Proceedings of the 13th ISTRC Symposium, 2007
pp. 423 - 434

The potential for storage of fresh sweetpotato under tropical conditions: Evaluation of physiological changes and quality aspects

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Abstract. This paper presents the results of two years of trials carried out on-station at Lake Zone Agricultural Research and Development Institute, Tanzania and gives recommendations for simple and low cost storage of fresh sweet potato. The optimum conditions for long term storage of sweet potato are well known, but little is known about the conditions in simple storage structures or if it is possible to influence them. To evaluate this, five different treatments were assessed. These were: effect of cultivar (SPN/0, Polista and Sinia B); level of root damage; lining with dried grass; ventilation; and store design (pits or clamps). Over a period of 18 weeks, the physiological changes of the roots in the stores were monitored via oxygen and carbon dioxide levels, relative humidity, temperature and root weight. The quality of the stored roots was assessed by sensory evaluation, external appearance and estimated market value. High temperatures and high weight loss of the roots indicated deterioration during storage. This was most strongly associated with storing damaged roots as opposed to good quality ones. Store type (pit or clamp) or ventilation did not have a consistent effect on shelf-life and suggests that any combination of these designs can be used. Sensory properties may change during storage and acceptable characteristics were found up to 12 weeks of storage. Stored roots may taste sweeter than freshly harvested roots. Success of storage, however, is also determined by other factors than just store design and this is discussed.

Introduction

Sweet potato roots can be stored under controlled environments for several months. The optimum conditions for long term storage of sweet potato are well known and in temperate areas in the United States, roots can be stored for up to one year (Picha 1986). Little is, however, known about the conditions in simple storage structures or if it is possible to influence them. In tropical areas where sweet potato consumption in an important part of the diet, the post-harvest shelf life of roots is short. An understanding of post-harvest changes in the commodity may help to improve store design and so make sweet potato available over longer periods of time. This may be a beneficial for food security or marketing roots out of season.

In some cooler areas of the tropics, fresh storage is currently practised and a number of traditional storage technologies have been reported. These include the use of pits, clamps (piles, mounds, heaps), cellars, bulk bins or just leaving roots in the ground. Information about environmental and physical changes (temperature, humidity, storage period and weight loss) during storage is, however, sparse. Lining stores with dry plant material, such as dried grass (NRI/NARO 1996; Hall and Devereau, 2000), bamboo

(Gooding and Campbell, 1964), with ash (Woolfe 1992) or sand (Sandifolo *et al.*, 1998) has been described as having a beneficial effect upon storage. The function of these materials is, however, not clear. In the highlands in south west Tanzania sweet potatoes are traditionally stored in pits under banana trees.

This paper summarises the results of two years of storage trials carried out at the Lake Zone Agricultural Research and Development Institute, Tanzania and gives recommendations for simple and low cost storage of fresh sweet potato roots. The research aimed to gain a better understanding of how store design affects the atmospheric conditions around the fresh produce, and how the atmospheric conditions in their turn affect quality aspects of the fresh roots during storage. The factors tested included: three cultivars, two levels of ventilation, pit and clamp types of store, lining with dried grass and the effect of damage to roots.

Materials and Methods

Trials were carried out with 36 stores in 2000 and 24 stores in 2001; each with a unique combination of design factors. Five different treatments were assessed: cultivar (Polista, Sinia B and SPN/0); ventilation where stores with extra ventilation contained six ventilation pipes, others two pipes; lining with dried grass (which was folded into bunches of 10 cm diameter and placed inside the pits or outside the clamps); store type using both pit and clamp types of store (Round pits were dug in the soil of about 0.6 m in diameter and 0.6 m depth. Clamps were built with the roots); and damage treatment that was carried out by rolling a sack of roots 10 times. This treatment simulates damage that occurs during handling and transport of roots which is known to cause 'skinning injury' and was only used in 2000.

Each store contained 70 to 100 kg roots of similar quality. Over a period of 18 weeks of storage, the physiological changes of the roots in the stores were monitored by measuring root weight, dry matter content, oxygen and carbon dioxide levels, relative humidity and temperature. The quality of the stored roots was assessed by "Estimated Market Value", sensory evaluation and external appearance, which included sprouting, shrivelling, rotting and weevil infestation.

During storage the conditions inside the stores were monitored (temperature, relative humidity (RH), oxygen and carbon dioxide). Temperature and relative humidity were determined using a probe (Hanna Instruments, Portugal), or Tiny Talk data loggers (Gemini, Chichester, UK) that were inserted into the store at least every week for 10 minutes. Gas samples were taken in duplicate at regular intervals (at least every week) from each store via tubing (Tygon 3603 (BDH), 3 mm). The measurements were made using a CO_2 meter and an O_2 meter (Anagas CD 98 and Oxycheck 2, David Bishop Ltd, UK).

Physiological characteristics were recorded at 0, 2, 4, 8, 12, and 18 weeks when stores were opened and inspected. Weight loss was determined by taking ten randomly selected roots per store labelling them and recording their weights every time the stores were opened. In addition rotten roots were removed during opening of the stores, and their total weight was recorded as a percentage of initial weight of roots stored. Dry matter contents were determined for three roots per store using both cooked and uncooked roots. To determine dry matter contents roots were sliced and dried for 48 hours in an oven at 80°C.

Respiration rates were measured at 25°C. Single roots were weighed and placed in a 3 L jar. Air samples were removed at intervals from each jar through a rubber septum using an air-tight syringe. Levels of carbon dioxide and oxygen were measured by gas chromatography using a molecular sieve (to separate carbon dioxide from oxygen/ nitrogen) and poropak column (to separate oxygen and nitrogen) and a thermal conductivity detector.

The quality of roots was assessed at 0, 2 , 4, 8, 12, and 18 weeks of storage. A sample of 20 randomly selected roots was used. To determine the "Estimated Market Value" the roots were divided into two heaps. Ten consumer panellists then estimated the value of the roots, in relation to standard heaps, consisting of roots bought on the market that day. All heaps of roots were weighed, and thus the price per kg was calculated for each heap of roots. For External Assessment all 20 randomly selected roots were scored by three scientists for breaks, cuts, skinning injury, shrivelling, rotting, weevil infestation and sprouting.

Sensory evaluation was carried out by an expert taste panel of 10 panellists. Equally sized pieces (3-5 cm) were boiled for approximately 20 minutes and until the texture assessed by a fork was considered correct for eating. Each panel member scored each store-sample for pre-determined important characteristics by placing a mark on a 10.5 cm line. Characteristics included: appearance, colour (inside and outside), taste, smell, sweetness, flouriness, texture, chewiness, stickiness and acceptability. Panellists were presented with three or four randomly selected samples labelled with a random number. Three sessions (morning, noon and afternoon) were conducted each day.

Statistical analyses were carried out using Genstat (Rothamsted, UK). Due to the incomplete design in 2000, the significance levels were calculated using type II and type III sums of squares. In year 2001 analysis was carried out using ANOVA. It only included only the main effects (store type, cultivar, ventilation and lining) because of the lack of replication.

Results

Physiological changes. Table 1 indicates which of the design factors had a significant effect ($P < 0.05$) upon physiological changes of the roots during the storage period. The average weight losses for stored roots were up to 4% (2 weeks), 7% (4 weeks) 15% (8 weeks) and 28% after 12 weeks (Figure 1). Weight losses were reduced in year 2000 when stores were lined. Significant effects were observed in weeks 4, 8 and 12, while in year 2001 the lining treatment significantly increased weight loss during the whole storage period ($p< 0.05$). In week 8 significant higher weight losses were observed in pits ($P<0.05$).

Dry matter content was measured for both the fresh and cooked roots sampled during storage. The pattern for both was similar. Cultivar, and to a lesser extent lining, were the factors that influenced dry matter content (Figure 1). Polista has the highest dry matter content when cooked ($P < 0.05$; 41 to 44% compared to 37 to 41% of the other cultivars and for fresh roots. In unlined stores the dry matter content was significantly lower in week 12 ($p < 0.05$).

The CO_2 concentration in the stores varied between 0.1% and a maximum of 13%. It increased during storage and the increase was in stores that were not lined and not ventilated. For lined stores (Figure 2) CO_2 levels increased from an average of 1.6% in the first four weeks of storage to 3.3% in the last four weeks, while unlined stores the increase was from 2.3% to 5.3%. Stores with the cultivar Sinia B showed high levels of CO_2. On average the levels did not rise above 7%.

The oxygen concentration in the stores varied between 15 and 21%. Overall, it followed an inverse response to CO_2 and the significant differences with respect to lining and ventilation were similar. Cultivar differences up to week 8 were noted where the concentration was least for Sinia B cultivar and highest for Polista.

The temperature (Figure 2) was about 3°C degrees higher in stores with damaged roots in the first two weeks of storage ($P<0.01$). This may be due to the higher metabolic activities of roots within the stores. The higher respiratory activity among the roots may have been due to wounding or even to rotting. Later during the storage period the temperature in stores with damaged roots was similar to other stores. Stores with cultivar

Table 1. Store design factors that had a significant effect ($P < 0.05$) upon physiological changes of the roots during storage in on-station trials in the Lake Zone of Tanzania.

Physiological changes	Store design factors with significant effect	Design effects on physiological changes
Weight loss	Lining with grass; Clamp/pit	Lower weight loss when stores were not lined. Store type affected weight loss in week 8.
Dry matter cooked roots	Lining with grass; Cultivar	Polista has the highest dry matter content when cooked ($P < 0.05$; 41-44% compared to 37-41% in other cultivars). Lower dry matter where there is no lining.
Dry matter uncooked roots	Cultivar	Polista has the highest dry matter content for fresh roots
Oxygen in store	Cultivar; Lining with grass; Ventilation	Oxygen levels were higher in stores with extra ventilation and grass lining. Stores with cultivar Sinia B showed low levels of oxygen
CO_2 in store	Lining with grass; ventilation	CO_2 levels were lower in stores with extra ventilation and with grass lining. Stores with cultivar Sinia B showed high levels of CO_2.
Temperature	Damaged roots; Ventilation	Temperature was about 3 degrees higher in stores with damaged roots in first 2 weeks ($P<0.01$). increased ventilation reduced the temperature
Relative Humidity	Ventilation	The relative humidity was higher in stores with little ventilation (2 pipes 80-95%) than in stores with increased ventilation (6 pipes; 70-80%)
Respiration rate	Cultivar	Higher rate of respiration for Polista (73.8 ml CO_2/Kg/h) compared to SPN/0 and Sinia B (45.5 and 43.9. ml CO_2/Kg/h). Polista could be more prone to anaerobiosis in sealed store.

SPN/0 recorded a lower temperature for the first four weeks of storage than the cultivars Polista and Sinia B. Ventilation only affected the temperature significantly after one week of storage, where two pipes ventilation resulted in higher temperatures than use of six ventilation pipes.

The relative humidity (Figure 2) was higher in stores with two pipes ventilation (80-95%) than in stores with six pipes ventilation (70-80%). This was highly significant after 1, 2, 7 and 14 days. After three weeks the humidity in the stores with two pipes dropped to under 80%. Respiration experiments indicated that Polista had a significantly higher rate of respiration (73.8 ml CO_2/Kg/h) than SPN/0 and Sinia B (45.5 and 43.9. ml CO_2/Kg/h), with no significant difference between the latter two cultivars. It would be predicted that Polista is less suitable for long-term storage than the other two cultivars. It would be expected that Polista be more prone to anaerobiosis within a sealed store (Rees 2002). This is however inconsistent with the O_2 and CO_2 measurements in the stores where Sinia B had the highest levels of CO_2.

Quality changes. Table 2 indicates which of the design factors had a significant effect ($P < 0.05$) upon quality aspects of the roots during the storage period. The estimated market value was mostly affected by choice of cultivar ($p = 0.009$). SPN/0 had the highest value per kg and was between 60 and 50 TSh/kg (exchange rate: US$1.0 = 775 TSh). This is in agreement with the findings of Rwiza *et al.* (2000) who found that the consumers have a preference for the cultivar SPN/0. Sinia B was valued lowest per kg. At this stage in storage the effect of damage was not significant ($p = 0.056$). During storage the estimated market value declined for all roots and was much steeper for damaged than for undamaged roots. The damaged roots were valued at 35.8, 25.9 and 20.9 TSh/kg for 2, 4 and 8 weeks respectively, while the undamaged roots were valued at 51.3, 43.8 and 31.2. Roots kept in pits were valued higher than roots kept in clamp stores and after eight weeks the

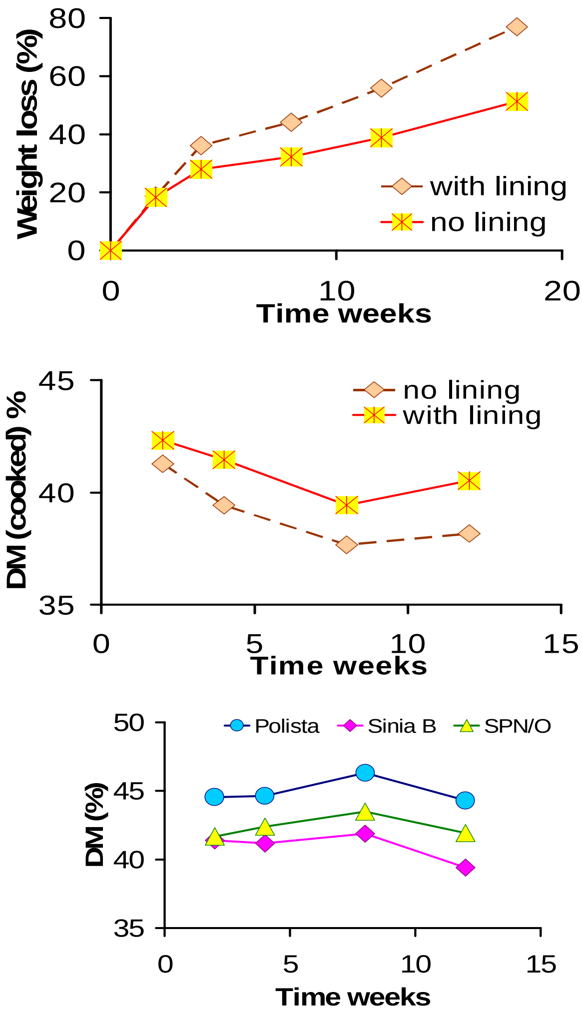

Figure 1: Changes in weight loss and dry matter (DM) of sweet potatoes stored in pits and clamps in the Lake Zone of Tanzania. Figures show effect of lining of stores with grass and variety.of sweet potato.

Table 2: Design factors with a significant effect (P < 0.05) upon quality aspects of sweet potato roots during the storage period in on-station trials in the Lake Zone of Tanzania.

Quality Aspects	Store Design factors with significant effect	Design effect on Quality Aspects
Estimated Market Value	Damaged roots; Lining with grass	Higher Estimated Market value for undamaged roots after 2-8 weeks storage. Roots from lined stores and clamps had a lower Estimated Market Value
Sprouting	Ventilation; Lining with grass; Cultivar	Most sprouts in stores with no lining, low ventilation, pits. The cultivar Sinia B had significant more sprouting.
Shrivelling	Lining with grass	The levels of shrivelling, expressed as a score during external evaluation, were significantly higher for roots from stores lined with dried grass.
Rotting	Damaged roots; Clamp/pit	Roots in clamps had a higher percentage rotted roots then roots from pits. Also stores of which the roots had a damage treatment had higher levels of rotting.
Deep weevils	Lining with grass	There was significantly more deep weevil (*Cylas* spp.) infestation in stores with dried grass lining.
SE (Sensory Smell, taste acceptability	Cultivar; Damaged roots; Lining with grass	Cultivar, damage and lining had significant Evaluation) negative effects on smell, taste and acceptability, especially after 2 and 4 weeks.
SE: Appearance, Colour (inside and outside)	Cultivar; Damaged roots; Lining with grass	Cultivar had significant effect on colour and appearance, with SPN/0 kept the best appearance during storage. Damage and lining affected the attributes in week 2 to 4.
SE: Sweetness and flouriness	Cultivar; Damaged roots;	Sweetness increased for the cultivars SPN/0 and Polista during the first weeks of storage. Sinia B was much less sweet.
SE: Texture, chewiness and stickiness	Cultivar; Damaged roots; Lining with grass	Cultivar had a significant effect on texture and chewiness. Damage resulted in lower texture in week 0, 2 and 4. Lining reduced chewiness of roots in the first 2 weeks.

estimated market value for roots from clamps was a third lower than of pit stored roots (20.8 and 31.8 Tsh/kg).

Roots in clamp stores were also more susceptible to rotting (Figure 3). Statistical analysis revealed that two factors significantly affected rotting: damage and type of store. Pit storage resulted on average in 11% rotten roots after four weeks and 25% after 12 weeks, while clamp storage resulted on average in 28% rotten after four weeks and 35% after 12 weeks. Damage affected rotting and 27% of the damaged roots were rotten after four weeks while 35% were rotten after 12 weeks. Of the undamaged roots 12% were rotten after four weeks and 35% after 12 weeks. Data for estimated market value and rotting were only analysed for the year 2000. Sprouting, assessed during the external assessment of 20 randomly selected roots, started to appear

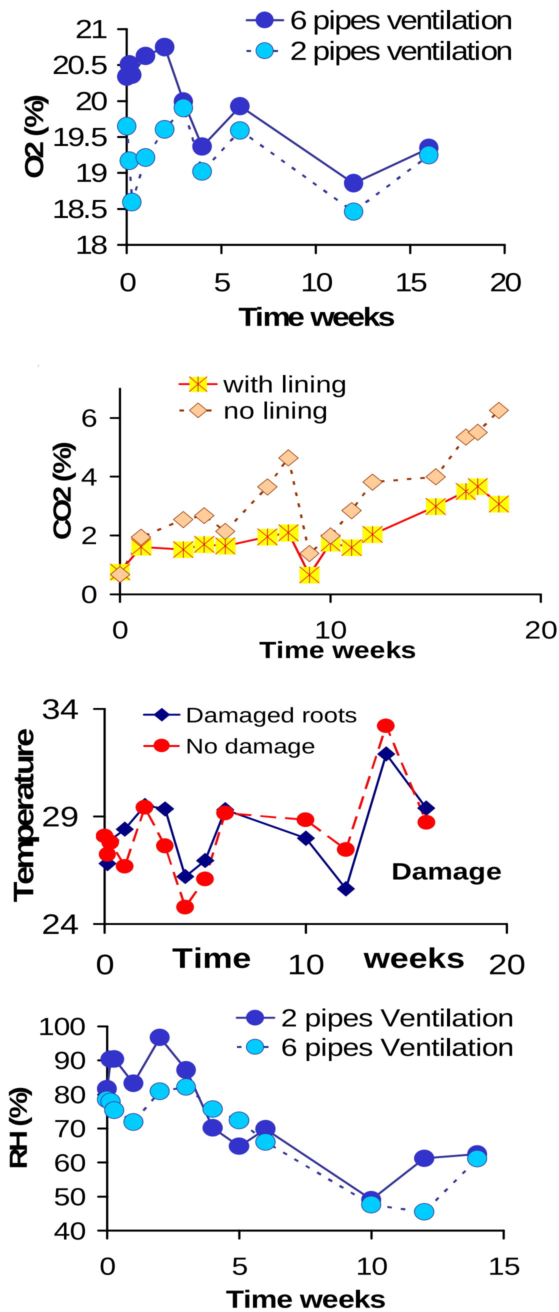

Figure 2: Changes in environmental conditions with pit and clamp stoes of sweet potato during storage in the Lake Zone of Tanzania. Figures show effect of ventitlation, lining and damage on selected environmental conditions (oxygen level, carbon dioxide level, temperature and relative humidity).

after two weeks. Many of the stores showed significant sprouting, sometimes even large green patches of green leaves could be seen outside of the stores. Susceptibility to sprouting was significantly affected by cultivar ($p < 0.005$ in week 4) and Sinia B was most susceptible for it (Figure 3). Less sprouting occurred when stores were lined with dried grass. Pits had a higher rate of sprouting than clamps. There was a

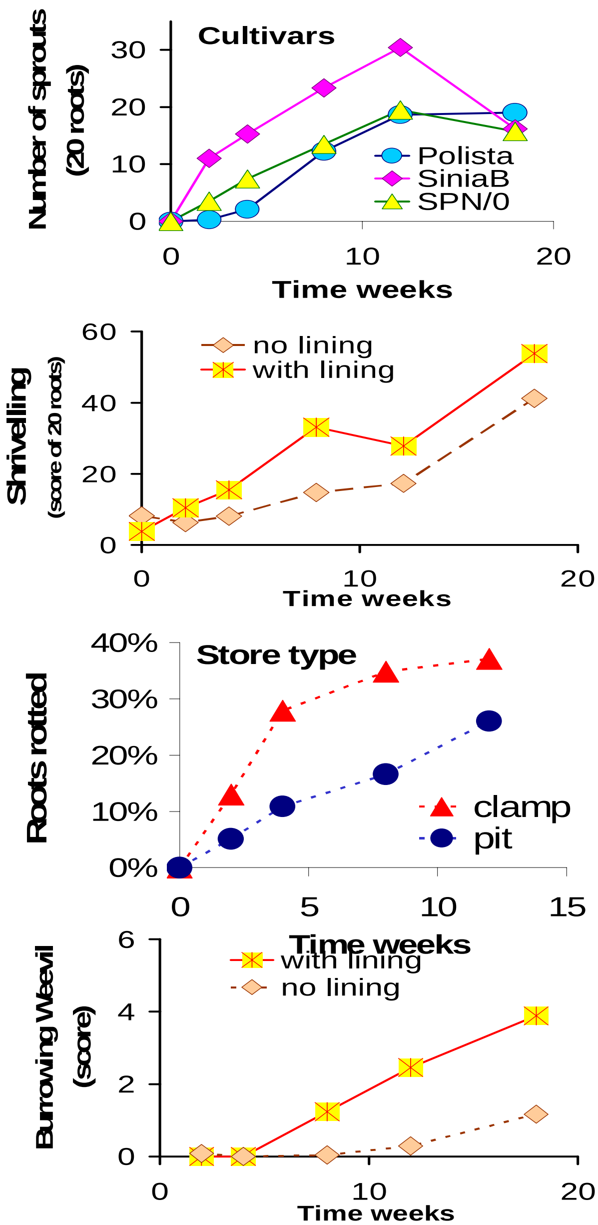

Figure 3: Changes in quality of sweet potato roots in pit and clamp stores in the Lake Zone of Tanzania. Figures show effect of variety, lining and store type on sprouts, shrivelling, rotting and burrowing weevil.

relationship between the level of sprouting and the level of rotting (Figure 4).

The levels of shrivelling, expressed as a score during external evaluation, were significantly higher for roots from stores lined with dried grass (Figure 3). The trend for shrivelling had very low occurrences up until week 12 after which shrivelling and rots dramatically increased, the greatest increase being in the lined stores (Figure 3). The levels of shrivelling increased during storage for all stores. Store design did not have a consistent effect on the level of shrivelling. Slightly more shrivelling was observed with grass lining, and ventilation had a slight effect in the first eight weeks. Polista was overall slightly more susceptible to shrivelling than the other varieites.

There was significantly more deep weevil (*Cylas* spp.) infestation in stores with dried grass lining at 8, 12 and 18 weeks ($p < 0.05$). Sweet potato weevil also increased more in the lined stores but this increase occurred from week 4 onwards whereas for unlined stores, the increase was delayed until after week 12 (Figure 3).

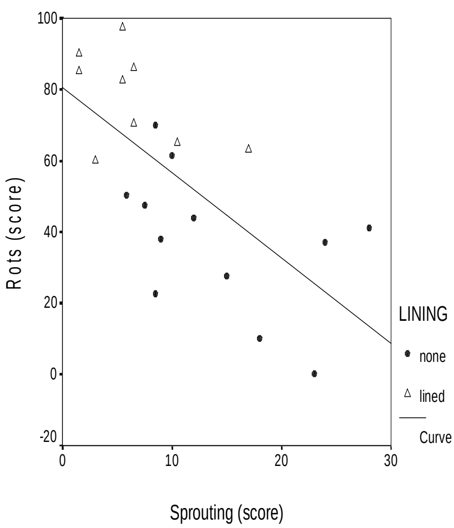

Figure 4: Relationship between rots and sprouting in sweet potato stored in pits and clamps with and without grass linings in the Lake Zone of Tanzania.

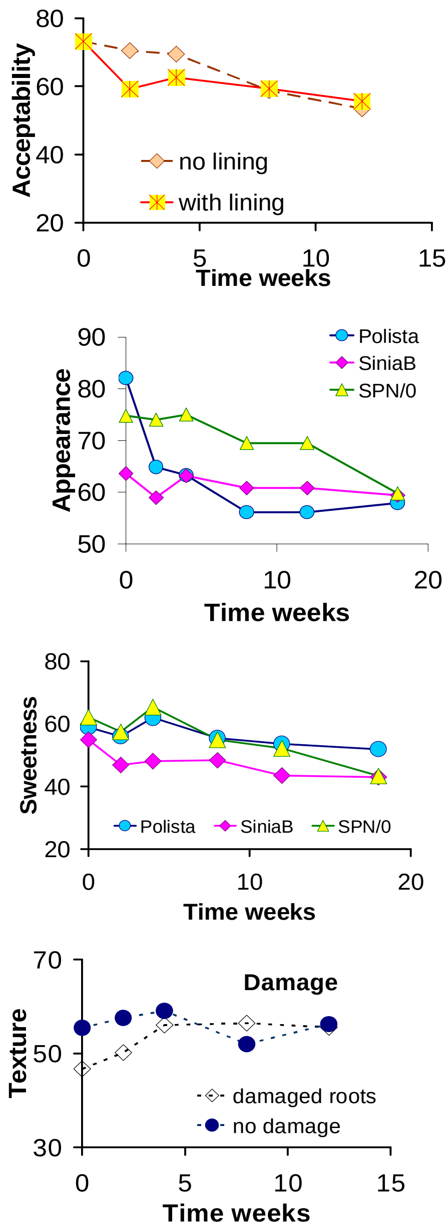

Figure 5: Changes in selected sensory properties of sweet potatoes stored in pits and clamps in the Lake Zone of Tanzania. Figures show effect of lining, variety and damage on sensory properties over time.

Taste, smell and acceptability were affected by cultivar, damage and lining especially after 2 and 4 weeks of storage. Cultivar had a highly significant effect after 4 weeks ($p < 0.005$). Taste scores increased for

SPN/0 since harvesting from 72 to 73.4 while it had decreased for Sinia B from 65 to 50.7. For Polista a slight decrease in scores was noted from 69 to 67.6. A similar pattern was observed for smell. Damage only affected taste, smell and acceptability at 0 ($p < 0.05$) and 2 weeks ($p < 0.01$) and damaged roots scored lower for all sensory tests. Grass lining had a significant negative effect on these sensory characteristics at 2 and 4 weeks.

Cultivar had significant effect on the inside and outside colour and appearance of the roots, with SPN/0 keeping the best appearance during storage (Figure 5). Undamaged roots gave a significant higher score for these characteristics immediately after harvesting ($p < 0.001$) and in week 8 ($p < 0.05$). Lining reduced the scores from appearance and colour significantly ($p < 0.01$) in week 2 (Figure 5).

Cultivar had significant effects on the sweetness and flouriness of the roots (Figure 5). This was significant at four weeks for flouriness ($p < 0.05$) and sweetness ($p < 0.005$). Both SPN/0 and Polista developed these tastes well during storage: a small reduction in sweetness after two weeks, increasing to scores higher than at harvesting time at four weeks. For Sinia B these characteristics did not develop so much during storage.

Stickiness, texture and chewiness tended to increase during storage. Stickiness was not affected by any of the design factors. Cultivar had a significant effect on texture and chewiness in weeks 2, 4 and 8. The scores for texture and chewiness of Polista decreased during storage, while it increased for SPN/0. Damage resulted in lower texture and chewiness scores in weeks 2 and 4 (Figure 5). Lining reduced chewiness of roots after two weeks.

Discussion

In order to determine the best strategy for storage it is important to determine which characteristic is most important for root quality. Previous work has indicated that weight loss is very important to determine the shelf life of roots (Rees, 2003b). Van Oirschot *et al.* (2000b) estimated that a rough guidance to saleability of roots is that with up to 20% weight loss sweet potato roots are still saleable. When the level of weight loss was 35% or greater they will become unmarketable. The weight losses recorded here, suggests that after 12 weeks, when weight losses are up to 12% roots can still be marketed. The estimated market value of the roots may decrease substantially during storage, and the value was less than 50% after 8 weeks storage. Thereafter the values were too low and missing data meant that the statistical analysis was not possible. A top ten of estimated market value roots included mainly undamaged roots (8), of the pit type (7). Six out of 10 had no lining and other 6 out of 10 no ventilation. The cultivar Sinia B was in 6 of the top ten stores, while SPN/0 only appeared once.

The results suggest that weight loss can be limited by not lining the stores. As weight loss is also affected by relative humidity it can be argued that reduced ventilation would lead to increased relative humidity, leading to reduced weight loss.

Ventilation seems especially important during the first two weeks of storage. This would appear to prevent too large an increase in temperature and build up of carbon dioxide, which would lead to anaerobic respiration. Later ventilation should be reduced, as it may reduce the relative humidity and increase water loss from the roots and lead to shriveling.

The temperatures measured and the RH should be high enough for wound healing to take place (van Oirschot *et al.* 2002). However, old wounds of damaged roots have a higher rate of water loss then the native periderm (van Oirschot *et al.* 2000a). Therefore it is recommended to keep damage as low as possible.

The dry matter content of roots is an important quality characteristic for sweet potato in East Africa, and has resulted in specific breeding programmes (Rees *et al.* 2003a). High dry matter after storage may however indicate desiccation. This may have been the case in the lined stores with dried grass that had an average DM of % in comparison with unlined stores. Lining may have contributed to lower RH, and therefore increased rate of water loss and reduced levels of wound healing, which resulted in higher levels of desiccation. High respiration levels of carbon dioxide in the stores and high weight loss for the roots indicated deterioration during storage. This was most strongly associated with damaged roots as opposed to good quality ones. Although a high dry matter content is a plus, it may also indicate water loss of the roots and shriveling. Good roots sprouted often. The question is whether sprouting is desirable or not.

Sprouting was in general an indication of good quality roots. Figure 4 illustrates the significant (P=0.001, R =-0.670) inverse correlation between rotten roots and sprouting. This illustrates the practical visual importance of sprouting in the stores because this indicates healthy roots as opposed to rotten/shrivelled ones. The points in the figure are identified as either coming from a lined or unlined store and also shows that roots are healthier in unlined stores. A related study monitored the effect of store type (pit or clamp), shade (shaded under a tree or located in direct sunlight) and pre-treatment with chemical fungicide on sweet potato storage. Locating the stores in the shade under a tree improved market value. Store type was found to be not important (Tomlins and Ndunguru 2001). On farm studies revealed that farmers liked pits because of safety and clamps because they were easier to build.

Sweet potato is consumed as a food source and so the sensory properties of the produce is very important. These studies have shown that good quality roots can still be obtained after storage.

Conclusions

The design factor with most pronounced effect on storage was lining with dried grass. Roots from lined stores had a lower estimated market values, higher levels of shriveling and more often deep weevil infestation. Lining also increased oxygen levels and reduced carbon dioxide levels. After 12 weeks, weight losses of roots were high, and the acceptability decreased. Very good sensory properties were obtained up to four weeks of storage. Cultivar differences for storage success exist and both SPN/0 and Polista can be used. Storage should only be carried out using good quality roots. Store type (pit or clamp) or ventilation did not have a consistent effect on shelf-life and suggests that any combination of these designs can be used. Some ventilation is necessary for gas exchange and to avoid build up of high levels of carbon dioxide, but high ventilation reduces the humidity. Roots in clamps more frequently showed rotting in the trials on station, but in subsequent on-farm trials they were as successful as pits.

Roots are more likely to be secure from animals (snakes, rats) in pits while clamps are easier to build, but require more materials.The positioning of stores is crucial.They must be positioned in the shade with good drainage. Cultivar had a relatively small impact on storage with polista and SPN/O cultivars leading to slightly improved shelf life. These cultivars also had significantly lower oxygen and higher volatile sulphur compounds at the 8 weeks of storage. This indicates possible differences between the cultivars with respect to curing and wound healing.

Acknowledgements

This publication is an output from research projects funded by the United Kingdom Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of DFID *[Crop Post-Harvest Research Programme R6507, R7495 and R7520].*

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