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Review Article
Quality and Shelf-life of Sweet Potato as Influenced by Storage and Postharvest Treatments

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Abstract
The high perishability of sweet potato roots during storage remains a major constraint to actors across sub-Sahara Africa. By using appropriate pre-storage treatments against microbial decay and sprouting, shelf-life can be extended up to 1 year at 12-15°C and 85-90% relative humidity. However, cold storage facilities are not available to the smallholder producers and traders due to cost. Currently both traditional and improved-traditional methods of storage are practiced. These include in-ground storage, heap storage, under-ground storage, platform storage, sand-pit method and pit under shade and covering with grass on platforms or in baskets. In some cases, ash, soil, sawdust and a cocktail of materials are added to improve shelf-life. The use of some of these methods for storage have often yielded irregular results with extreme weight loss, sprouting, decay and damage by *Cylas* spp., starting from 3-6 weeks after storage. Integrated pre and postharvest treatments and design considerations that can reduce these limitations are required to reduce current losses. Effective management rather than sophisticated of such technologies is critical in reducing current losses. This study reviews some salient progress made in storing sweet potato via traditional or improved-traditional methods at ambient conditions as well as postharvest treatments to prolong shelf-life.

Key words: Smallholder storage, sprout suppression, biochemical changes, irradiation, decay

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INTRODUCTION

Sweet potato (I*pomoea batatas* L. Lam) is currently ranked as the seventh most important crop in the world with a total production of 103 million tonnes in 2013[1]. Asia accounts for close to 76% of world production, followed by the African continent (19.5%). The top five producers of sweet potato are China, Nigeria, Uganda, Indonesia and the United Republic of Tanzania[1]. China is the highest producer with production figures around 75.6 million tonnes, followed by Tanzania and Nigeria that produce up to 3.57 and 2.73 million tonnes, respectively. Sweet potato is one of five most important crops in 40 developing countries besides rice, wheat, maize and cassava[2]. It also ranked as the 3rd largest cultivated root crop (7.9 million ha) after potato and cassava worldwide[1,3]. The crop has good adaptive ability due to the short growth cycle and ability to survive in diverse agro-ecologies, marginal lands and water stress soils[3,4]. These traits project sweet potato high among resource-poor farmers as yields of 15-50 t ha^{-1} have been obtained with minimum use of external inputs.

Although, the leaves are edible, the starchy tuberous roots are by far the most important product[5]. The roots are mostly boiled, fried, roasted or baked for their rich source of dietary energy and quite recently for their beta carotene and vitamin C. The crop is a staple food for a large proportion of the population in many parts of sub-Saharan Africa but has greater importance in the food systems of Uganda, Rwanda, Burundi and eastern Congo where it forms a major component of diet[6]. It is one of the most widely grown root crops particularly in countries surrounding the Great Lakes in Eastern and Central Africa, in Angola, Madagascar, Malawi and Mozambique in Southern Africa and in Nigeria in West Africa. In Uganda for instance, sweet potato is the third most important source of carbohydrates after banana and cassava and is grown in all parts of the country, with annual production close to 2.7 million tonnes mainly by smallholder farmers on plots that rarely exceed 0.5 ha[6,7]. Across Africa, sweet potato yields hovers around 14-21 t ha^{-1} in 140 days after planting. In some West African countries (Guinea, Sierra Leone and Liberia) as well as in North-eastern Uganda and East Africa, the consumption of tender leaves and vine tips of as a vegetable is common.

During storage, the roots are very perishable because they contain high moisture content (60-75%) hence low mechanical strength as well as high susceptible to microbial decay. They have high respiratory rate and the resultant heat production softens the textures which make them susceptible to damage. Postharvest quality deterioration emanates from respiration, weight loss, microbial attack, weevil damage and sprouting. Respiration and sprouting result in loss of nutritive value of organs[8]. Sprouting in particular leads to weight loss, reduction of nutritional, processing and marketable quality of roots[9]. The shelf-life therefore vary from few days or months according to the cultivar and storage conditions. In general, integrated pre and postharvest treatments, design considerations or improved-traditional storage methods that can reduce these limitations may be a viable option to improving shelf-life in smallholder production systems. This work provides a review of some salient progress made with regards to storing sweet potato via traditional or improved-traditional methods in most parts of Africa or developing countries.

PROGRESS IN SWEET POTATO STORAGE

Preserving the fresh produce shelf-life remains a major challenge to farmers, traders and consumers across sub-Sahara Africa[10,11]. High losses in quantity and quality are recorded as the smallholder farmers and traders lack the capacity to use cold chain to reduce physiological and microbial breakdown[12-15]. Traders often attempt to sell-off their consignments within 3-4 days upon arrival to avoid decay losses[12,13]. The practice of quickly disposing off the harvested produce results in seasonal glut leading to low prices which affects the economic returns to actors. Though cold storage is being used to prolong the shelf-life in the developed countries, this method is not available to smallholder growers and traders because of cost. Generally, combined with appropriate pre-storage treatments against microbial decay, the shelf-life can be extended up to 1 year at 12-15°C and 85-90% relative humidity[16].

Processing into semi-preservable forms offers some opportunities such as reducing post-harvest losses, higher returns on income, convenience and enhanced nutrition[17,18]. Processing generally helps to preserve and ensure availability of products throughout the year. Processed sweet potato products targeted at higher income groups could help break the image of sweet potato as a poor person's crop. However, high loss of nutrients such as carotenoids after processing is still a critical concern[19,20]. Carotenoid loss after drying of orange-flesh varieties under solar and sun drying showed 9% loss of β-carotene just after processing[20]. Figure 1 shows that carotenoid loss was highly influenced by storage temperature and oxygen level with up to 75% loss after 4 months storage. No simple technological solution is currently available to reduce such losses but limiting the storage time to about 2 months appears to be the immediate solution.

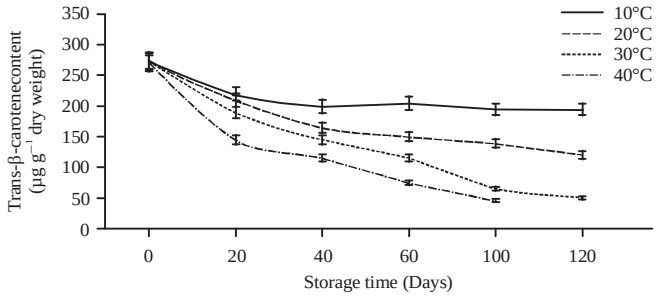

Fig. 1: Carotenoid loss after 4 months following open-sun and solar drying of orange flesh varieties
Source: Westby *et al.*[20]

Table 1: Changes in nutrients in sweet potato before and after 5 months of storage

Storage treatments	Moisture (%)	Protein (%)	Starch (%)	Vitamin A (mg g^{-1})	Vitamin C (mg g^{-1})
Before storage	71.00	7.90	16.90	0.015	0.540
Pit storage with alternate layers of grass	74.40	6.90	12.90	0.069	0.703
Pit with alternate layers of fresh river sand	86.70	7.20	10.00	0.020	0.448
Storage in moist sawdust in wooden box	63.50	6.50	12.50	0.023	0.537
Mean	72.50	7.20	13.20	0.029	0.546
$LSD_{p<0.05}$	19.74	1.32	4.56	0.090	0.274

Source: Dandago and Gungula[14]

IMPROVED METHODS OF STORAGE

Currently both traditional and improved-traditional methods of storage are practiced in most parts of Sub-Sahara Africa (SSA) and some other developing countries[12-16]. These include in-ground storage, heap storage, platform storage, pit storage, sand-pit method and pit under shade and covering with grass, on platforms or in baskets. In some cases, ash, soil, sawdust and cocktail of materials are added to improve shelf-life. However, attempts to use most of these methods for prolonged storage have often yielded irregular results with extreme weight loss, sprouting, decay and *Cylas* spp., infestation starting from 3-6 weeks after storage[14,15]. Occasionally, sweet potato is harvested piece meal and consumed immediately after harvest without intermediate storage[13,16]. This method however is not appropriate since infestations by sweet potato weevil (*Cylas* spp.,) can cause severe losses with delayed harvesting[13]. Another option involves staggering planting, so that crops will not all mature simultaneously.

PIT STORAGE

Pit storage has widely been reported in countries such as Zimbabwe, Tanzania, Malawi and Nigeria[5,21,22]. Pit storage generally is considered to be moderate for rural communities since it requires minimum materials. The method appears to be the best traditional method because deteriorations such as sprouting, moisture loss and pathological losses were minimal compared to other storage methods. However, some modifications in this method have become necessary because it does not completely prevent deteriorations and changes in the composition have been reported.

In a study, Dandago and Gungula[14] evaluated the effect of various storage methods on the quality and nutritional composition. Storing in moist sawdust in wooden box or pit storage with layers of fresh river sand showed good potential for up to 5 months without significant change in nutrients and consumptive quality. Moisture content increased from 71-74 and 87% in the samples stored in pit with alternate layer of river sand and in pit with layer of river sand, respectively. There was a general decrease in protein and starch levels with prolong storage (Table 1). However, severe weight loss of 59.7-66 and 11-38% sprouting was recorded by 5 months of storage.

SAND-BANK OR SAND-PIT

Mutandwa and Gadzirayi[11] assessed the effectiveness of three techniques of preserving sweet potatoes in soil, ash and grass, all are indigenous preservation methods that are traditionally being used by smallholder farmers in Zimbabwe. They reported that considering the value of root colour and weight loss, preservation in soil was most recommended. This was similar to other studies that highlight the importance of using sank bank as a means of preserving sweet potato roots[13,21]. Nonetheless, in terms of maintaining freshness of the stored roots, all three methods were recommended to

resource-constrained farmers in Zimbabwe. Roots stored in the sand-bank suffered less weight loss compared to ambient conditions. Sand-bank storage may provide a modified atmosphere by limiting the supply of oxygen and maintaining low temperature.

Two recent reports on breaking postharvest bottlenecks in long-term sweet potato storage in Ghana and Malawi[13,22], reveal possible long-term on-farm storage in simple containers or pits at ambient conditions. Storage trials in Ghana in sand-box and traditional moistened heap showed that shrinkage of orange flesh varieties was very high compared to the local white flesh variety by 11 weeks of storage. The sand-box method was superior to the moistened heap method with respect to decay incidence but was equivalent to the moistened heap method with respect to cooked root quality. In Malawi, three types of storage were evaluated namely: Ventilated pit store without sand, pit store with alternate layer of dry sand over root and elevated traditional granary store. The elevated traditional granary has the interior of the structure plastered with mud and sweet potatoes were packed in dry sand. Stored root quality of 3 varieties assessed at 1.5, 3.5 and 6.5 months showed that granary stores provided better storage conditions in aspects of decay incidence, termite and rodent damage. However, weight loss was severe and the granary require some modifications to improve the convenience of handling particularly to women.

SMALLHOLDER COOLING SYSTEMS

The use of traditional and improved smallholder cooling systems to achieve low temperatures and high relative humidity, in combination with appropriate pre-storage treatments can protect the integrity of fresh sweet potato roots against various forms of deterioration. In a study, Amoah *et al.*[15] evaluated the performance of roots stored in passive evaporative cooling barns alondside three pre-storage treatments (ash, brin and *Lantana camara* extract) on weight loss, shrinkage, weevil damage, sprouting and decay. Use of evaporative cooling barns reduced storage temperature to 23-25°C over ambient 32±5, although 13-15°C is optimum for sweet potato. *Lantana camara* treatments yielded better results, recording overall root whole somness of 76%, followed by the control (56%), ash (50%) and brin (48%) by 12 weeks after storage (WAS). *Lantana camara* treated roots recorded the lowest weight loss (28%), shrinkage 3.8% and weevil damage (47.5%) compared to other treatments. Weevil damage increased almost linearly for all treatments from 6 WAS. By 2 WAS, the control had suffered complete weevil infestation becoming unwholesome compared to 54% weevil damage by 12 WAS in the evaporative cooling barns. Sprouting was noticed at 4 WAS with higher sprouting in control, followed by roots treated with *L. camara* and brin; albeit with no significant difference was noticed. This was attributed to higher cell potency with active physiological activity in the control and *L. camara* treated roots compared the brine.

The improved sand-pit or sand-box method is now promoted in most parts of Malawi and Tanzania. This method was previously described as the soil bank method for preserving sweet potato roots[13,22]. In this method, a layer of fine sea-sand (about 2 cm thick) is applied on the floor before packing the sweet-potato roots followed by sprinkling of little amount of water to reduce desiccation. The same procedure is repeated and subsequent layers of sweet potato roots, each 12-15 cm thick, added and the last layer covered with a 2 cm layer of sea-sand. A ratio of 1 L of water to 5 kg of sea sand can be applied per pit.

The improved housed pit (mjinge) is now promoted in Tanzania. This involves a pit measuring 1.5×1.8×1.2 m with a small hut measuring 1.8×1.8×1.5 m which is plastered with mud leaving a small door and some opening close to the roof for ventilation. Mpagalile *et al.*[10] evaluated the storability of improved sweet potato varieties in Tanzania using traditional pit, improved open pit, improved housed pit (mjinge) and raised woven structure (kihenge). Housed pit storage (mjinge) performed comparatively well whereas the traditional method was the poorest in all attributes. Sugar content of stored roots using mjinge method increased significantly from 6.25-9.25%. Although kihenge method performed well with respect to crude protein which increased from 4.9-6.1%, its performance in other attributes was poor. In addition, storing in the mjinge recorded good quality attributes for sweetness, starchy mouth feel, smell, colour and general acceptability. Sprouting of roots at storage did not affect overall acceptability and the chemical composition after storage. The mjinge storage method can extent shelf-life up to three months but this method like the rest results in substantial loss of vitamin C.

Some studies on the interactive effects of poultry manure, NPK, intercropping and different traditional storage methods on yield, sensory and shelf-life qualities have been conducted[12]. After harvest, the roots were preserved in perforated cartons, pits, wooden platforms and bagged sawdust. Intercropping did not influence shelf-life but sawdust and pit storage were superior to the carton and platform methods in aspects of shelf-life and consumer acceptability. Application of NPK or poultry manure resulted in lower

Table 2: β-carotene and vitamin C content of sweet potato root with/without *γ*-ray irradiation with different storage periods at 25°C

Nutrient contents	Storage period (weeks)	0	0.1	0.2	0.4	1
		(kGy)				
β-carotene	0	113.4±10.2	118.2±12.6	107.4±10.2	109.2±16.5	96.2±12.4
	2	121.2±15.5	123.6±10.2	118.6±10.8	125.4±13.2	127.8±10.2
	4	130.2±11.4	126.1±17.2	124.6±14.5	120.4±12.8	132.4±8.40
	6	135.4±14.2	128.6±10.2	137.2±14.2	133.2±11.2	133.4±11.5
	8	134.3±12.4	136.2±9.2	125.4±11.4	130.4±11.5	137.2±10.5
Vitamin C	0	24.8±2.8	26.5±3.2	27.4±4.0	25.4±3.5	29.8±4.2
	2	25.6±3.8	28.7±3.0	30.2±4.2	33.8±3.4	29.4±3.2
	4	30.3±3.0	27.5±3.4	28.4±4.0	30.9±3.4	25.6±4.2
	6	31.9±2.8	34.4±4.4	29.0±3.7	28.9±3.2	29.4±3.6
	8	28.5±3.5	27.4±3.2	29.3±3.2	25.1±3.7	26.1±4.3

The data represent the mean values ±SE, Source: Lim *et al.*[27]

percentage weight compared to other treatments. Although higher yield were observed with white fleshed cultivars, their storability was poor with the application of poultry manure. High sprouting rate was recorded from 4-12 WAS, except in the carton and platform methods, with pit storage showing the most sprouting. By 12 WAS, the roots had formed a hard crust with variable thickness; this crust formation on the stored roots was maximal in the platform storage method compared to sawdust method.

In parts of Ghana, burying (pit), traditional barn, heaps on floor covered with litter and open-sided shelves store with rodent guards are being used to preserve quality of fresh sweet potato, yam and Frafra potato[13,23,24]. The traditional barns are usually erected in open air, where sufficient shade and ventilation are available. These open sided storage, with higher ventilation access, perform best in respect to weight loss, sprouting, decay, pest damage and nutritional composition[24]. The moisten heap storage appear to be common in Ghana for sweet potato storage[13]. However, poor ventilation, air circulation, heat build-up and high humidity level are often challenges. Poor air circulation in heap storage accelerate the build-up of heat and increase humidity as a result of respiration. This induces spores germination and growth of pathogens and subsequent decay incidence[24].

IRRADIATION

Irradiation is a physical process that can be applied to harvested fruits, vegetables and root and tubers to eliminate microorganisms, pest and diseases as well as delay ripening, sprouting or decay incidence[25-27]. Irradiation treatment is thus a viable alternative to chemical fumigation in sweet potato storage[27]. Albeit, there is varied opinion on the influence of irradiation on functional and physico-chemical, in addition to food safety concerns. According to the Food and Drug Administration (FDA), doses of γ-ray irradiation up to 1.0 kGy are permitted to inhibit sprouting and delay maturation in fruits and vegetables. The optimum irradiation dose against insects and microbial contamination without affecting quality may lie between 100 and 500 Gy[25,27]. A dose of 600 Gy did not reduce the overall quality or taste of purple-fleshed and yellow-fleshed sweet potatoes. There are reports suggesting that orange-fleshed roots treated with a 300 Gy dose did not differ from control roots in colour or organoleptic ratings[27,28]. In another study, sweet potato roots treated with γ-ray irradiation (0-1.0 kGy) showed slightly higher weight loss compared to control but hardness, sugar content, β-carotene and vitamin contents were not significantly different from those of control (Table 2)[27]. The amount of hydroxyl radical (•OH) reached was similar to the control at 2 weeks after storage. Also, γ-ray irradiation inhibited sprouting at all storage temperature but the control sprouted at storage temperatures of 12 and 25°C from 6 and 4 weeks after storage, respectively. Furthermore, peroxidase and indole acetic acid oxidase activity of all roots with γ-ray irradiation were higher than those of the control. Ocloo *et al.*[29] reported that the functional and physico-chemical properties of sweet potato irradiated at 0, 0.2, 0.3 and 0.4 kGy decreased with increase in irradiation dose. Beginning of gelatinization temperature of starch increased with increase in dose (i.e. from 75.5-79.6°C) (Table 3). Maximum viscosity decreased from 1008.2-937BU as the irradiation dose increase. Setback and breakdown viscosities decreased with increase irradiation dose.

BIOCHEMICAL CHANGES

Both storage method and time can induce many biochemical changes in carbohydrates, proximate and functional properties of stored roots. The carbohydrate composition in sweet potato roots greatly affects the eating quality and processing traits[30]. Generally, longer storage periods of raw roots prior to processing results in products with decreased firmness. Studies on the amylase activity in fresh and stored roots have shown marked differences in individual and total sugar concentrations

Table 3: Effect of irradiation on moisture content, pH and some functional properties of sweet potato

Dose (kGy)	Moisture content (%)	pH	Swelling power (g g^{-1})	Solubility (%)	Water absorption capacity (%)	Bulk density (g cm^{-3})
0	11.9±0.2	7.0±0.02	4.3±0.72	24.7±0.00	10.0±0.00	0.79±0.02
0.2	11.4±0.4	7.1±0.04	3.9±0.75	27.6±2.08	10.0±0.00	0.77±0.01
0.3	10.0±0.3	6.3±0.10	3.9±0.74	34.1±4.29	10.0±0.00	0.73±0.01
0.4	11.7±0.7	6.8±0.09	3.9±0.70	35.3±0.00	10.0±0.00	0.69±0.01

The data represent the mean values ±SE, Source: Ocloo *et al.*[29]

Table 4: Total starch, α-amylase activity and trypsin inhibitor activity in fresh sweet potato roots at harvest

Genotypes	Dry matter (%db)	Total starch (%db)	α-amylase activity (Ceralpha U g^{-1}, dry basis)	Trypsin inhibitor activity (μ mg^{-1}, dry basis)
Hi-dry	33.5±0.9	73.6±0.5	0.41±0.01	16.5±1.84
Yan1	29.3±1.6	55.3±0.1	0.81±0.01	18.6±2.56
Chao1	22.6±0.6	46.8±2.0	1.73±0.06	3.9±0.18
Yubeibai	27.9±0.1	52.6±1.1	1.25±0.18	4.9±0.17
Guang7	26.9±1.2	57.6±3.4	1.14±0.04	8.7±0.80
Guang17	24.3±0.4	49.9±1.1	1.14±0.04	21.8±1.74
Mean	27.4	55.9	1.13	12.4
$LSD_{p<0.05}$	2.59	4.8	0.20	3.5

The data represent the mean values ±SE, Source: Zhang *et al.*[32]

among sweet potato cultivars as well as differences in α-and-β-amylase activity during storage[31,32]. Total soluble sugar consisting of sucrose, glucose and fructose, ranged from 4.1-10.8/100 g with signi cant differences due to maturity and cultivar. The highest total soluble sugar contents were recorded in 5 months samples at planting (7.36-10.34/100 g) and 4 months samples after short-term storage (8.66-10.82/100 g) under tropical ambient conditions. Estimated amylase enzyme activity varied significantly with harvest age but reducing sugar contents were low and fructose levels in 5 months samples increased considerably after storage[31].

Zhang *et al.*[32] evaluated the changes in carbohydrate level, digestibility, α-amylase, trypsin inhibitor activity and pasting properties of roots of six genotypes of sweet potato differing in dry matter content during storage (Table 4). There was a decrease in starch content during 180 days of storage but α-amylase activity increased during the first 2 months of storage, followed by a continuous decrease to a level similar to that at harvest. The decline in starch content was correlated with α-amylase activity in the first 60 days of storage. Trypsin Inhibitor Activity (TIA) in the fresh roots varied among genotypes from 3.90-21.83 U mg^{-1} but storage exerted little influence on TIA level. There was considerable genotypic variation in digestibility, with up to 27% reduction in digestibility after 120 days in storage. Glucose and sucrose concentration increased at early storage and then remained fairly constant. Storage reduced flour pasting viscosities, with up to 30% decline in peak viscosity.

In a study, Agbemafle *et al.*[33] assessed the effect of storing sweet potato in wooden boxes with or without moist sawdust and wood ash with respect to shelf-life, proximate and functional properties. No significant variations was noticed in fibre, reducing sugar, foaming capacity and swelling power with respect to storage methods and time but moisture, ash, protein, fat, carbohydrate, foaming capacity and swelling power varied significantly with storage time. The study showed optimum proximate values for moisture (59±0.7%), ash (2.3±0.2%), protein (7.9±0.1%), fat (0.95±0.0%), fibre (0.2±0.0%), carbohydrates (62.7±8.0%) and reducing sugars (2.41±0.0%). Functional properties analyses also showed up to 1.95±0.1, 1.4±0.3 and 4.03±0.05 mL g^{-1} and 8.9±0.8 g g^{-1} for water absorption capacity, oil absorption capacity, foaming capacity and swelling power, respectively.

FUNGI ASSOCIATED WITH SWEET POTATO ROTS

Postharvest rots of sweet potato have been substantially reported[34,35]. A wide variety of microorganisms, particularly moulds have been implicated in tuber spoilage but relatively few are implicated as primary pathogens[34]. The fungi associated with sweet potato rots include*: Aspergillus niger, Fusarium oxysporum, Rhizopus stolonifer, Botryodiplodia theobroma* and *Penicillium* sp.[35]. Pathogenicity test revealed that four of the isolated fungi were highly pathogenic. *Aspergillus niger* and *Rhizopus stolonifer* induced the most extensive rots, *Botryodiplodia theobroma* and *Fusarium oxysporum* were moderately pathogenic while *Penicillium* sp., was the least pathogenic. This suggests that, *Penicillium* spp., is not likely to be a pathogen of sweet potato but rather a contaminant. Bruised or cut roots readily become colonized by propagules of pathogens associated with the surface and those from adjacent infected roots. Colour, magnitude and texture of the symptoms vary with the organism.

Table 5: Changes in nutrient composition of sweet potato inoculated with four prevalent rot fungi after 21days incubation at 27±2°C

Fungi	Moisture	Carbohydrate	Protein	Fat	Ash
Aspergillus niger	43.7[a]	39.0[b]	5.8[c]	5.9[b]	5.6[b]
Fusarium oxysporum	46.9[b]	37.5[a]	5.2[c]	5.3[b]	5.1[b]
Botryodiplodia theobroma	47.6[b]	36.6[a]	5.4[c]	5.1[b]	5.1[b]
Rhizopus stolonifer	45.1[b]	38.0[c]	5.7[c]	5.9[b]	5.3[b]
Control (uninoculated)	49.6[c]	41.2[d]	4.6[a]	2.2[c]	2.4[c]

*Means followed by same letters(s) in same column do not significantly vary using $LSD_{0.05}$ at $p<0.05$, Source: Olaitan[35]

Inoculation of roots with pure cultures of *Aspergillus niger*, *Fusarium oxysporum*, *Botroydiplodia theobroma* and *Rhizopus stolonifer* increased the crude protein, lipid and ash contents[35]. However, there was decrease in carbohydrate and moisture content (Table 5). The decrease in carbohydrate was attributed to the hydrolysis of complex carbohydrates to glucose which is used as a source of carbon and energy for microbial growth. Loss of moisture content in produce has generally been attributed to difference in water vapour pressure within the commodity and surrounding air. Moisture reduction could further be exacerbated by respiratory activities of both the roots and moulds.

These rots are attributed to physical, physiological and microbiological factors. Mechanical damage during harvesting, storage or transportation has been implicated in predisposing roots to rots[12,13]. Pathogenic contamination through natural openings or wounds is considered the most critical factor in root decay[34]. The degree of pathogenicity varies and is largely dependent on storage conditions and location. The high rainfall pattern, high humidity and temperature of between 19 and 35°C prevailing in tropical agro-ecologies favour the development of fungal diseases in field, market and storage. Despite the present trend to discourage the use of chemical fungicides to control postharvest diseases of produce, they may be employed in developing countries to manage these pathogens.

SPROUT SUPPRESSION

Many chemical compounds (e.g., ethylene, ozone, camptothecin, volatile monoterpenes, jasmonates, ethanol, nonanol, abscisic acid, indole-acetic acid, imazethapyr, salicylaldehyde, trans-3-nonen-2-one, dichlorbenil dimethyl naphthalene and diisopropyl naphthalene) are known to inhibit sprouting[36-42]. Ozone has been tested as a sprout inhibitor of stored potatoes. 1,4-dimethylenapthlene (DMN) is now reported as a new sprout suppressant but the metabolic mode of action for this compound has yet to be elucidated[37]. Ellagic acid (2,3,7,8-tetrahydroxy-chromeno [5,4,3-cde]chromene-5,10-dione) is the main monomer of ellagitannins, which are secondary metabolites present in some superior plants. Sprout suppression as well as other medicinal and industrial applications have been found in this acid including: Antitumoral, antioxidant, antimicrobial, antiviral and antiflamatory activities and it is being implicated in managing heart diseases[37]. Some studies have found carvone to be efficacious in sprout suppression[39]. Though quite expensive, it has been registered as a sprout inhibitor for commercial use in some countries.

The sprout inhibition by using Maleic Hydrazide (MH) has been extensively reported[39]. Maleic hydrazide, when applied to the foliage of a mature healthy plant at 4-6 weeks before harvest is absorbed and stops cell division but not cell expansion; thereby controlling sprouting during long-term storage. But timing of MH application is delicate because if the treatment is carried out too early, the yield will be reduced but late treatment will have an insufficient effect on sprouting. The efficacy of MH also vary depending on weather conditions, crop growth, application rate and cultivar. Gibberellins (GA) and cytokinins (CK) are thought to be involved in release of dormancy whereas abscisic acid (ABA) and ethylene have been associated with the onset and maintenance of dormancy. Trials using GA and GA synthesis inhibitors suggest that GA may be associated with sprout stimulation in sweet potatoes[40]. The possibility of using glyphosate as a pre-harvest foliar application in potato to inhibit sprouting during subsequent storage has been reported[41]. Relative comparison between chloropropham (CIPC) and glyphosate showed that glyphosate is safer in terms of lower mammalian toxicity with respect to oral LD_{50}, contaminant level for long-term human toxicity, acceptable daily intake limit and acceptable residue limit for human consumption.

ETHYLENE

The role of ethylene in sprout suppression in sweet potato roots was evaluated by observing the effect of an ethylene synthesis inhibitor, aminoethoxyvinylglycine (AVG) and the ethylene antagonist, 1-methylcyclopropene (1-MCP), in the presence and absence of exogenous ethylene on root sprouting and associated sugar accumulation[42]. Continuous exposure to 10 μL L^{-1} ethylene, 24 h exposure to

625 nL L^{-1} 1-MCP or dipping in 100 µL L^{-1} AVG all inhibited sprouting in two cultivars over 4 weeks of storage at 25°C. The observations that both ethylene on its own and 1-MCP, which inhibits ethylene action, inhibit sprout growth indicate that while continuous exposure to exogenous ethylene leads to sprout growth inhibition, ethylene is also required for sprouting. In potato tubers ethylene is required to break dormancy, while continuous exposure inhibits sprout growth. Monosaccharide concentrations in ethylene, 1-MCP or AVG treated roots were lower than in untreated roots and for ethylene treated roots this was associated with higher respiration rates. This is consistent with the activation of some additional process by ethylene which uses energy through sugar metabolism. The 1-MCP and AVG both inhibited this increase in respiration rate and counteracted the decrease in monosaccharide concentrations. The 1-MCP presumably counteracts the ethylene stimulation of this process, while the effect of AVG is attributed to its possible inhibitory effects on protein synthesis.

CIPC

For nearly 50 years now, the primary method of controlling sprouting in potato storage has been the application of Isopropyl N-(3-chlorophenyl) carbamate (Chloropropham; CIPC)[42-44]. In general, CIPC inhibit sprouting by interfering with spindle formation during cell division with long term site effect. It is applied in the form of aerosol on the stored produce as a post-harvest application. The CIPC application as Emulsifiable Concentrate (EC) at commercial application requires some applicator experience as well as specialized equipment for application as aerosols. Also the effectiveness of CIPC as sprout inhibitor is influenced by such factors as storage conditions, application technology and cultivar. But today, the future of CIPC is uncertain as there is increasing consumer awareness and health lobby against postharvest treatments. Due to health concerns, the U.S. EPA for instance have now classified CIPC as a carbamate and has placed strict limit on CIPC residue in potatoes. As a result, the allowable CIPC residue on fresh potatoes in the United States now ranges from 30-50 ppm[40,42]. Other countries have set even stricter limits on residue levels; some have even imposed zero tolerance policies. Currently, the recommended application rate is up to 10 ppm for EU standard markets.

Alternative sprout inhibitors to CIPC are being continuously evaluated. Essential oils (e.g., caraway, peppermint, spearmint, clove) or their components (e.g., s-carvone and eugenol), food-grade waxes and hydrogen peroxide-based materials are now promoted[43-45]. Essential Oils (EO) are volatile, natural, complex compounds characterized by a strong odour and are formed by aromatic plants as secondary metabolites. However, repeated application of these compounds may be necessary for efficacy. Substituted naphthalenes (e.g., dimethyl naphthalene, diisopropyl naphthalene) may help reduce the amount of CIPC applied or the dependency on CIPC for sprout suppression at storage. Studies on edible food-grade waxes reveal the potential of using shea butter and palm kernel cream for plantain, white yam and other roots[44,45]. Such waxes could play a tremendous role in addressing consumer safety concerns. Across the world now, fresh fruits, vegetables and roots are sold in areas far from their production sites; thus requiring extended safe shelf-life. The widespread use of pesticides has drawbacks including increased cost, handling hazards, concern about pesticide residues on food and threat to human health and environment.

CONCLUSION

There is the need to accelerate interventions to improve postharvest handling and marketing of fresh produce in most parts of Sub-Sahara Africa (SSA) and some other developing countries. Current recommendations for fresh fruits, vegetables, roots and tubers have worked for export-oriented growers but the potential benefit to domestic markets remains trailing. Apparently, integrating such recommendations requires technologies and infrastructure which is not within the resource limits of smallholder growers and traders. Minimizing rough handling, sorting to separate bruised and diseased produce and effective temperature management will help to maintain postharvest quality. General cold storage systems that could target fresh produce for instance in urban markets, where retail prices will merit such investments, could be a starting point in such countries. The actors must be trained to understand the biological and environmental factors influencing quality deterioration, followed by adopting postharvest technologies or treatments to delay senescence. Training of actors at national levels provided by the Department of Agriculture and allied agricultural service providers should as well be prioritized.

SIGNIFICANCE STATEMENTS

This study reviews salient progress made in storing sweet potato as well as postharvest treatments to prolong shelf-life. It is possible to use sprout suppressants, irradiation, essential oils alongside low temperatures (12-15°C) and high relative humidity (85-90%) to maintain quality up to 1 year in storage.

However, significant postharvest losses are still recorded because the growers lack capacity to adopt improved storage systems in most parts of Africa. Future research should consider postharvest treatments that can simultaneously address the high weight loss, sprouting, *Cyla*s damage and decay incidence when using improved traditional storage methods. However, the long term solution remains to be the use cold storage systems with temperature, gases and relative humidity control systems.

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