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Research paper

Post-harvest handling practices and associated food losses and limitations in the sweetpotato value chain of southern Ethiopia

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ABSTRACT

Household food insecurity is a chronic problem in Ethiopia; the situation is being exacerbated by high population growth rates and recurring droughts in the country. The interest to address post-harvest value chain (VC) constraints leading to food losses has increased significantly to provide adequate nutrition to the growing population. In this study, mapping of sweetpotato VC not only quantifies the degree of losses but establish links between distinct VC constraints and respective food losses and limitations. Harvest and handling at farm level and shelf life issues at distribution were identified as vulnerable hot-spots of the sweetpotato food losses. Apart from physical and biological factors, demand and supply mismatch during the main harvest season at the wet markets leads to food (up to 25%) and economic losses (33–75%) followed by deficiencies in the lean season. A multi-stakeholder cooperation is required to mitigate food losses, which can have a high impact on the nutritional and financial status of the producers, market operators, and the consumers.

1. Introduction

Starchy roots and tubers such as Ethiopian banana (*Ensete ventricosum*), potato (*Solanum tuberosum*), sweetpotato (*Ipomoea batatas*) and taro (*Colocasia esculenta*) are the second most important source of daily dietary intake in Ethiopia following cereals [1]. Sweetpotato is the most important tropical root crop in the country, especially in the densely populated southern and southwestern parts of the country [2]. The Ethiopian national sweetpotato production has quintupled in the last decade, making it the 4th largest producer globally after China, Nigeria and Tanzania [3]. Sweetpotato is attractive to small-scale resource-poor farmers as it provides more carbohydrates per hectare than any other crop and has an ability to endure in poor soils and dry conditions [4,5]. The importance of sweetpotato as a source of β-carotenoids, ascorbic acid, and anthocyanins have also been widely recognized and promoted [6–8]. Because of these unique features sweetpotato is classified as a typical food security crop. In the semi-arid plains of East Africa, sweetpotato is sometimes called '*Cilera Abana* – protector of the children' which is a reflection of its crucial role in fighting malnutrition [9].

Being perishable and poorly handled in developing countries such as Ethiopia sweetpotato roots may suffer significant post-harvest losses along the value chain (VC). Current global estimates suggest that 45 up to 54% of roots and tubers are spoiled post-harvest in sub-Saharan Africa (SSA) [10,11]. A recent meta-analysis by Affognon et al. [12] provides a staggering 45–69% loss for sweetpotato. The distinct causes and magnitude of such losses depend on the particular conditions prevailing in specific locations. Many recent studies raised this concern and demanded location specific detailed information regarding the scale and nature of these losses [10,12–14]. The most recent global effort towards bringing the issue of food loss in the forefront was the release of United Nations sustainable development goals (SDG). SDG-12.3 targets a reduction of 50% in per capita global food loss at retail and consumer level by 2030 and propose the requirement to multiply efforts towards reduction of losses at production and supply stages.

Food security in Ethiopia is still a critical issue, 25–35% of the country's population is undernourished [15]. Reduction in food losses and food waste is one of the sustainable solutions to enhance future food availability [13,16,17]. Little information is available from the country about the post-harvest handling practices and associated food losses, despite Ethiopia being the fourth largest producer of sweetpotato. In a review Jones et al. [18] highlighted that information from Ethiopia on sweetpotato post-harvest handling practices, storage and magnitude of losses is almost nonexistent.

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Table 1
Damage classes at farm and market levels.

Code	Damage class	Definition[a]
UD	Undamaged	Root is whole, and there is no mechanical injury apart from the breaking point from the vine.
LD	Lightly damaged	Roots are not whole and carry one small cut other than the breaking point from the vine.
SD	Severely damaged	Roots are not whole and carry more than one cut, apart from breaking point from the vine.
PD	Pest damage	Roots which are infested by the pest, visual identification by looking at the holes present on the surface due to weevil attack.

[a] Skinning injuries were ignored at retail and wholesale level as 100% of the roots were found to be affected by skinning and minor bruising.

In the course of this study, a diagnostic survey was carried out during the main harvest season along the sweetpotato VC in southern Ethiopia. The objective was to capture the current status of the post-harvest VC from harvest to retail, identify the key actors and their respective roles, and quantify food losses. The principal focus was to assess how much, where and when food losses occur and what the main causes and types of these losses are.

2. Materials and methods

2.1. Study location

The SNNPR (Southern Nations, Nationalities, and Peoples' Region) borders Kenya in the south and southwest, and South Sudan in the west. It is one of the most rural regions of Ethiopia, with an estimate of 90% rural inhabitants. The region constitutes 52% of the total land allocated for sweetpotato production at the national level. The Sidama and Wolayita zones are the centers of sweetpotato production in SNNPR, contributing 72% of the total regional production [1]. Hawassa and Sodo main markets and Addis Ababa market (*markatu*) were the key markets visited to track commercial consignments of sweetpotato roots. Hawassa is the capital city of SNNPR and about 275 km south of the national capital Addis Ababa. Sodo is the central administrative town of Wolayita zone located 150 km southwest of Hawassa and 312 km south of the national capital. According to the Ethiopian national census of 2007, the population of Hawassa and Sodo towns was 157,139 and 76,050 respectively. However, current estimate suggests that the population of these cities may have grown two fold since then mainly due to rural-urban migration. The cities represent the urban centers of the respective zones, with literacy rates of 72.5 and 88.7%, and economic activity rates of 52.2 and 58.9% for Sodo and Hawassa respectively [19]. The geographical location and elevation of Hawassa and Sodo are 038° 28′ E, 07° 03′ N, 1694 m and 037° 44′ E, 06° 49′ N, 1854 m respectively. The rainfall pattern in the study area is bimodal, with a short rainy season in March and April and the long second rainy season from June to mid-October.

2.2. Definitions and system boundaries

Maintaining a consistent definitional framework and clearly stating the system boundaries are keys to compare food losses results to existing studies and measuring future developments against the current status. Throughout this study the FAO definitional framework of food loss and system boundaries was followed [20], where food loss is referred as *'decrease in quantity or quality of any substance (processed, semi-processed or raw) which originally was intended for human consumption'*. Four boundaries which were selected for this study were *agricultural production (during harvest); post-harvest handling and storage (during packaging, transportation); processing (industrial or domestic processing) and distribution (whole-sale and retail)*. Food waste is referred as the food loss occurring at consumption stage, which is a major problem in developed countries [10,13]. Therefore, food waste was not considered during this study.

2.3. Damage assessment

After conducting a preliminary investigation at the farm and wholesale stages, four classes of the damages was conceptualized (refer to Table 1).

2.4. Field survey and measurement

A survey (semi-structured questionnaires) and field measurements (direct weighing/counting) were conducted for the assessments at retail, wholesale and farm levels. An upstream approach of stakeholder identification was used starting from the retail level. All the sweetpotato retailers in Hawassa and Sodo markets were interviewed. Retailers were asked to provide the contact of wholesalers delivering sweetpotato roots to them. Similarly, information from wholesalers was obtained to reach collectors and subsequently the farmers. The primary sweetpotato supplier *woredas* (sub-regional administrative units) to the selected urban markets and the respective *kebeles* (smallest administrative units) which were surveyed during the study are illustrated in Table 2. In total 61 VC actors were interviewed including 30 farmers, and 31 traders (19 retailers, nine collectors, and three wholesalers). Background characteristics of VC actors are presented in Tables 3 and 4.

2.5. Trials at market conditions

Freshly arrived sacks (weighing ~110 kg) at the wholesale level were procured for shelf life (keeping quality) trials at market conditions during the month of March at Hawassa main market. The consignment was a day old harvest and had traveled a distance of 35 km (Kebele: *Mesinkala)* by mini-truck involving loading and unloading activities (please refer to Fig. 1 for transition points and approximate delays for Hawassa market). All the roots suffered skinning injuries. For in-sack keeping quality trials, 30 sweetpotato roots were kept in polypropylene bags, representing the marketing situation. The purpose was to investigate critical quality deterioration during marketing rather than long-term storability. Rees et al. [21] clearly distinguish between long term storage (>3 months) and shelf life (keeping qualities during marketing ranging 2–3 weeks). A period of 4 weeks was considered to represent the maximum length of time fresh roots may stay in the marketing stage. Two sets of bags with three replicas each were prepared. Set one (unsorted) constitutes an imitation of the commercial sack with all the different classes of roots (UD, LD, SD, PD) in the same proportion as it was identified at the wholesale level. Another set (sorted) of bags with only undamaged (UD), lightly damaged (LD) and severely damaged roots (SD) was prepared after sorting the original commercial sack to analyze the effect of injury type on weight loss and rotting. Weight loss and surface rotting were observed weekly, and at the end of the 4th week, all the roots were cut vertically and horizontally to detect the types of infection. *'Sweetpotato DiagNotes: A Diagnostic Key & Information Tool for Sweetpotato problems'* was used for identification of rotting and responsible microorganism [22].

Retail conditions were categorized into three types: shade (S), semi-shade (SS) and no shade (NS). S retail: roots are placed under

Table 2
Primary producer locations and linked markets surveyed.

Urban markets	Feeder Zone	Woreda	Kebeles	Distance from market
Hawassa	Sidama	Dale	Mesinkala	35 km
		Dore Bafana	Jara Karara	20 km
Sodo	Wolayita	Boloso Sore	Ukara	30 km
		Sodo Zuria	Offasere	20 km
Addis Ababa	Wolayita	Sodo Zuria	Offasere	340 km

Table 3
Background characteristics of traders interviewed.

Background characteristics	Retailer (n = 19)	Wholesaler (n = 3)	Collector (n = 9)
Sex (%)			
Male	0.0	33.3	100.0
Female	100.0	66.6	0.0
Age (Average years)	36 ± 12	35 ± 14	29 ± 3
Education (%)			
No formal education	21.1	0.0	11.1
Primary education	63.2	66.6	44.4
Secondary Education	15.0	0.0	11.1
Higher Secondary	0.0	0.0	33.3
University	0.0	33.3	0.0
Market (n)			
Hawassa	9	1	4
Sodo	8	1	3
Addis Aababa	2	1	2

Table 4
Background characteristics of farmers interviewed.

Background Characteristics	Survey Area		
	Overall (n = 30)	Sidama (n = 10)	Wolayita (n = 20)
Sex (%)			
Male	90.0	100.0	85.0
Female	10.0	0.0	15.0
Education (%)			
No formal education	13.3	0.0	20.0
Primary education	56.6	80.0	45.0
Secondary Education	16.6	10.0	20.0
Higher Secondary	3.3	10.0	0.0
University	10.0	0.0	15.0
Family size (%)			
1–3	13.3	30.0	5.0
4–6	53.3	60.0	50.0
above 6	33.3	10.0	45.0
Age (%)			
18–30	56.7	80.0	45.0
31–40	20.0	10.0	25.0
41–50	20.0	10.0	25.0
above 50	3.3	0.0	5.0
Land holdings (%)			
≤1 hac	70.0	60.0	80.0
>1 hac	30.0	40.0	20.0
Major crops (%)			
Sweetpotato	100.0	100.0	100.0
Enset	53.3	70.0	45.0
Taro	40.0	0.0	60.0
Maize	36.7	60.0	25.0
Teff	26.7	0.0	40.0
Potato	20.0	30.0	15.0
Coffee	13.3	30.0	5.0
Carrots	3.0	10.0	0.0
Sugarcane	3.0	0.0	5.0

a shelter providing complete protection from direct sunlight and have three walls. In the SS: roots are placed in the shade, but there are no walls; shade typically is provided by an umbrella, tree or a poorly constructed shed on four wooden pillars. NS retail: roots are sold under direct sunlight without any form of shade. Ten medium size roots of each damage class in each retailing condition were displayed on polypropylene sacks on the ground during the market hours and packaged in the sack during the night (which is the

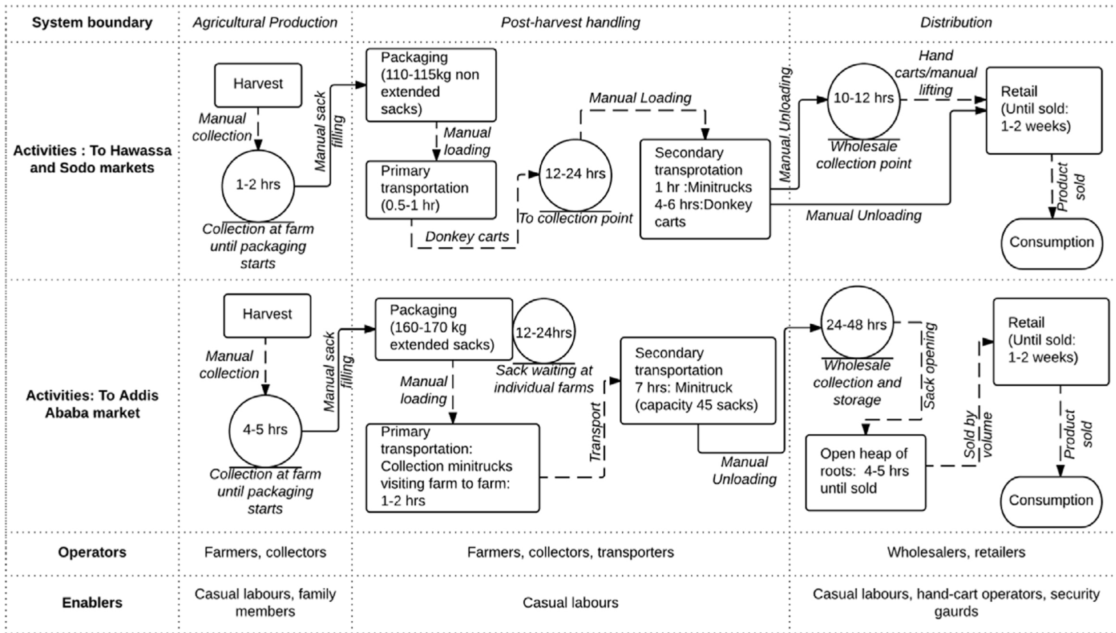

Fig. 1. Post-harvest value-chain actors and activities in the study area.

standard retailing practice in the study area). The samples were weighed every 24 h for a seven day period. The analysis of variance between subject and factors was performed using SPSS version statistics 22 (IBM, Armonk, USA) to test the significance of damage class and retail condition on the mass loss characteristic of sweetpotato roots. Environmental conditions during the trials were recorded by digital data logger *Testo, 174H (Lenzkirch, Germany)*.

3. Results

3.1. Value chain characteristics

The major VC operators identified during the survey were farmers, collectors, wholesalers, and retailers. The definition of these operators in the framework of GTZ [23] VC methodology are as follows: a farmer is '*an individual who is involved in the cultivation of sweetpotato roots and responsible for activities related to production such as land preparation, planting, weeding and applying manures/fertilizers to the crop*.' Collectors are '*a group or an individual who is involved in the collection of freshly harvested sweetpotato roots from various farmers and bring them together as one consignment and responsible for harvesting, packaging and final transportation (with the help of casual labours and transporters) to the wholesale and retail markets*.' Wholesale refers to '*a group or an individual who purchase bulk consignments of sweetpotato roots sacks from collectors or farmers and then further distributes the product to retailers without any change or value addition to the product*.' Retailers are the final link in the marketing chain and can be defined as '*an individual who is responsible for the final sorting and grading and sale to the consumer in smaller units*.' There are other actors in the VC, but their role is more of an enabler, such as daily wage labours (or casual workers), mini-truck and donkey cart operators, who never own the product but carry out the activities such as harvesting, packaging, and transportation. Hawassa and Sodo markets were considered independent, as none of them found to be intersecting each other. At Addis Ababa market, 100% of the sweetpotato roots came from the Wolayita zone as per the wholesaler's account.

There are three common paths by which the sweetpotato roots reach the final step of retailing. In the first, collectors pick up roots from many farmers and bring them to the wholesaler from where retailers purchase. The second path is when farmers are selling directly to wholesalers without any involvement of collectors. Third, the farmers and collectors who sell directly to retailers, which happens at small village-level markets. Fig. 1 presents the post-harvest VC by the market, the length of time in the sack and transition points along with actors and their related roles.

The VC actors performed no curing and storage activities at any stage. As soon as the product was harvested, it was packed and transported to wholesale/retail market. There were delays of 1 or 2 days after packaging depending on the distance to the market and the transportation systems. During these delays, the product was kept under shelter or outside in the shade at ambient environmental conditions packed in polypropylene sacks. Consumption was in the form of boiled whole roots; no value added primary or secondary processed sweetpotato products were available in the study area. There are small street vendors who sell boiled sweetpotato roots with local sauces, which was consumed by economically poor members of the society. Anecdotal evidence and observations suggest that sweetpotato is food for the financially weaker section of the community.

As far as the variations in cultivar were a concern, only one white flesh sweetpotato variety, locally called *Gadissa* (Hawassa-83) was commercially available in the surveyed area. The main reasons behind low diversification of sweetpotato cultivars were the taste preference of the local population, better shelf life, white flesh, and higher yields per hectare. According to the Hawassa Agriculture Research Center, Hawassa-83 is the highest yielding variety among all sweetpotato cultivars which are available at the research station. The maturity period of this cultivar is 150–160 days with on experimental station yields of up to 36.6 t/ha. Dry matter content of the variety is about 30–33%. However, the drawback of this cultivar is that it has no β-carotenoids, and the root geometry is long tapering (Fig. 2) which makes it susceptible to injuries during harvest, packaging, and transport.

The farmers were asked to recall the total number of sacks produced per hectare in the current season, the average productivity was 18.7 t/ha, which is almost half of the potential yield. FAO [3] estimates the national productivity of 45 t/ha, which was not the case at least in the study area. The price was determined by market demand, availability of the produce, and negotiation among

Fig. 2. Randomly selected roots at harvest depicting root geometry.

stakeholders depending on the quality of the product. At every stage of the VC high-quality roots were defined as '*freshly harvested medium to big size roots which are free from pest and other damages and have a shiny, smooth and bright colored skin*'. The communication between all the actors was excellent as far as the desired root quality was concerned.

3.1.1. Harvesting

There are two main crop harvest seasons in Ethiopia referred to as *Meher (Sept to Feb)* and *Belg (Mar to Aug)* in the local Amharic language. In the Sidama zone, most of the sweetpotatoes are harvested in the *Meher* season. Planting is conducted at the onset of the rainy season in April to June. In Wolayita, *Belg* harvest was available in addition to *Meher* which ensures year around supply of the roots. Standard maturity indices which farmers use to determine the time to harvest are: counting the months from planting (5–6 months), swelling and cracking of the soil around the plant and change of leaf color from green to yellow. Progressive harvesting throughout the harvesting season *(Meher)* was the predominant practice for sale, whereas piecemeal collection for home consumption. Harvesting for commercial purpose was conducted by hired casual labour. In the majority of the cases, labourers were employed by collectors, who go from farm to farm and harvest the desired number of quantities for next day market. Harvesting starts in the morning carries on until evening for market deliveries. In most cases, the harvesting period was extended to 2–3 months after maturity, which increases the risk of sweetpotato weevil attack especially in the dry season (main harvest). 90% of the respondents (farmers and collectors) said that they protect freshly harvested roots from direct sunlight, mostly by putting them in the shade or covering them with vines and polypropylene sacks. The Haulm of the sweetpotato roots was removed just before the harvest, canopy removal 1–2 weeks before harvest as pre-harvesting curing was not practiced in the study area. The most common harvesting tools in the surveyed area were: *Forka (digging fork)*, *Safya (hoe)*, and *Teke (small digging fork). Forka* and *Teke* were the preferred tools for harvesting as they works well in dry soils and results in relatively fewer root injuries.

3.1.2. Packaging and transportation

Polypropylene sacks were used for packaging and transportation of commercial sweetpotato roots consignments from the farm to the retail market. The soil on the roots was dusted moderately as no form of washing was involved before packaging. The weight of the commercial sacks was 110–115 to 150–160 kg for non-extended and extended sacks respectively. Sack height varied from 115 to 170 cm, with a cylinder radius of ~23 cm. The sacks were firmly packed (density ~571.4–605.3 kg/m^3) which may provide a potential for in-sack curing, but collectors and wholesalers were unaware of this practice. The open top of the sack was closed with sweetpotato vines which were tied with locally available threads and plants fiber (such as *ensete* fiber). At no point in the VC were sweetpotato roots sold on a weight basis; trade took place by volume (sack or heap). At the retail level, roots were kept in the same polypropylene sacks until sold, parts of the batch were taken out gradually, sorted by size and displayed on the sacks (on the ground) for sale. Extended bags were typically used for the packing and transportation to distant markets. Whereas, non-extended bags were used for nearby markets as donkey carts can easily transport them. Depending on the distance to the market, three major modes of transportation were available in the studied area: donkey, donkey cart and mini-truck with capacities of 1, 3 and 45 sacks respectively. To Hawassa market from *Dale* mini-truck was operating (estimated travel time: 1 h), whereas from *Dore-Bafana* donkey carts were common (estimated time of the trip: 5 h). In the case of Sodo primary mode was a donkey and donkey carts: estimated travel time of 4–6 h. To Addis Ababa market mini-truck with a full load (45 sacks) was operating (travel time 7–8 h).

3.1.3. Wholesale and retail

Wholesalers purchase the product from collectors or farmers and transfer it to the retailers. No sorting, grading, packaging or any other value-adding activities take place at the wholesale level. The wholesaler has the advantage of having the capital to purchase in bulk, which a poor retailer cannot afford. Wholesalers also lend sacks to retailers who do not have readily available money to buy the product for retailing and collect money after the sale. Wholesalers and collectors were in close contact about the market situation and demand. Farmers were paid by the collectors immediately on the harvest for long distance markets (Addis Ababa). However, for short distance markets (Hawassa and Sodo) farmers were paid after the product was sold to the wholesalers/retailers. At Hawassa and Sodo there were nine and eight sweetpotato retailers respectively, and one wholesaler served each market. The majority of the sweetpotato vendors were working under the NS and SS retail conditions in the Hawassa and Sodo markets. At the Addis

Ababa market, three wholesalers work in close collaboration with each other in logistics and determining the price of the product.

At Hawassa most of the sweetpotatoes arrive as *Meher* crop, hence at the beginning of the harvest season (September to January) the supply is high, and the price is low (Table 5). The supply starts to diminish around February and March tends to increase the wholesale price of sweetpotato up to 60%. In Sodo, sweetpotato roots are available in both seasons; however, during *Belg,* production is low which leads to a price higher in comparison to the dry season.

Economically poor women dominated retailing. 100% of the retailers at Hawassa and Sodo markets were female. In Hawassa, the primary source of fresh sweetpotato roots for retailers were the wholesalers. However, in Sodo, 75% of the retailers were buying directly from the farmers or collectors. No storage facilities were available in the retail, in most of the cases, retailers had to leave their product in polypropylene sacks at the marketplace in normal ambient conditions to sell on the next day. No particular method to control evaporation (i.e. wet jute sacks) was carried out by the retailers during the display of the roots. The retailers performed sorting and grading activities before final sale to the consumer. Small and fibrous, rotten and pest infested roots were sorted out, and size graded the remaining product.

At retail, roots were displayed on polypropylene sacks or jute sacks as a bunch of small and big size root with equal numbers of roots. The price of sweetpotato roots in the current season (March 2015) was 5 ETB (0.25 USD) for a bunch of small size roots, and 10 Birr (0.50 USD) for a bigger size roots bunch consisting of 10–12 roots. By the weights of the sweetpotato purchased at Hawassa and Sodo retail markets, the price was calculated as 2.9 ETB (0.15 USD) and 2.35 ETB/kg (0.12 USD) respectively.

3.2. Food losses and damages

The estimated magnitudes of food losses, related causes, and primary VC actors who provided information at each stage are presented in Table 6. It is evident from these results that hot-spots of post-harvest losses are at the farm (harvest) and retail levels. Packaging, transportation, and wholesale operations do not lead to any discards as the product is kept enclosed in sacks. The sorted outs and the roots which are not sold in time before they becomes unmarketable as human food are the major food losses at retail. Retailers are compelled to sell 6–25% of the sweetpotato roots at discounted prices for alternative uses (animal feed), depending on the season and demand. The discount can vary from 33 to 75% of the original price, subjected to the quality and extent of shriveling. As far as the seasonal variations are concerned, the majority of the VC actors mentioned that maximum losses take place during the dry months (November–March). The primary causes of seasonal variations were: higher availability of the produce as this is the main harvest season, dry and hot weather conditions leading to weight loss and high incident of insect (sweetpotato weevil) damage.

The current harvesting practices result in high mechanical damage. The magnitude of SD roots ranged from 20.4 to 40.2% (Table 7). The motivation to minimize injuries (during digging, packaging, loading and unloading activities) among casual labours was low, as they did not own the product and were in a hurry to complete the activity. During loading and unloading activities polypropylene sacks (weighing 110–160 kg) were dropped from shoulder height resulting in additional mechanical injuries. At the wholesale level, 100% of the roots had skinning injuries, more than 50% of the roots were suffering from one or several forms of damage (SD = 21.3%; LD = 30.5%; and PD = 5.6%). Weevil damage was low in *Dale* and *Dore Bafana* (harvested five months after planting). Whereas, in the Wolayita zone (harvested nine months after planting) infestation was extreme indicating a relation between delayed harvest and weevil attack.

3.3. Trials at market conditions

3.3.1. In-sack keeping quality

The daily ambient minimum and maximum temperatures during the trial ranged from 11–14 °C and 28–37 °C with a relative humidity of 20–69% for four weeks. The mean temperature and relative humidity inside the sacks was 24 °C (21.6–27.8 °C) and 74% (46–87%) respectively. For unsorted sack replicas, after one-week the average weight loss was 13.5%, signs of in-sack curing were visible as the roots seemed to have developed a thicker skin as compared to the fresh roots. Mean weight loss at the end of the second, third and fourth week was 19.9, 27.6 and 29.4% respectively. After one week 6.0% of the roots developed visual signs of fungal activity specifically on the wounded surfaces. From the second week onwards there were only minor visible changes in the roots conditions, the fungal activity on the injured surfaces seemed to have dried off, and infection penetrated into the roots. The results of the visual diagnostics test and pictorial indications of these infections for unsorted sack replicas are presented in Table 8 and Fig. 3 respectively. Fusarium surface and Fusarium root rot had the maximum presence (54%). The second most dominant infection was footrot caused by fungus *Plenodomus destruen*.

For sorted sacks, weight loss was not significantly different (p-value > 0.05) among damage classes. At the end of the fourth week, the weight loss was 30.4, 30.8 and 31.9% for undamaged UD, LD and SD roots respectively. Similar to the unsorted sack replicas the dominant infection in sorted (according to damage classes) sacks was also Fusarium surface and Fusarium root rot. Infection free roots had significantly (p-value < 0.05) less UD and LD roots when compared to SD. About 33.0% of the UD roots and 16.7% of the LD roots were infection free. However, none of the SD roots were free from infection. The infection among UD roots should be the result of skinning injuries, as all the roots suffered minor to severe excoriation (skinning) at wholesale.

3.3.2. Retail shelf life

Ambient conditions during the retail trial were: mean rainfall of 0.0 mm, the maximum temperature of 31–34 °C and a relative humidity of 20–48%. These conditions are a good representation of the dry season when the bulk of the Ethiopian sweetpotato harvest and marketing take place. The percentage weight loss for seven days, comparing all three damage classes and retail conditions is presented in Fig. 4. The days (duration of the retail display) (p-value $\leq$ 0.001), retail condition (S, SS, and NS) (p-value $\leq$ 0.001) and interaction between retail condition and damage class (U, LD, and SD) (p-value $\leq$ 0.001) had a significant effect on weight loss.

Keeping the threshold weight loss as 20% [24], after which roots tends to become unmarketable, roots of all damage classes can be maintained marketable under S retail conditions up to seven days. In SS retail conditions weight loss for roots of all damage classes remained below the threshold until the fourth day. However, on the fifth day, first the SD and then all other damage classes crossed the mark. Understandably, the NS retailing condition was worse whereas SD, LD and UD roots cross the threshold on the third and fourth day respectively.

4. Discussion

4.1. Value chain limitations and implications

The VC of sweetpotato in southern Ethiopia was found to be underdeveloped, where fresh sweetpotatoes were transported from farm to retail, lacking any form of curing, storage, and processing. A cause and effect dendrogram summarizing problems and limitations contributing to food losses is illustrated in Fig. 5.

Table 5
Seasonal variations in wholesale price.

Season	Belg						Meher					
Market/Months	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Hawassa	Max	Max	NA	NA	NA	NA	Min	Min	Min	Min	Min	Max
Sodo	Min	Min	NA	Max	Max	Max	Max	NA	NA	Min	Min	Min

Max: Maximum price ETB 250–300 (12.5–15 USD); Min: Minimum price ETB 160–190 (8–9.5 USD).
Price is per sack referred as quintal (110–115 kg).
NA: No information available, as this is cultivation season so normally roots are not ready for harvest and sale.

Table 6
Food losses at different stages of the value chain.

Activities	Primary Responders	Food losses (%)	Causes	Destination use
Farm/Harvest	Collectors, farmers	5–20	Pest damage, rotten and small roots which are not suitable for marketing.	Animal feed.
Packaging	Collectors, farmers	NEGL	NA	NA
Transportation	Collectors, farmers	NEGL	NA	NA
Wholesale	Wholesalers, collectors	NEGL	NA	NA
Retail	Retailers	6–25	Retail sorting based on pest damage, severely wounded and cut, small size. The product which is not sold in time and develop shriveling due to weight loss.	Sold at discounted price. 33–75% discount off the original price as animal feed.

NEGL- Negligible, NA – Not applicable.

Table 7
Farm level mechanical damages.

Woreda	Zone	UD (%)	LD (%)	SD (%)	PD (%)
Dale	Sidama	49.1	10.7	40.2	0
Dore Bafana	Sidama	44.1	20.4	24.7	10.8
Sodo Zuria	Wolayita	39.5	14.5	27.1	18.9
Boloso Sore	Wolayita	17.1	13.2	20.4	49.3

Table 8
Percentage of roots affected by various post-harvest infections during in-sack keeping quality trials.

Diseases	Cause	Symptoms[a]	Roots (%)
No infection	Not applicable	No symptoms of rotting or decay were present apart from mass loss.	14.0
Foot rot	Fungus: *Plenodomus destruens* Harter	Development of firm, dry, dark brown decay. Starts from the proximal end which has been attached to the mother root.	22.0
Fusarium surface rot	Fungus: *Fusarium oxysporum*	Circular, dry, light to dark brown lesions on the surface. Visible white mycelium, hard and mummified roots. Usually restricted to the cortex.	36.7
Fusarium root rot	Fungus: *Fusarium solani*	Enters into the vascular ring, lesions are concentric light to dark brown circles. Root seems dry, firm and dark brown. Internal cavities may contain white mold hyphae.	17.3
Bacterial rot	Proteobacteria: *Erwinia chrysanthemi*	Wet and soft rot which mostly is internal. The affected tissue has a peculiar smell, which becomes watery.	4.0

[a] *Source:* O'Sullivan et al. [25].

Fig. 3. Pictographic representations of the different infectious rotting in sweetpotato roots during in-sack keeping quality trials.

Mechanical injuries, weevil infestation and lack of storage/curing facilities were found to be some of the primary causes of food losses. Lack of diverse usage and the image of sweetpotato as a poor man's food appeared to be some of the broader reasons causing neglect in the improvement of the sweetpotato VC. Similar situations have been recorded in other parts of East Africa where traders were compelled to sell their product in wet markets within 3–10 days before significant weight loss and rotting occurred [24,25]. Injuries at harvest continue to aggravate during the next stages of the VC, contributing to the rapid weight loss and microbial rotting, reports from developing regions of Asia and Africa estimates 26–35% of the roots sustained severe mechanical damages at harvest [26,27]. In the current study from Ethiopia, the situation was similar and even worse in some cases where damages could reach up to 40%.

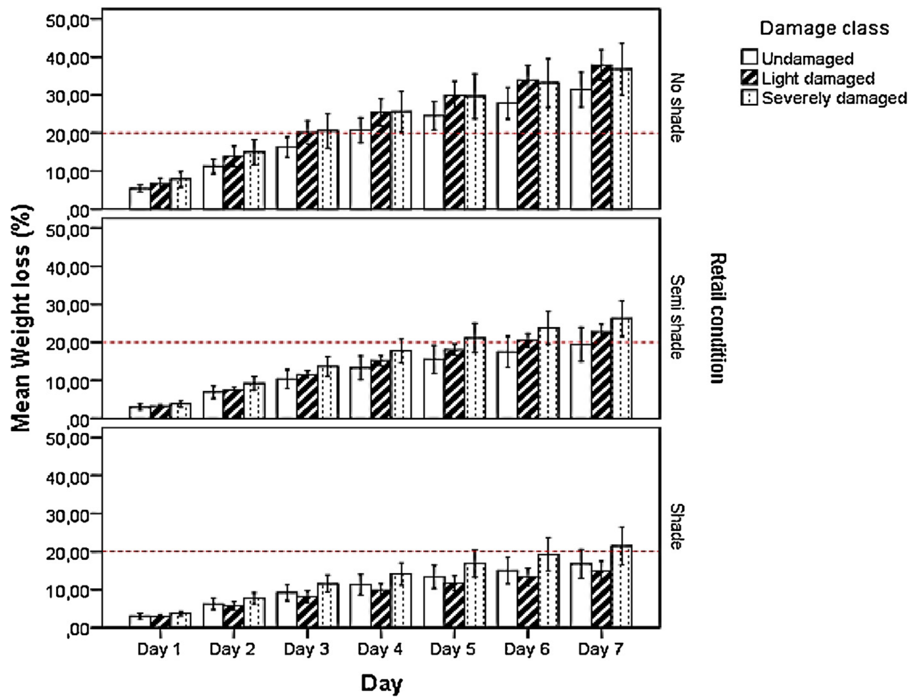

Fig. 4. Daily percentage weight loss for three damage classes of sweetpotato roots in three different retail conditions. (*The red dotted line represents threshold weight loss = 20% after which roots tends to become unmarketable for human food*)

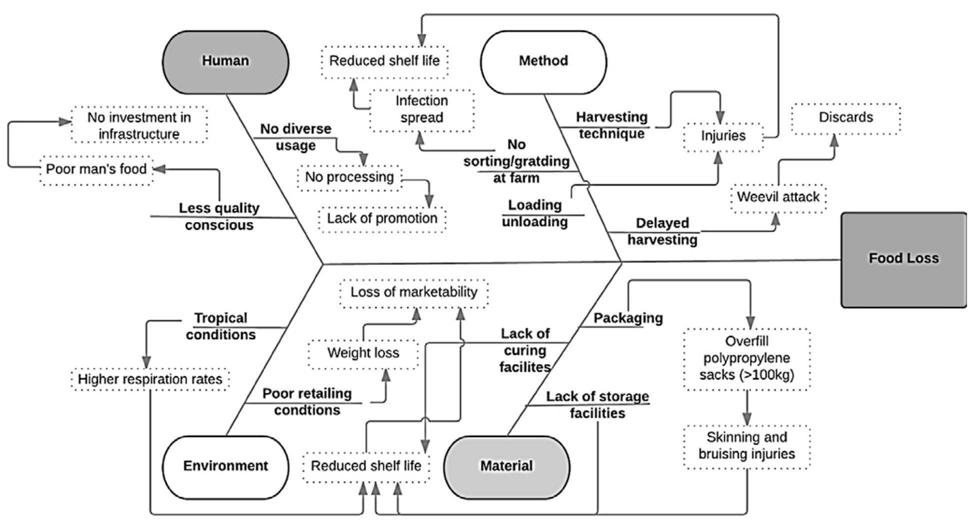

Fig. 5. Cause and effect for sweetpotato food losses in the study locations. (*Source: Authors*).

Clark et al. [28] found that mechanical damages are higher when sweetpotatoes are harvested in the dry season, which was evidently the main harvest in Ethiopia. Polypropylene sacks weighing more than 100 kg are common in many East African countries resulting in significant skinning and bruising injuries during loading and unloading activities [26,29]. In the main markets of the study locations, 50% and above of the roots were suffering from mechanical breakages and 100% of the roots had skinning injuries. Comparable studies from Tanzania state that 20% of the commercial consignments of sweetpotato were severely damaged and 86% had skinning injuries at market level, resulting in economic losses of up to 13% [29]. Rees et al. [24] observed that from 41% up to 93% of all the roots arriving in urban markets of Tanzania were damaged in some form resulting in a reduction of the market value by 11–36%. Sweetpotato weevils (*Cylas puncticollis* and *C. brunneus)* infestation is a challenge in the whole of Eastern Africa [30,31]. Examples from Uganda and Tanzania suggest that keeping roots underground for prolonged durations of the dry season leads to higher levels of weevil damage [30–32].

Results from the shelf life trials during marketing clearly demonstrated that wounds and cuts during harvesting and handling have a significant effect on susceptibility to post-harvest infection and weight loss. These outcomes are in coherence with previous studies where wounding during the harvesting/handling in combination with improper storage and, warm/humid environments were some of the main factors for fungal and bacterial infections [27,28]. Sweetpotato roots may become unmarketable after a substantial weight loss; it was hard to sell the roots which had experienced a moisture loss of 20–30% in wet markets eastern Africa [24]. Economic loss due to non-marketability of roots as food was one of the biggest problems of the retailers of southern Ethiopia, where they were forced to sell their product at significant discounts (33–75%)

as animal feed. Kapinga et al. [33] report from Tanzania that after two weeks during marketing the economic losses were up to 60% due to quality degradation resulting from weight loss.

The estimated overall sweetpotato food losses in Ethiopia was about 11–45%, out of which agricultural production contributed to 5–20% and distribution 6–25%. Comparing these figures with Gustavsson's [10] estimates for roots and tubers losses from SSA, present a slightly different picture particularly in the distribution stage at the wet market. There is a need to update the food loss and waste data regularly especially for developing and transitional countries. Perhaps a built in system of food loss data recording has to be created which can be published yearly just like production and yield figures to track the progress against set targets (SDG 12.3).

4.2. Prospective control measures

Future work should focus on improving the harvesting and packaging practices to minimize the mechanical damages. Training of farmers and collectors in good harvesting practices, grading, and sorting at the farm gate are some of the simple interventions which can be immediately executed. One of the intrinsic factors which need to be considered is creating a sense of ownership and incentivizing undamaged roots among casual labours who are involved in harvesting, packaging, loading and unloading activities. The potential inexpensive and straightforward techniques such as pre-harvest/in-ground curing [34,35] and in-sack curing can be explored to prevent skinning injuries. At farm level with undamaged roots, and routine store inspections sweetpotatoes can be economically stored for up to 4–5 months with traditional storage methods such as pits and clamps [27,36]. Such facilities would also balance the demand and supply gaps in high and low seasons and control price fluctuations. Farmers and collectors can reduce the weevil damage, which remains an unsolved problem in the region by having an alternative to keep roots in-ground for extended durations. However, early maturing and deep rooted varieties, crop rotation, clean planting material, sex pheromone traps, and hilling-up are some of the management strategies which need to be adopted to control weevil damage [27,31,32]. Shifting from overfilled sacks to boxes and crates has been suggested by previous studies [27,29,34]. However, limited success has been achieved in replacing the polypropylene packaging due to higher costs involved in buying and transporting plastic or wooden crates. Smaller bag sizes (~15–30 kg) can provide an economical option and reduce damages during loading, unloading, and transportation [37].

The retail trials during this study demonstrated that improving the environmental conditions and providing undamaged roots at retail can enhance marketing shelf life. Zero Energy Cool Chambers (ZECC) developed during the 1980s in India to provide short term storage for various horticultural crops can be an attractive proposition for wholesalers and retailers during the dry season [38,39]. A humidity of up to 90% and temperature fall of 10–15 °C (from ambient) can be obtained by watering such evaporative coolers twice a day. The construction of ZECC is simple and requires locally available materials such as bricks, sand, wood, and straw. In some areas of Asia and Africa traditionally fresh sweetpotato roots are covered with ash to prevent fungal decay during short term storage [40].

Value addition has been on the agenda to transform rural agroeconomies in SSA, but the development of sweetpotato processing in the region has not reached that level of significance, which was also reflected in this study. The introduction of sweetpotato flour and other processed products in traditional food VCs (such as Injera: the Ethiopian stable flat bread) can provide a potential. However, such introduction is challenging, due to the local taste preferences and competition from other crops such as cassava and maize in price and quality [6].

The key to long-term success of food loss reduction strategies is that it has to provide tangible financial returns on investment. Short and long term cost-benefit assessment of the possible interventions must be conducted based on specific locations and conditions to convince policy-makers to take the necessary steps. Experiences from SSA suggest that food losses reduction and value-addition measures failed previously for not being economically viable, their inability to follow best practices, poor performance, mismatching user/market needs and high initial investment in case of smallholders [12–14]. Following a more holistic system approach may produce better results by bringing cultural and socio-economic aspects into consideration rather than a pure technical intervention.

5. Conclusion and outlook

Identifying the VC constraints and linking them to specific food losses is a key to developing better mitigation strategies and improve VC efficiencies and in turn enhancing food security in developing countries like Ethiopia. Around a quarter of the total sweetpotato production in the study area is lost only at marketing and distribution stages of the VC. The poor retailing condition in addition to physical and biological factors along the VC severely restricted the sweetpotato shelf life. The loss reduction measures must be taken at all stages simultaneously to have maximum effect as in most cases the origin of the spoilage cause is in a preceding stage. A considerable loss reduction potential is available in sweetpotato value chains of southern Ethiopia towards achieving SDG 12.3. Moreover, keeping the history of war and famine in Ethiopia the experience shows that food security is not only a prerequisite for healthy but also peaceful societies. Biophysical factors such as maintaining intact skin during harvest and handling; and providing shade and lower temperatures at distribution stages can improve the shelf life. However, such efforts should be complemented with effective government policy at institutional and regulatory levels.

In a recent outlook on food insecurity and post-harvest losses, Bourne [41] stated that the core nature of the problem is of handling inconsistent food supply and consistent demand. This occurrence was prevalent in the sweetpotato value chains in southern Ethiopia resulting in nutrition and income losses during the peak season and scarcities in the lean season. Continuous reporting and monitoring of food losses are vital to track progress and evaluate the impact of the interventions. Examples of government policies on post-harvest loss information systems based on nationally representative household surveys from Africa and its importance was highlighted by Kaminski and Christiaensen [42]. In the least developed countries like Ethiopia policy interventions to adopt joint marketing (co-operatives) and access to micro credits at the producer level and public, private partnerships in market infrastructure investment can reduce losses and improve economic efficiencies of the VC. Such policy and regulatory efforts based on VC collaborations have been recognized by previous studies as one of the important contributory factors to achieve development goals [43,44]. Hence, the involvement of all the VC actors including consumers, policy makers, and development organizations is crucial in developing resilient and sustainable food systems with minimal losses.

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References

[1] CSA, Agricultural Sample Survey: Area and Production of Major Crops, Addis Ababa, 2015.
[2] T. Tadesse, H. Fikre, M. Gemu, Prevalence incidence and distribution of sweet potato virus: it's effect on the yield of sweet potato in southern region of Ethiopia, Int. J. Sci. Res. 2 (2013) 591–595.
[3] FAOSTAT, FAOSTAT On-line. Rome United Nations Food and Agriculture, Organization, 2014. http://www.fao.org/faostat/en/#home. Accessed on 5 September 2016.
[4] V. Lebot, Tropical Root, and Tuber Crops: Cassava, Sweet Potato, Yams, and Aroids., Crop Prod Sci. Hortic. No. 17, CABI Publ., Oxfordshire, UK, 2009, pp. 167–177, http://dx.doi.org/10.1017/S0014479709007832.
[5] D. Rees, A. Westby, K.I. Tomlins, Q.E.A. van Oirschot, M.U. Chemma, E. Cornelius, M. Amjad, Tropical root crops, in: D. Rees, G. Farrel, J. Orchard (Eds.), Crop Post-Harvest Sci. Technol. Perishables, first ed., Wiley Blackwell Publishing Ltd, UK, 2012, pp. 392–396.
[6] M. Andrade, I. Barker, D. Cole, H. Dapaah, H. Elliott, S. Fuentes, W. Grüneberg, R. Kapinga, J. Kroschel, R. Labarta, B. Lemaga, C. Loechl, J. Low, J. Lynam, R. Mwanga, O. Ortiz, A. Oswald, G. Thiele, Unleashing the Potential of Sweetpotato in SubSaharan Africa: Current Challenges and Way Forward, International Potato Center (CIP), Lima, Peru, 2009.
[7] C. Hotz, C. Loechl, A. de Brauw, P. Eozenou, D. Gilligan, M. Moursi, B. Munhaua, P. van Jaarsveld, A. Carriquiry, J.V. Meenakshi, A large-scale intervention to introduce orange sweet potato in rural Mozambique increases vitamin A intakes among children and women, Br. J. Nutr. 108 (2012) 163–176, http://dx.doi.org/10.1017/S0007114511005174.
[8] M.H. Grace, G.G. Yousef, S.J. Gustafson, V. Den Truong, G.C. Yencho, M.A. Lila, Phytochemical changes in phenolics, anthocyanins, ascorbic acid, and carotenoids associated with sweetpotato storage and impacts on bioactive properties, Food Chem. 145 (2014) 717–724, http://dx.doi.org/10.1016/j.foodchem.2013.08.107.
[9] A.C. Bovell-Benjamin, Sweet potato a review of its past, present, and future role in human nutrition, Adv. Food Nutr. Res. 52 (2007) 1–59, http://dx.doi.org/10.1016/S1043-4526(06)52001-7.
[10] J. Gustavsson, C. Cederberg, U. Sonesson, R. van Otterdijk, A. Meybeck, Global food losses and food waste: extent, causes, and prevention, 2011. Doi: 10.1098/rstb.2010.0126.
[11] FAO, Food loss, and waste facts, http://www.fao.org/save-food/resources/infographic/en/, 2003.
[12] H. Affognon, C. Mutungi, P. Sanginga, C. Borgemeister, Unpacking postharvest losses in sub-Saharan Africa: a meta-analysis, World Dev. 66 (2015) 49–68, http://dx.doi.org/10.1016/j.worlddev.2014.08.002.
[13] J. Parfitt, M. Barthel, S. Macnaughton, Food waste within food supply chains: quantification and potential for change to 2050, Philos. Trans. R. Soc. Lond. B Biol. Sci. 365 (2010) 3065–3081, http://dx.doi.org/10.1098/rstb.2010.0126.
[14] B. Lipinski, C. Hanson, J. Lomax, L. Kitinoja, R. Waite, T. Searchinger, Reducing Food Loss and Waste. Working Paper, Installment 2 of Creating a Sustainable Food Future., Washington DC, 2013. http://www.worldresourcesreport.org.
[15] WFP, Hunger Map, https://www.wfp.org/content/hunger-map-2015, 2015.
[16] R.J. Hodges, J.C. Buzby, B. Bennett, Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use, J. Agric. Sci. 149 (2011) 37–45, http://dx.doi.org/10.1017/S0021859610000936.
[17] M. Kummu, H. de Moel, M. Porkka, S. Siebert, O. Varis, P.J. Ward, Lost food, wasted resources: global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use, Sci. Total Environ. 438 (2012) 477–489, http://dx.doi.org/10.1016/j.scitotenv.2012.08.092.
[18] D. Jones, M. Gugerty, L. Anderson, Sweetpotato Value Chains: Ethiopia, Evans School of Public Affairs, Washington DC, 2012.
[19] CSA, Population and Housing Census of Ethiopia, Addis Ababa, 2007.
[20] FAO, Global Initiative on Food Loss and Waste Reduction: Definitional Framework of food loss, Rome, Italy, 2014.
[21] D. Rees, R. van Oirschot, Q.E. Kapinga, K. Mtunda, D. Chilosa, L. Mbilinyi, E. Rwiza, M. Kilima, H. Kiozya, R. Amour, T. Ndondi, Extending root shelf-life during marketing by cultivar selection, in: D. Rees, Q.E.A. van Oirschot, R. Kapinga (Eds.), Sweet Potato Postharvest Assessment. Exp. from East Africa, University of Greenwich, London, 2003, pp. 51–65.
[22] J. O'sullivan, V. Amante, G. Norton, E. van de Fliert, E. Vasquez, J. Paradales, Sweetpotato DiagNotes: a diagnostic key and information tool for sweetpotato problems, http://espace.library.uq.edu.au/view/UQ:161094, 2005.
[23] A. Springer-Heinze, ValueLinks Manual – The Methodology of Value Chain Promotion, Eschborn, Germany, 2007.
[24] D. Rees, R. Kapinga, K. Mtunda, D. Chilosa, E. Rwiza, M. Kilima, H. Kiozya, R. Munisi, Effect of damage on market value and shelf-life of sweetpotato in urban markets of Tanzania, Trop. Sci. 41 (2001) 1–9.
[25] G. Thiele, J. Lynam, B. Lemaga, L. Jan, Challenge theme paper 4: sweetpotato value chains, in: C. Barker (Ed.), Unleashing Potential Sweetpotato Sub-Saharan Africa Curr. Challenges W. Forw., Peru, Lima, 2009: pp. 106–120.
[26] G.T. Ndunguru, A. Westby, A. Gidamis, K.I. Tomlins, E. Rwiza, Losses in sweetpotato quality during post-harvest handling in Tanzania In5th Trienn Congr. African Potato Assoc. Potatoes Poverty Alleviation, 2000. pp. 477–479.
[27] R.C. Ray, V. Ravi, Post harvest spoilage of sweetpotato in tropics and control measures, Crit. Rev. Food Sci. Nutr. 45 (2005) 623–644, http://dx.doi.org/10.1080/10408390500455516.
[28] C.A. Clark, G.J. Holmes, D.M. Ferring, Major fungal and bacterial diseases, in: G. Loebenstein, G. Thottappilly (Eds.), The Sweetpotato, Springer, Netherlands, 2009, pp. 80–81.
[29] K.I. Tomlins, G.T. Ndunguru, E. Rwiza, A. Westby, Postharvest handling, transport and quality of sweetpotato in Tanzania, J. Hortic. Sci. Biotechnol. 75 (2000) 586–590.
[30] R. Adam, K. Sindi, L. Badstue, Farmer's knowledge, perceptions and management of diseases affecting sweetpotatoes in the Lake Victoria Zone region Tanzania, Crop Prot. 72 (2015) 97–107.
[31] N.E.J.M. Smit, The effect of the indigenous cultural practices of in-ground storage and piecemeal harvesting of sweetpotato on yield and quality losses caused by sweetpotato weevil in Uganda, Agric. Ecosyst. Environ. 64 (1997) 191–200, http://dx.doi.org/10.1016/S0167-8809(97)00022-4.
[32] E. Ebregt, P.C. Struik, B. Odongo, P.E. Abidin, Piecemeal versus one-time harvesting of sweetpotato in north-eastern Uganda with special reference to pest damage, Njas-Wagen J. Life Sci. 55 (2007) 75–92.
[33] R. Kapinga, D. Rees, A. Westby, G. Ndunguru, E. Rwiza, K. Tomlins, T. Stathers, S. Jeremiah, L. Mbilinyi, Increasing the contribution of sweet potato to sustainable rural livelihoods in Tanzania, in: Trienn. Symp. Int. Soc. Trop. Root Crop., Tsukuba, Japan, 200AD: pp. 285–291.
[34] K.I. Tomlins, G.T. Ndunguru, E. Rwiza, A. Westby, Influence of pre-harvest curing and mechanical injury on the quality and shelf-life of sweet potato (Ipomoea batatas (L.) Lam) in East Africa, J. Hortic. Sci. Biotechnol. 77 (2002) 399–403.
[35] G. Kyalo, Improved Curing for Improved Shelf-life, Sweet Potato Knowl. Portal, 2014 http://www.sweetpotatoknowledge.org/wp-content/uploads/2016/02/2014FIND14_ImprovedCuring.pdf.
[36] A. Devereau, Fresh storage of sweetpotatoes in Uganda: evaluation of on station trials, Chatham, United Kingdom, 1995.
[37] S. Saran, S.K. Roy, L. Kitinoja, Appropriate postharvest technologies for small scale horticultural farmers and marketers in Sub-Saharan Africa and South Asia-Part 2. Field trial results and identification of research needs for selected crops, XXVIII Int. Hortic. Congr. Sci. Hortic. People (2010) 41–52.
[38] S.K. Roy, D.S. Khurdiya, Keep your vegetables fresh in summer, Indian Hortic. 27 (1981) 56.
[39] S.K. Roy, R.K. Pal, A low cost zero energy cool chamber for short-term storage of mango, Acta Hortic. 291 (1991) 519–524.
[40] T. Stathers, A. Bechoff, K. Sindi, J. Low, D. Ndyetabula, Everything You Ever Wanted to Know About Sweetpotato: Reaching Agents of Change ToT Manual. 5: Harvesting and Postharvest Management, Processing and Utilisation, Marketing and Entrepreneurship, International Potato Center (CIP), Nairobi, Kenya, 2013.
[41] M.C. Bourne, Food security: postharvest losses, Encycl. Agric. Food Syst. 44 (2014) 338–351, http://dx.doi.org/10.1016/B978-0-444-52512-3.00035-8.
[42] J. Kaminski, L. Christiaensen, Post-harvest loss in sub-Saharan Africa—what do farmers say? Global Food Secur. 3 (2014) 149–158.
[43] R.J. Hodges, J.C. Buzby, B. Bennett, Postharvest losses and waste in developed and less developed countries: opportunities to improve resource use, J. Agric. Sci. 149 (2011) 37–45, http://dx.doi.org/10.1017/S0021859610000936.
[44] S. Vellema, G. Ton, N. De Roo, J. Van Wijk, Value chains, partnerships and development: using case studies to refine programme theories, Evaluation 19 (2013) 304–320, http://dx.doi.org/10.1177/1356389013493841.