in the store (Nischwitz et al., 2013; TAMU, 2019; PNW Plant Disease, 2019).

Managenent of onion rot

Seeds or bulbs should be dressed with fungicides such as benomyl (1 g/kg seed) before sowing. In the field, ensure that pre-mature onion bulbs are sprayed with maleic hydrazide (MH-36% a.i) 5.5 liters in 553-675 liters of water per ha to suppress untimely sprouting of matured bulbs during storage. Also, ensure that bulbs are well matured before harvesting. Do not harvest mature crops during and immediately after rains. Ensure that the bulbs do not suffer bruises, wounds or injuries during harvesting as these could become portals of entry to soil-dwelling rot causing bacteria and fungi such as *F. oxysporum* which is common in most tropical agricultural soils.

Air-dry bulbs quickly after harvest to reduce their moisture content (Nischwitz et al., 2013). Warehouses should be fumigated to rid them of insects with sprays of neem kernel oil and their roofs properly mended to prevent leaks which would increase humidity and hence build up of pathogenic fungi (Enyiukwu et al., 2014a).

Where artificial ventilation is the order in large scale production systems stores, store bulbs in jute bags and where not store in local bamboo baskets or cartoned floors; and don't stack them above 3 meters (Nischwitz *et al.*, 2013). Where possible in large scale onion production systems, spray stored bulbs with botanical fungicides such as neem oil or synthetic ones such as carbendazim, mancozeb, hexaconazole and captan (Wani and Taskeen-un-Nisa, 2011). In smallholder farm unit stored bulbs should be admixed with lime or lemon fruits to ward off microbial degradation (Personal communication, 2018)

5.1.3 Bacterial soft rot of carrot

Soft rot is one of the most destructive diseases of carrot (root crop) and other vegetables during transit and storage. It leads to economically important losses in the form of huge rots and decreased product vitality; as well as reduced product marketability (Green Life, 2019). In susceptible varieties, the disease occurs as characteristic soft decays of the fleshy vegetable. It begins as small water-soaked spots which enlarge rapidly. Affected tissues become mushy, cream coloured and leak water. Soft rot is caused by a non-spore forming Gram negative bacilli called *Erwinia carotovora* pv *carotovora* (Green Life, 2019). The organism grows well at a wide range of temperatures but thrives better at optimum ambient temperature value of 25°C. The pathogen has wide host range affecting potatoes, onions, tomatoes, cucumbers and other fleshy vegetables (www.gadeningknowhow.com/soft_rot....). It is a cosmopolitan organism surviving in a wide range of soils and aquatic habitats. In fields, rogue and destroy affected plants by burning since the disease is difficult to control. Post harvest, the pathogen usually invades bruises on the crop, and secretes pectolytic enzymes with which it attacks and degrades cementing substances of the middle lamella, cell walls and then being assisted by other enzymes the cell contents. *Erwinia carotovora* pv *carotovora* overwinters unfavourable conditions on the crop debris, seeds, and in soils. Harvesting bruises, freeze (or chill) injury, and wounds by insect increase the chances of attacks of the disease on susceptible cultivars of carrot. Abundant moisture at wound sites and high atmospheric humidity also encourage the development of the disease. In any case damaging rots ensue following attacks by the bacterium which weather and store condition could exacerbate (Nischwitz *et al.*, 2013).

Management: Carrot is the enlarged tap root of the crop which we eat. Ensure that the flesh surfaces of the produce are dry and free from moisture. Also avoid bruising them when harvesting, transplanting and storing carrots. Maintain good air flow in storage areas and store houses. In high-tech farms; cool carrots to 4-6°C on arrival from shipment before storing. Never store wet, wounded or decaying carrots. Ensure that you store at optimal relative humidity, and keep stores clean, leaks

and insect free (Green Life, 2019). In low input farming systems store carrots in bamboo baskets impregnated with dried absorbent plant leaves (Personal Communication, 2018)

5.1.4 Leafy and other vegetables

Telferia occidentalis (Fluted pumpkin) and *Amaranthus esculentus* (Amaranth) are choice leafy vegetables in West Africa especially Nigeria (Afolabi *et al.*, 2012). Fluted pumpkin is an important fast growing indigenous medicinal and nutrient rich seed and leafy vegetable in very high demand in Nigeria (Odiaka *et al.*, 2013). In addition to spicing up the kitchen, its phosphorus and protein-rich seeds are widely used in ethno-medicine as tonics, to protect against cardio-vascular diseases; for treating anaemia, convulsions and malaria (Ajuru and Nmomo, 2017). Seeds of the crop furthermore are used in boosting sexual libido and as panacea against low sperm counts in human males (Munaya, 2016). Also, nursing mothers consume the seeds for its lactation-inducing properties. While the seeds oil is reported to possess potential activity against kidney or bladder stone disease and have ameliorated quinine-induced testicular damage in a trial (Akang *et al.*, 2010).

Harvesting of leaves of the crop is done at maturity when the leaves are luxuriant while fruits are deferred till the end of the cropping season (November-December). Leaf harvesting should be done in cool weather either early in the morning or late in the evening when the sun has set. Harvested vegetables should be kept under shades away from scorching sunlight (Personal communication, 2018). After harvesting, the produce should be graded and tied into bunches with ropes, and wrapped with jute bags in the case of amaranths. Shipment to points of sale must be as quick as possible as dehydration reduces the marketability of the produce. At points of sale these leaf vegetables should be sprinkled with water periodically to keep them moist and remain maximally attractive. Nevertheless, fresh vegetables may be contaminated with rot causing organisms from soil or water-borne fecal matter or manure between the farmstead and points of their sale. Recent surveys conducted at points of sale of vegetables in Iran showed contamination of fresh and minimally processed vegetables by species of *Fusarium*, *Geotrichum*, *Cladosporium*, yeast and *salmonella* (Jeddi *et al.*, 2014). Leafy vegetables therefore should not be packed so tightly in storage especially when damp to avoid pathological decays. However, produce do not keep well more than 4-6 days with good attention without cool storage. Vegetables for salad may be preserved with brine solution or vinegar. Generally leafy vegetables should be unwrapped and spread on thatch roof or table tops every night to allow dew to fall and keep them fresh and humid (Personal communication). Association of *T. occidentalis* with *R. stolonifer*, *Botrydiploia theobromae*, *A. niger* and *Erwinia carotovora* ssp *carotovora* leading to its fruit rot has been reported with virulence highest in *R. stolonifer* and least in *A. niger*. (Nwufo and Emebiri,

1990). These workers attributed 95 % incidence of the rots to the fungal agents and 5% to the bacterial agent. These agents are likely responsible for the decay of its leaves in damp conditions. Seed protein, carbohydrate and lipid contents reduction of 48-61.0 %, 63-79.0 % and 60.3-71.5 % by these fungal agents has been documented (Nwufu and Emebiri, 1990).

Ptericarpus osun popularly called *Uha* in eastern Nigeria is a well appreciated potherb. It suffers dehydration and wilting when exposed in the air for a long time after harvesting. The leafy vegetable should be kept dry and wrapped with printing papers or old newspapers before storing in a refrigerator where available in which form it can keep well for about 7-14 days. Alternatively, the fresh leaves of the plant should be stored in open bamboo baskets overlaid with old newspapers under tree shades. Damp leaves of the crop are easily attacked by decay causing microbes, therefore avoid storing the produce when damp (Personal communication).

Biter leaf (*Vernonia cordata*, *V. amygdalina*) is another widely consumed potherb especially in eastern Nigeria. fresh leaves are washed and squeezed in warm water and the resulting minimally processed leaves are soaked in fresh water stored with the water changed each morning. In other instances, the leaves are first minimally by sun or air dried and then wrapped with old newspaper and stored in cool dry places such as under trees or thatched roofs (Personal communication).

Plantains and bananas are well grown and eaten in Nigeria being common in western and eastern parts of the country. In agronomic terms, they may be regarded as fruits or vegetables depending on variety or use to which they are put. Plantains and bananas should be harvested at three-fourth maturity and stored in cool dry places to allow for gradual bunch by bunch ripening. During shipment, bunches should never be packed tightly, however, they should be packed with dried banana leaves sandwiched between bunches. Field infection of bananas with anthracnose (*Colletotrichum spp.*) makes the produce unsightly and should be controlled by sprays of benomyl or neem kernel oil at 3-monthly intervals (Enyiukwu et al., 2014a). Bunches should never be stored in ethylene laden environments as this could facilitate ripening and encourage attacks by rot inciting microbes. If possible store plantains and banana along with plenty of lime or lemon fruits to forestall unwarranted microbial decays (Personal communication, 2017).

***Dacryodes edulis* (African Pear, Butter fruit, Safou pear)**

African pear commonly called Ube in Igbo is a highly cherished fruit in southern Nigeria. It is seasonal and is commonly on sale between March and June. Mature fruit turns from pink to blue-black in colour when ripe; and is

usually eaten boiled or roasted with roasted corn. Harvesting is done using go-to-hell or hooks made from tree forks either early in the morning or late in the evening. The fruit is reported to be highly perishable storing less than 1 week post-harvesting in the warm humid tropics especially when harvested in wet weather (NAP, 2008). Rot in the crop is reported to be quite huge, being triggered or worsened by wounds incurred due to poor pre- and postharvest handling, poor storage and shipment practices or conditions (Hai, 2019). In fact losses, spoilages and wastages amounting up to 50 % have been documented in the African (safou) tree fruits (www.worldwidefruits.com/dacryodes-edulis-safou-tree.html, 2019). Fungi and bacteria namely *B. theobromae*, *R. stolonifer*, *A. niger* and *Erwinia spp.* were implicated in the rots of the crop with the first two organisms actively virulent and destructive accounting for 80 % of the rots in most cases (NAP 2008; Hai, 2019).

Management

Harvest African pear fruits only in dry weather (www.worldwidefruits.com/dacryodes-edulis-safou-tree.html, 2019). Like other perishable agro-produce, avoid wounding the fruits during harvesting. Ensure you store them in local bamboo baskets without lids or jute bags, in cool airy and moist-free places (Hai, 2019). Never store the fruits in hermetic containers and do not store them densely. Dampness on fruits or moisture migration into store-houses should be strongly avoided as these trigger unwarranted softening and mould deterioration of the fruits (NAP, 2008). Never stack baskets one upon another so as not to pressure the fruits to rots and decays. Introduce few fruits of lime fruit into the storage baskets and cover the tops of baskets with dry moist-free leaves and twigs of bitter leaf (*Vernonia cordata* L.) before storing (Personal communication, 2018).

Canarium shweinfurthi (African elemi, canarium) is widely distributed in the rain forest-guinea savana belt from Senegal, Ghana, Nigeria, Cameroon etc. The fruit is commonly called *Ube osa*, *Ube nwanunu* or *Gbaruruo* in Igbo speaking region of Nigeria. Mature fruit of the crop is blue-black in colour in much the same way as African Pear, however it is smaller and harder than the African pear and unlike it, requires longer soaking in hot water (2-3 days) to soften (Okpala, 2016). It is rich in many kinds of fatty acids such as palmitic, stearic, oleic and linoleic acids. Resins from the plant provide local candles for natives while the char is used in making ink. Various parts of the plant find applications in a plethora of ethnobotanical uses (Okpala, 2016). The fruit is harvested by picking also, stored damp-free under tree shades away from scorching sunlight and shipped in local bamboo baskets padded with dried plantain leaves or jute bags (Personal communication, 2019).

Chrysophyllum albidum (African star apple) commonly called *Udara* in Igbo is another well cherished fruit making debuts about the onset of farming seasons. The fruit which is somewhat heart shaped is golden yellow in colour, and contains about 4-5 seeds. Harvesting is done by picking of mature fruits from the tree. Post-harvest losses in the crop are huge too due to poor handling and post-harvest microbial deteriorations. Though cool storage at 10°C makes the fruit keep well for a long time without spoilage (Nwugo *et al.*, 2002); but in village level farmsteads the fruits are stored in un-lidded bamboo baskets and kept under cool tree shades (Personal communication, 2018).

Persea americana (Avocado pear, Alligator pear)

This fruit is commonly called *Ube bekee* in Igbo speaking areas of southern Nigeria. They vary in shape from round to pear; and colours from green in most cases to dark brown (FM, 2015; Gunmars, 2018). Because of its high nutrient density, avocados are termed superfoods. One hundred grams of the fruit is reported to contain protein (2 g), fat (15 g), calories (160 g) and about 20 vitamins and minerals including vitamins K (26 %), C (17 %), E (10 %), B₅ (14 %), B₆ (13 %), folic acid (20 %) and K (14 %). Mature fruits are harvested by picking just like the African pear; like many other fruits it does not store for a long time before rotting, being attacked by *Botryotinia* (*Botrytis*) *spp.*, *Colletotrichum* *spp.* and *Aspergillus* *spp.* (Gunnars, 2018). In most cases these organisms affect the fruits from the field while expressing symptoms in the store. Anthracnose caused by *Colletotrichum* *spp.* attack a variety of crops and agro-produce in the field and store (Awurum and Enyiukwu, 2013). *C. gloeosporioides* in particular causes unsightly necrotic lesions of the avocado fruit which leads to pulp blackening and rot to the stone of the fruit. This organism attacks mango and papaya leading to serious fruit blemishes. Alongside other rot organisms, up to 70 % postharvest losses or wastages have been attributed to this fungus in mangoes (Madrid, 2011). Also stem rot caused by *B. theobromae* is another serious spoilage disease which affects avocado fruits as small pale brown necrotic lesions which rot the fruit pulp being exacerbated by injury and damp conditions (FRM, 2015).

Management

Do not harvest avocados during the rains and avoid moist soils sticking on the fruits. Picked fruits should be kept under tree shades away from direct sunlight. Avoid bruises on fruits during harvesting and down the value chain lines as these pose portals of entry to rot inciting microbes. Ensure that store houses are well ventilated and leak-proof; and store only damp-free fruits in local baskets overlaid with dried banana leaves to cushion shocks during shipment and reduce the effects of rot causing agents (Kebede and Bailey, 2019). Generally, post-harvest management of fruits are similar. Natives

follow the same manners to handle, store and ship fruits with little modifications to the practice here and there.

5.2 Cereals

5.2.1 Maize storage rot

Mature maize should be harvested from the field when the moisture content (MC) is less and equal to ($\leq$) 20-25% (Tan, 2015). They should be stored immediately in cribs or over fire places in tropical traditional homesteads (Personal communication, 2018). The produce stores well when its moisture content is less than 12 % and the surrounding air is warm enough to discourage fungal propagules from growing on the crop (www.knowledgebank.irri.org/sep-by-step-..., Tan, 2015). Storage rots reduces the market grade and the feeding value of the maize grains. Insects infestation of maize cobs in field, transit and storage not only lowers its nutritional profile; it contributes immensely to making grains loose more moisture and when stored in enclosed store houses lead to development of hotspots, undue sprouting and increased damage to seed viability. Ultimately all these predispose the stored grains to fungal colonization (www.knowledgebank.irri.org/sep-by-step-..., Tan, 2015).

Moist store environment in tropical settings contributes to making produce go mouldy some of these fungal contaminants such as *Fusarium graminearum*, *Aspergillus flavus*, and *Penicillium oxalicum* produce noxious toxins. Consumption of maize grains or feeds contaminated with various toxins from these microbes have been reportedly linked to chronic or severe impairment of the metabolic processes of the liver, skin, kidney and the CNS (Enyiukwu *et al.*, 2014b; Enyiukwu *et al.*, 2018). Threshed kernels store longer with every 1 % fall in seed moisture content and 5 % drop in ambient temperature storage life of kernels is doubled. However, though there is greater danger of breaking kernels during threshing when moisture content has reached 3 %; at this moisture level storage moulds are completely and successfully kept at bay.

Management of maize storage rots:

Ears should be harvested in dry state and stored in maize cribs. The cribs should be rectangular in shape and positioned perpendicular to prevailing wind direction to give maximum air circulation and drying. Depending on the prevailing regulations, the walls should be dusted regularly with insecticides such as essential oils such as neem kernel and tea tree oils or extracts of black pepper (Asawalam and Emosairue, 2006; Awurum *et al.*, 2014). Ensure that the crib has adequate roof overhang and well protected from rodents. Don't keep ears beyond 3-6 months in cribs. When the moisture content of kernels falls to 12 %, cobs should be shelled and grains stored in hermetic/airtight containers such as tins, screw drums and polythene bags. Ensure also that the grains are

cooled before storing in the air tight containers (Lane, 2016).

5.3 Oil seeds

5.3.1 Groundnuts

Groundnut should be harvested at 18-20 % moisture content from the fields. They should be dried with the thrash and husk to about 15 % moisture content which is good for threshing and dehushing (www.knowledgebank.irri.org/step-by-step-production/prot..., 2019). Dehusked nuts should be dried to less than 7-8 % moisture content to discourage fungi from growing on the nuts. Nuts should be spread out on platforms which can be carried inside at night or during wet weather. Very high temperatures stimulate a degradative lipid process (lipolysis) leading to release of free fatty acids (FFAs) in oils from groundnuts. Poorly dried produce attract the growth of some mycotoxigenic moulds such as species of *Fusarium*, *Aspergillus*, *Penicillium*, and *Claviceps purpurea* (Enyiukwu et al., 2014a, 2014b). Following harvest, aflatoxins and other hazardous fungi-derived toxins contamination of the nuts would be prevented by rapid drying of the produce at 30°C in the sun for 6-7 days to moisture content of 12 %. At this point though the nuts will not be entirely fungi-free, but the inocula density will be tolerable.

Relative humidity (RH) of 70 % (or less) is essential for good nut storage. Above this, there may be a stimulation of successive mould growth on the nuts

and RH of 85 % activates aflatoxigenic moulds to grow and contaminate the nuts. Other factors which can encourage fungal growth and production of aflatoxins during storage of nuts include:

- Presence and activity of insects,
- Rodent activity,
- Moisture migration through the store,
- Badly maintained store houses

Mycotoxins occur on a wide range of agro-produce especially oil produce such as groundnuts and have been implicated in mycotoxicosis in humans and domestic animals when ingested. The effects could be chronic leading to deleterious effects on the CNS, cardiovascular system, hepatic organs, liver, and the alimentary canal or acute exposures culminating ultimately to death if not well treated. Effects such as immune-suppression, carcinogenicity, mutagenicity and teratogenicity have also been linked with these toxic microbial metabolites (Enyiukwu et al., 2018).

Aspergillus flavus is ubiquitous in the hot humid tropics and can colonize groundnuts at various stages of development in the field. Moisture and temperature are important weather parameters which determine the incidence of the disease on oil seeds. Insects could exacerbate occurrence of mycotoxins contamination of nuts and oil seeds. Some important moulds and their mycotoxins which commonly contaminate nuts and oil seeds are presented below in Table 1.

Table 1: Some important moulds and their mycotoxins on oil seeds

Moulds	Toxic metabolite(s) on oil produce
<i>Aspergillus flavus</i>	Aflatoxins B1 and B2; Cyclopiazonic acid
<i>A. parasiticus</i>	Aflatoxins B1, B2, G1 and G2
<i>Fusarium sporotrichoides</i>	T-2 toxin
<i>F. verticilloides</i>	Fumonisin B1 and B2
<i>F. graminearum</i>	Deoxynivalenol, Zearalenone
<i>Penicillium verrucosum</i>	Ochratoxin A
<i>A. ochraceous</i>	Ochratoxin A

Source: Enyiukwu et al. (2014a; 2018)

Management of groundnut rots

Avoid application of nitrogen-rich fertilizers late in the growth stages of groundnuts and other oil seeds. Harvested oil nuts and seeds are best air dried in artificial chambers as sun drying takes about 5-7 days at 30°C and 75 % RH, which long period could permit mycotoxigenic rot microbe to grow even to threshold levels. Stored nuts should be maintained at 8 % moisture content in well cleaned environments (Enyiukwu et al., 2014b). Packing stores in large agro-concerns should be fumigated with phostoxin or methyl bromide. In low-input agriculture, open village level stores should be well ventilated and possibly installed with fans if cost and power permits. Stored nuts should

be processed for oil as quick as possible and the resultant cakes adequately sundried before use in feeds.

5.4 TUBERS

5.4.1 Sweet Potato

Sweet potato should only be held for a short period in storage prior to marketing. A wide range of storage is used in the tropics including storage in caves and trenches (Maranzu, 2019). Like other perishable high moisture produce, ensure they sustain no or minimal bruises during harvesting, transportation and marketing. Where tubers wounds are minimal or non-existent, it is necessary to cure the tubers immediately after

harvesting at 30°C and relative humidity of 85-90 % for 5-7 days. Avoid harvesting just before or after rains or irrigation as this could predispose the produce to microbial spoilage. Ideally, the produce should be stored at 13-16°C and relative humidity of about 90 % (Enyiukwu et al., 2014a; Maranzu, 2019). Generally, the red skinned varieties store better than the white skinned ones (Personal communication, 2018). At present vitamin A rich orange fleshed novel varieties which can be eaten raw or cooked to help fight vitamin A deficiency (VAD) diseases in humans have been developed (Inyang, 2010). In traditional tropical farmsteads, storage of sweet potatoes are mainly done in caves, pits or trenches lined with straw, bamboo and covered with thatch or asbestos roof for protection against dew and rains. Depending on agro-ecological zone, it can also be stored in clamps or huts whose walls are lined with dry old newspapers, off-cuts and floors littered with dry saw dust or grasses (Personal communication, 2018). The saw dust must be dry to keep tubers cool and dry and discourage microbial rot development on the produce. When storing large volumess of produce, ventilation is necessary to circulate air through the mass of produce and keep them dry and maintained at optimum storage temperature of about 25°C (Personal communication, 2018).

5.4.2 Cassava

Traditionally in tropical farms of sub-Saharan Africa, cassava is left in ground and harvested only when needed while in larger ago-concerns they may be harvested for immediate use or processed into other longer storing products such as garri (Personal communication, 2018). On-plant in-ground storage may be desirable, but it decreases other useful uses to which the land could be put into. In this kind of method, susceptibility of the tubers to pathogenic attacks and losses increase; while palatability and extractable starch content declines when harvesting is greatly delayed (Personal communication). Re-burial of small quantities of cassava tubers can preserve them for a few days in moist soil. They may be alternatively coated with mud to keep them fresh for a few days. Clamp storage has proved very successful and should be used to store fresh tubers for 6-8 weeks. Clamps are made by heaping cassava on a straw mat and coating it with a layer of mud, before covering it with soil. An air vent is usually created in the clamp. Periodically the clamp is watered and covered with palm fronds or dried grasses (Personal communication). Cassava tubers keep well in clamps which provides them with curing temperature and humidity (Maranzu, 2019).

5.4.3 Yam

For ages yams have been stored by traditional means in barns. Though during dry season can be left in the soil without appreciable loss of quality, however it is better to harvest them into barns away from rodents and pig

attacks. In some small scale production systems they may be stored in room whose floors are matted with dry straw or stovers. Typically West African barns have the advantage of maximum air circulation (Enyiukwu et al., 2014b). Yams for barn storage are first cured for 4 days at 29-30°C and 85-90 % RH at which time satisfactory healing occurs around deep cuts. Tubers which do not heal such bruised areas are cut off. Yam barns should be created under forest shades at the back of the farmers' houses (Personal communication). In general, cured yams should be stored at 16°C and 70 % RH for 3-4 months. Removal of shoots from sprouted tubers helps to prolong the storage life of yams and other tubers (Markson, 2010; Maranzu, 2019).

5.4.4 Irish and Hausa potatoes

Irish potatoes are commonly grown in southern Kaduna and around the Jos plateau areas of Nigeria. Care should be taken during harvesting, transporting and marketing of potatoes to minimize abrasions which could predispose them to microbial attacks. Harvested tubers should be cured at 8-20°C, 90% relative humidity for 5-8 days. Ensure that moisture does not accumulate on the surface of the tubers. Potato is sensitive to oxygen tension; they should therefore be stored in well ventilated stores which should be dark and dry (Enyiukwu et al., 2014a; Tsedaley et al., 2014). In many traditional agro-systems, potato is stored in clamps or partial underground pits with air ducts under the tubers to allow the produce utilize cool night air. Hausa potato (*Solenostemon rotundifolius* Poir) J. K. Morton which are small-sized tubers and a commonly consumed tuber crop in the middle belt and northern regions of Nigeria are handled in much the same way. However, their storage is many in eaten vessel or in underground pits located under tree shades (Enyiukwu et al., 2014a; Nwaneri, 2017).

Management of tuber crops

Attacks by microorganisms are probably the most serious cause of postharvest losses in root and other tuber crops in the country. Most postharvest bacteria and fungi are wound requiring parasites launching their attacks from sites of injury. Hence physical injury during harvesting, handling and transportation of tubers serves to predispose the produce to microbial attacks. Quantitative losses have been attributed to pathogenic breakdown of tuber tissues by several microbes. The pattern of attack is frequently as an initial infection either from harvest or commonly through a postharvest wound by a few specific pathogens, which is later followed by massive attacks from a broad spectrum of organisms which grow on dead or moribund tissues of the tubers. Qualitative losses on tubers also results from blemishes incurred from nematodes and other parasites which renders the tubers unsightly, less attractive and so reduces the market value. Some pathogens which attack tubers include *Macrophomina phaseolina* (charcoal rot),

gray mould rot (*Botrytis* sp.) on sweet potato, *Botrydiplodia theobromae* on Hausa potato, *Sclerotium* root rot (*Sclerotium rolfii*), *Phytophthora* root rot (*Phytophthora* sp.) and bacterial blight (*Xanthomonas manihotis*) on cassava; watery rot (*Erwinia* sp), dry rot (*Corynebacterium* sp.) and *Rhizopus* sp., *Aspergillus* sp., *Penicillium* sp. and *Fusarium* sp etc on yams. Some of these pathogens and their low-key botanical controls on tubers have been broadly reviewed by Enyiukwu et al. (2014a). Ensure you cure bruised tubers by sun drying them. Store tubers in barns shaded by trees or in stores whose floors are adequately cartoned or littered with saw dust. Ensure there are no leaks from the roof and that a proper roof-overhang of stores is maintained (Personal communication, 2018)

6.0 CONCLUSION

The place of fruits and vegetables in human diets cannot be over emphasized. They represent classes of produce associated with providing the body with wide ranging amino acids, calories, vitamins and minerals in addition to anthocyanins (constituents responsible for plant colours) which helps to strengthen heart health and fight certain diseases and inflammatory conditions including cancer. However, high doses of post-harvest losses averaging 10- 50 % in fruits and vegetables have been reported to occur due to pathological influences especially from wound-requiring fungi and bacteria. Stemming post-harvest food wastages through avoidance of undue wounds on produce during harvesting, curing, proper handling and transit or ensuring prevention of insect and water migration into the store houses could contribute to elongating shelf-lives of produce and food security in the continent.

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APPENDIX 1: PERSONAL COMMUNICATIONS (2018, 2019) INTERVIEWS

A total of 8 farmers (growers) and 12 marketers/sellers (all adults) of various kinds of fruits and vegetables were randomly interviewed at the farm-gates and two major markets (Ndoru and Ariam) markets respectively in Ikwuano Local Government Area of Abia State on what things they do and how they them to prolong the shelf-lives of their agricultural produce. The brief interviews were carried out in the wet season (April-September) and dry season (November-December) of 2018; with a total of 10 respondent per cropping season. The views of or practices by these growers and marketers of agricultural produce were captured in the interview as structured below.

My Name is am a **Researcher** at t..... I am conducting a research on the **simple ways natives of this LGA preserve their fruits and vegetables at home before transiting to the markets, as well as during and after sales at the weekly markets.** Could you answer these few questions intended to capture some data/information for use in the above research topic.

1. What is your name?
2. What is the name of your community/village? And your LGA?
3. How old are you (Sir /Madam)? (What is your age?)
4. Are you a farmer, grocer or both?
5. Do you preserve your harvested fruits/vegetables? **Yes or No**
6. If yes, where? On the farm, home or market, all of the above?
7. Do you think that bruises add to accelerated spoilages/decays? Yes; No.
8. How do you minimize the spoilages? Storing under tree shades, wrapping with old newspapers, admixing with lime or lemon, spraying with botanical oils.
9. How do you ship your fruits and vegetables – with local baskets or rubber crates?
10. Either ways do you overlay with plant leaves (such as *igo*, dry banana or *Tectonia spp.*) or old newspapers? Yes or No
11. If yes, how often? (That is do you use them: Regularly, Sometimes and Occasionally)
12. How do you store your left-overs after sales each day? In Fridges or others
13. If others, how? In the open at night with cover or without cover?
14. How long can your produce last in these traditional storage forms? **1-3; 4-7; above 1 week**
15. What are your challenges and t what stage do you have the most challenge along the chain harvesting, handling, transit of marketing, all of the above?
16. **Thank you very much.**

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