Changes in β-carotene, dry matter, sugar and starch content in two orange-fleshed sweetpotato (*Ipomoea batatas* (L.) Lam) cultivars as influenced by curing and household-level storage methods

Richard A. Atuna[1], Edward E. Carey[2], Jan W. Low[3] Tawanda Muzhingi[3], Daniel Mbongo[3] and Francis K. Amagloh[4*]
[1]Department of Biotechnology and Molecular Biology, University for Development Studies, Tamale, Ghana, richtuna024@gmail.com
[2]International Potato Center, Kumasi, Ghana, e.carey@cgiar.org
[3]International Potato Center, Nairobi, Kenya, j.low@cgiar.org
[3]International Potato Center, Nairobi, Kenya, T.Muzhingi@cgiar.org
[3]International Potato Center, Nairobi, Kenya, D.Mbongo@cgiar.org
[4]Department of Food Science and Technology, University for Development Studies, Tamale, Ghana, fkamagloh@uds.edu.gh
* Author to whom correspondence should be addressed; E-Mail: fkamagloh@uds.edu.gh
Tel.: +233-(0) 26-257-7434

ABSTRACT
The effects of three curing and two household-level storage methods (sand box and heap) on the compositional quality of two orange-fleshed sweetpotato cultivars were investigated for two successive years. The curing treatments were: in-ground/dehaulming, field-piling and uncured. Roots from the curing treatments were stored in either sand box or heap methods. The β-carotene content of "Apomuden" and "Nangungungu" respectively ranged from 13.80 to 28.29 mg/100 g and 11.33 to 17.20 mg/100 g for both years with "Apomuden" having a significantly ($p < 0.001$) higher β-carotene content. "Apomuden" also had significantly higher ($p < 0.05$) fructose, glucose and sucrose content compared to "Nangungungu". However, "Nangungungu" had higher starch (54.86 to 56.16% *vs*. 46.16 to 46.30%, respectively) and dry matter content (30.43 to 32.89% *vs*. 25.05 to 25.62%, respectively) than "Apomuden". Curing did not have a significant ($p = 0.352$) influence on the β-carotene content of roots except for the second year where field-piled cured roots in storage had a significantly higher β-carotene content (24.96 mg/100 mg; $p = 0.007$) compared with stored roots from the dehaulmed (22.26 mg/100 g) and uncured (21.01 mg/100 g) treatments. The sand box and the heap storage methods respectively resulted in 10% and 19% decline in β-carotene after 2 months of storage. This indicates that, β-carotene retention is better in the sand box relative to the heap storage and should be recommended for small scale storage of sweet potato in Ghana.

Key words: Curing, Storage, Sweetpotato, β-carotene

INTRODUCTION

Sweetpotato (*Ipomoea batatas* (L) Lam) is a widely grown crop in most countries in sub Saharan Africa. In terms of production, it is globally ranked as the third most important food crop and fourth in Ghana (Faostat3.fao.org, 2013). Over 95% of the world's sweetpotato crop cultivation is done in developing countries (Dayal *et al*., 1991). The United States and Japan are among the developed countries with significant level of production (Crissman *et al*., 2007). There are several cultivars of sweetpotato with a range of flesh colours, from white, cream, yellow, orange, to purple (Burri, 2010); (Bovell-Benjamin, 2007). The white- and cream-fleshed cultivars are most commonly grown and eaten in most parts of northern Ghana. However, the orange flesh sweetpotato (OFSP) cultivars are currently making inroads in the country and the sub region due to several nutritional and health campaigns.

Sweetpotato, especially the orange-fleshed cultivars have been reported to contain significant amounts of β-carotene (a provitamin A) (Hagenimana and Low, 2000), and other important nutrients, capable of tackling vitamin A deficiency (VAD) which is a public health concern in most developing countries (World Health Organization, 2009). The prevalence of subclinical VAD in Ghana is high; almost three-quarters of children under age five being deficient, with 35% of them classified as severe (serum retinol <10 μg/dL) (World Health Organization, 2009). Consumption of boiled and mashed OFSP by young (≤ 10 years) school children in South Africa improved their vitamin A status (van Jaarsveld *et al*., 2005).

Therefore, there have been a global drive by local and international organisations for the inclusion of OFSP in African diets (Kapinga *et al*., 2005) as a food-based approach to address VAD. Unfortunately, the short shelf life (3 weeks) of OFSP cultivars (Rees *et al*., 2001) in particular may limit availability of fresh roots for consumption and this could jeopardize the efforts being made to address VAD.

Curing and storage play key roles in ensuring the availability of fresh sweetpotato roots for household consumption. Curing is a post-harvest practice whereby storage roots are held under moderate temperature (29-33°C) and high relative humidity (90-95%) for about a week prior to storage (Edmunds *et al*., 2008). The practice

promotes wound healing through formation of wound periderm (Woolfe, 1992) and could help extend the shelf life of the storage roots.

Sadly, unlike developed countries, in low-income tropical countries, the high initial and running costs of suitable curing and storage structures serves as a disincentive for curing. However, an incidental curing may occur in the tropics as ambient conditions are reported to be similar to the ideal curing conditions (Ravi *et al*., 1996) (Woolfe, 1992). Field-piling, an indigenous curing method have been reported to promote wound healing and linked with good storability in sweetpotato roots (Atuna *et al*., 2017). In-ground curing (dehaulming), an alternative to controlled atmosphere postharvest curing (Tomlins *et al*., 2002) has been reported to reduce skinning injury in sweet potato by 62% after removal of sweetpotato canopy 14 days prior to harvest (La Bonte and Wright, 1993).

Although curing is important, reports show that the temperature, curing and storage time may affect phytochemical content of agro-produce (Grace *et al*., 2013). Furthermore, curing and storage may induce changes in the β-carotene, dry matter (Vimala *et al*., 2013), sugar (Adu-Kwarteng *et al*., 2014) and the starch contents (Scott and Mathews, 1957) (Takahata *et al*., 1995) of the storage roots. For instance, five out of six genotypes of sweetpotato showed increased total sugars during the earlier stages of storage and maintained fairly constant levels with further storage (Zhang *et al*., 2002). However, Morrison *et al*. (1993) reported slight decline in total sugar concentration with storage. A good curing or storage method should not only preserve, protect and maintain the physical integrity of the produce but also its nutritive value.

The aim of this study was to assess the changes in β-carotene, dry matter, sugar and starch content in two OFSP cultivars after being cured using either field-piled or in-ground and then stored using two household-level storage methods: sand box storage (improved method) and the, current farmer's storage method, the heap storage.

MATERIALS AND METHODS

Field work (storage root production and curing) was carried out in the fields of Council for Scientific and Industrial Research-Savanna Agricultural Research Institute, Nyankpala, and Bontanga Irrigation Scheme, Kumbungu. The storage experiment was carried out at University for Development Studies, Nyankpala Campus from December, 2014 to February 2015 and November 2015 to January 2016 for the first and second years respectively.

The experimental deign used was a 3 x 2 x 2 factorial in a completely randomized design arrangement in triplicates. Thus three curing methods: in-ground, field-piled and uncured; two cultivars: "Apomuden" and "Nangungungu"; and two storage methods: Heap and sand box storage.

Curing and storage methods

In-ground curing by dehaulming (Plate 1a) was done by removing the foliage, leaving only 30 cm of the vines from the base seven days prior to harvest. In the field-piled curing (Plate 1b) treatment, roots were carefully harvested, trying to avoid wounding, sorted and heaped on the field and covered with fresh sweetpotato vines. Freshly harvested roots (uncured), together with roots from the two curing treatments were stored in either sand box (Plate 2a) or under heap storage methods (Plate 2b) in two successive years.

Plate 1a: In-ground/dehaulming method

Plate 1b: Field-piled curing method

Plate 2a: Sand box storage (proposed method)

Plate 2b: Heap storage (farmers' method)

Sand box storage

The sand boxes were built with laterite in a thatched-roofed room with dimensions of 0.5 m × 0.5 m × 0.6 m. Five kilograms of roots of each cultivar was tied in a net bag and carefully stacked in the sand box and air-dried cold sand was then spread on top. In the second year, 15 kg of roots from each of the two cultivars was stored. Out of these, 5 kg was tied in a net bag for monitoring weight loss, rots, weevil damage and sprouts.

Heap storage (farmers' method)

Five kilograms of roots of each cultivar was tied in a net bag. These roots were then placed on straw, and then covered with the same straw followed by sprinkling of water. The sprinkling of water was continued at two days interval. In the second year about 15 kg of roots from each of the two cultivars was stored.

The β-carotene analysis of stored roots was carried out in the first year using Near Infrared Reflectance Spectroscopy, XDS Rapid Content Analyser (Hoganae, Sweden) at the Sweetpotato Quality and Nutrition Laboratory for Post-harvest Technology in Fumesua, Kumasi, Ghana. In the second year, the β-carotene analysis was done in the Food and Nutrition Laboratory, International Livestock Research Institute, Kenya.

All extraction of carotenoids from OFSP fresh roots were done under yellow-golden lights in FANEL. Extraction and chromatographic separation of carotenoids was performed according to the previously published methods with some modifications (Riso and Porrini, 1997). Extraction of carotenoids from OFSP fresh roots was performed using direct extraction with methanol and tetrahydrofuran (THF) as published previously (Muzhingi *et al*., 2008). Briefly, 1 g of OFSP fresh root grates was extracted for carotenoids by incubation with 10 mL methanol for 10 mins at 85°C and vortexed for 1 min at 5 min intervals. Afterwards, the mixture was homogenized for 30 s in an ice bath. The mixture was centrifuged at 800-xg for 5 min. The methanol layer was transferred into a 50 mL volumetric flask and the extraction was repeated four times with 10 mL of THF, followed by vortexing and centrifugation. The THF layers were combined with the methanol layer and the volume brought up to 50 mL. One mL of the extract was dried under a gentle stream of nitrogen using an N-Evap System (Organomation, Berlin, MA). The dried test tube contents were re-constituted in 1 mL of ethanol, sonicated for 1 min, vortexed for 30s and transferred into a 2-mL HPLC vial. Then 50 µL was injected into the HPLC system for analysis. The HPLC systems consisted of a Shimadzu CBM -20A Prominence Bus Module, SPD –M20A Prominence Photo Diode Array (PDA), DGU 20A5R Prominence Degasser Module, SIL 30AC Nexera Autosampler, two Nexera X2 LC 30AD pumps, a YMC Carotenoid S-3µm, 150 x 3.0mm I.D column, and Shimadzu LabSolutions data management software. The HPLC mobile phase was methanol: methyl-tert-butyl ether: water (83:15:2 v/v/v, with 1.5% ammonium acetate in the water, solvent A) and methanol: methyl-tert-butyl ether: water (8:90:2 v/v/v, with 1% ammonium acetate in the water, solvent B). The gradient procedure at a flow rate of 1 ml/minute was as follows: 1) 90% solvent A and 10% solvent B for 5 minutes; 2) a 12-minute linear gradient to 55% solvent A; 3) a 12-minute linear gradient to 95% solvent B; 4) a 5-minute hold at 95% solvent B; and 5) a 2-minute gradient back to 90% solvent A and 10% solvent B. Carotenoids were monitored at UV maximum absorption of 450 nm and DAD spectral data from 250 to 550 nm were stored to examine spectrum peaks for carotenoids. Carotenoids were quantified by determining peak areas in the HPLC chromatograms calibrated against known amounts of standards.

The dry matter, fructose, glucose, sucrose and starch were analysed using the NIRS at the Sweetpotato Quality and Nutrition Laboratory for Post-harvest Technology in Fumesua, Kumasi, Ghana.

RESULTS

Total sugar

"Apomuden" had a significantly higher ($p < 0.001$) level of glucose, fructose and sucrose compared with "Nangungungu". For the two years, the glucose content of "Apomuden" ranged from 6.19 to 6.78%, and fructose 3.74 to 4.23%, almost twice that of "Nangungungu" for both glucose and fructose (Table 1 and 2). The sucrose content followed a similar trend with that of "Apomuden" ranging from 20.05 to 20.74% and "Nangungungu" 16.74 to 18.97%. Both glucose and fructose level of cultivars and storage roots either cured or uncured generally decreased over storage time while the sucrose levels increased for 2015 (Table 3). A similar observation was made in 2014 before and after storage in sand box. The decline in glucose content of roots stored in the heap and sand box was 40 and 26%, respectively over 2-months period of storage. Fructose on the other hand declined by 39% in heap storage and 32% in the sand box storage over 2-months storage period.

Starch

The starch content of sweet potato cultivars varied significantly ($p < 0.001$) with "Nangungungu" having the higher starch content ranging from 54-56%, almost 1.2 times higher than "Apomuden" for both years (Table 1 and 2). However, neither curing nor storage types significantly ($p > 0.05$) influenced the starch content of roots for the two years. On the other hand, the interaction between cultivar and storage time as well as between curing types and storage time was significant ($p < 0.05$) while the combined effect of storage type and time was not significant ($p > 0.05$) as shown in Table 4 and 5. Although not significant ($p > 0.05$), there was generally a marginal decline in the starch content as storage progressed.

Dry matter

Generally, dry matter content of stored roots increased as storage time progressed. However, cultivars varied markedly ($p < 0.001$) in dry matter content with "Nangungungu" having higher dry matter content than "Apomuden" in both years (Table 1 and 2). The curing type had a significant ($p = 0.011$) effect on the dry matter content in the first year. Conversely, in the subsequent year, curing type did not have a significant ($p = 0.092$) effect on the dry matter content of roots. The dry matter content of roots stored in the heap method was significantly higher (29% *vs*. 27%, respectively; $p < 0.001$) compared with the sand box storage (Table 2). During the 2 month period of storage, the dry matter content of storage roots (irrespective of the cultivar) in heap storage increased by 15%, almost 2.4 times more than sand box storage.

β-carotene

The β-carotene content of "Apomuden" and "Nangungungu" for 2014 and 2015 is respectively presented in Table 1 and 2. "Apomuden" had a significantly ($p < 0.001$) higher β-carotene compared with "Nangungungu" in both years. Field-piled curing in 2014 had a significantly higher ($p = 0.007$) β-carotene content compared with dehaulmed and uncured roots. However, in 2015 (Table 2), curing type had no significant influence on the β-carotene content of cultivars.

A paired sampled t-test showed no significant ($p = 0.124$) influence on β-carotene before and after storage in sand box (Table 1) for year 2014. The roots stored in the heap storage method all got rotten and samples could not be taken for analysis in 2014, therefore, the two storage methods could not be compared. However, in 2015, storage in the sand box showed a significantly (12.93 mg/100 g *vs.* 12.20 mg/100 g; $p = 0.015$) higher β-carotene content compared with the heap storage (Table 2). The β-carotene content of "Apomuden" and "Nangungungu" stored in either sand box or by the heap storage methods over a 2-months period in 2015 showed significant ($p < 0.001$) differences. For both cultivars, the β-carotene content generally declined over the 2-months storage period.

Storage type interacting with length of storage, showed some significant ($p = 0.045$) difference in β-carotene during the second year. The β-carotene content ranged from 10.77-13.74 mg/100 g for heap storage and 12.25-14.00 mg/100 g for sand box storage. The decline in β-carotene content of storage roots was 10% in the sand box while in the heap storage; the decline was 19% (Table 2). These indicate better β-carotene retention in the sand box storage compared with the heap storage method.

DISCUSSION

Total sugar

Both glucose and fructose levels of cultivars and storage roots either cured or uncured generally decreased over time while the sucrose levels increased. The finding agrees with Zhang *et al.* (2002) who reported that both reducing fructose and glucose and non-reducing sucrose sugar vary widely with sweet potato genotype. This inverse relationship between the monosaccharides, glucose and fructose and disaccharide, sucrose could be as a result of the synthesis of sucrose during storage from glucose and fructose since the two monosaccharide units form sucrose. In wild-type potato tubers, water stress led to the synthesis of sucrose (Geigenberger *et al*., 1999). This observation could also be linked to the increased levels of sucrose during storage as observed in this current study. Our findings support Chattopadhyay *et al.* (2006) who reported that the roots stored in the sand medium had better retention of sugar compared with exposed roots and sawdust storage methods.

Starch

Our data shows that the starch content of sweet potato cultivars varied significantly, with "Nangungungu" having the highest starch content (56%), about 1.2 times higher than that of "Apomuden". The findings support earlier works (Zhang *et al*., 2002) that sweetpotato genotypes vary in starch content. The data further shows that starch constitute more than half of the total dry matter portion of sweetpotato and this corroborates previous findings that the dry matter portion of sweetpotato is

mainly starch (Rukundo *et al*., 2013) (Woolfe, 1992). Thus, the higher the starch content, the higher the dry matter. This was confirmed in this study as the dry matter content of "Nangungungu" was higher than that of "Apomuden".

Curing and storage types did not to affect the starch content of roots. However, the interaction between cultivar and storage duration was found to be significant. The findings in this study supports previous works (Zhang *et al*., 2002) and (Chattopadhyay *et al*., 2006) who reported a slightly declined starch content during storage and this varied among genotypes. The likely reason for the declined trends could be mainly due to breakdown of starch to sugars by the activities of α-amylase enzymes. The α-amylase activity among four lines of sweetpotato was related to increase in dextrin content and decreased starch content during storage (Zhang *et al*., 2002) confirming the above observation. Furthermore, the declined starch content may also be attributed to starch being used as a respiratory substrate during storage (Dandago and Gungula, 2011).

Dry matter

Generally, dry matter content of stored roots increased as storage progressed due to depletion of moisture (Vimala *et al*., 2013). The same pattern was observed in this study. The higher dry matter content of "Nangungungu" after curing and storage compared to , , "Apomuden", could be related to its higher starch content as reported in other studies (Rukundo *et al*., 2013) (Woolfe, 1992). The variation between "Nangungungu" and "Apomuden" in terms of starch and dry matter content could also be due to varietal differences (Tomlins *et al*., 2012). The high dry matter content of the uncured and stored roots as compared with the cured ones could be due to rapid moisture depletion of the uncured ones compared with the field-piled and in-ground cured and stored roots during the first year. However, in the second year, curing type had no effect on the dry matter of roots. Storage type on the other hand, had an effect on the dry matter content as the heap method recorded higher dry matter content relative to the sand box method. The likely reason for this observation could be that, the sand medium protected the roots well enough to reduce respiration and evapotranspiration, hence reduced moisture loss. The findings support previous studies elsewhere (Chattopadhyay *et al*., 2006) who

showed that the medium of storage had a remarkable influence on the dry matter content of roots irrespective of the cultivar. Similar findings were made after 50 days when sweetpotato roots were stored in either sand medium, sawdust or under ambient condition (Chattopadhyay *et al*., 2006).

β-carotene

"Apomuden", the released variety in Ghana being higher in β-carotene makes it superior to "Nangungungu" when considering them as food-based crops to address VAD. The results support previous studies that showed that sweetpotato cultivars vary widely in β-carotene content (Grace *et al*., 2013); (Vimala *et al*., 2011). However, it is worth highlighting that over the 2-months storage period, the β-carotene content of "Apomuden" reduced drastically, about 19% compared with "Nangungungu" that recorded about 2.7% loss of its β-carotene. This observation could be attributed to varietal difference. Thus some varieties are able to retain their β-carotene content better than others. The finding conforms to the findings of (De Moura *et al*., 2015) who reported that two sweet potato varieties, MGCL01 and Resisto, were significantly different in carotene retention during storage.

In this current study, curing was found to have an influence on β-carotene content of roots only in the first year. This data confirms earlier studies (Grace *et al*., 2013) that, carotene levels increased during curing and storage. This is possible because, carotenogenesis is continuous if fruits and vegetables remain intact after harvest (Rodriguez-Amaya, 1997).

In the first year, all the roots stored in the heap storage method got rotten even before samples could be taken for the β-carotene assay due to low root quality during harvest. The quantities of storage roots were few; hence selections of wholesome roots were not strictly adhered to. This confirms the recommendation of the relevance of selection of sound roots of sweetpotato for storage (Ray and Ravi, 2005). However, in the subsequent year, both the sand box and the heap storage methods had roots for β-carotene assay at 2-months after storage, because the yields were better and selection of wholesome roots was strictly adhered to. The data implies that the sand box storage method retained β-carotene better than the heap

storage method. The current findings corroborates previous works by Chattopadhyay *et al.* (2006) who reported better β-carotene retention in sand medium compared to sawdust and ambient storage methods. It has also been reported elsewhere that pit storage of sweetpotato roots resulted in high β-carotene retention relative to ambient and dark room storage conditions (Tumuhimbise *et al*., 2010). High temperature (Dutta *et al*., 2005) or a combination of temperature and cultivar type (Chattopadhyay *et al*., 2006) has been cited for the degradation of β-carotene in sweetpotato. Therefore, the sand medium in the study current could have provided favourable temperature that minimized the degradation of β-carotene compared to the heap.

CONCLUSION

The β-carotene content was higher in "Apomuden" than "Nangungungu". However, the degradation in storage was higher in "Apomuden" than "Nangungungu". The sand box and the heap storage methods respectively resulted in 10% and 19% decline in β-carotene after 2-months of storage. Curing and storage types had no adverse influence on the starch content of stored sweetpotato roots. "Nangungungu" had the highest dry matter and starch contents at harvest, curing and in storage. This indicates that, β-carotene retention is better in the sand box relative to the heap storage and should be recommended for small scale storage in Ghana.

Acknowledgements

Funding received from International Potato Center under the project SASHA II: Sweetpotato Action for Security and Health in Africa is heartily valued and acknowledged.

REFERENCES

Adu-Kwarteng, E., Sakyi-Dawson, O. E., Ayernor, S. G., Truong, V.-D., Shih, F. F. & Daigle, K. (2014). Variability of sugars in staple-type sweet potato (Ipomoea batatas) cultivars: the effects of harvest time and storage. 17, 410-420.

Atuna, A. R., Carey, E. E., Low , W. J. & Amagloh, K. F. (2017). Wound healing and dry matter content of orange-fleshed sweetpotato cultivars as influenced by curing methods. Open Agriculture, 2, 274-279.

Bovell-Benjamin, A. C. (2007). Sweetpotato: Review of its past, present, and future role in human nutrition. Advances in Food and Nutrition Research, 52, 1-59.

Burri, B. J. (2010). Evaluating sweetpotato as an intervention food to prevent vitamin A deficiency. 10.

Chattopadhyay, A., Chakraborty, I., Kumar, P. R., Nanda, M. K. & Sen, H. (2006). Uncontrolled storage behaviour of sweet potato (Ipomoea batatas L. Lam). Journal of Food Science and Technology-Mysore, 43, 41-45.

Crissman, C., Anderson, P., Fuglie, K., Kapinga, R., Lemaga, B., Devaux, A., Thiele, G., Ilangantileke, S. & Bussink, C. (2007). Trends in the potato and sweetpotato sectors in sub-Saharan Africa and their contribution to the Millennium Development Goals. In: Kapinga, R. E., Kingamkono, R., Msabaha, M., Ndunguru, J., Lemaga, B. & Tusiime, G. (eds.) Tropical Root and Tuber Crops: Opportunities for Poverty Alleviation and Sustainable Livelihoods in Developing Countries:Proceedings of the Thirteenth Triennial Symposium of the International Society for Tropical Root Crops (ISTRC). Arusha, Tanzania: International Society for Tropical Root Crops.

Dandago, M. A. & Gungula, D. T. (2011). Effects of various storage methods on the quality and nutritional composition of sweet potato (Ipomea batatas L.) in Yola Nigeria. International Food Research Journal.

Dayal, T. R., Mehra, S. K. & Scott, G. J. (1991). Global perspective of sweetpotato production and use. In: DAYAL, T. R., SCOTT, G. J., KURUP, G. T. & BALAGOPALAN, C. (eds.) Sweetpotato in South Asia: Postharvest handling, processing, storage and use. India: CIP and CTCRI.

De Moura, F. F., Miloff, A. & Boy, E. (2015). Retention of provitamin A carotenoids in staple crops targeted for biofortification in Africa: cassava, maize and sweet potato. Critical reviews in food science and nutrition, 55, 1246-1269.

Dutta, D., Raychaudhuri, U. & Chakraborty, R. (2005). Retention of [beta]-carotene in frozen carrots under varying conditions of temperature and time of storage. African Journal of Biotechnology, 4, 102.

Edmunds, B. A., Boyette, M. D., Clark, C. A., Ferrin, D. M., Smith, T. P. & Holmes, G. J. (2008). Postharvest handling of sweetpotatoes, North Carolina State University Cooperative Extension Service.

Faostat3.Fao.Org. (2013). (Food and Agriculture Organisation of the United Nations Statistics Division) [Online]. FAO. Available: http://faostat3.fao.org/download/Q/QC/E [Accessed 20th October, 2015].

Geigenberger, P., Reimholz, R., Deiting, U., Sonnewald, U. & Stitt, M. (1999). Decreased expression of sucrose phosphate synthase strongly inhibits the water stress-induced synthesis of sucrose in growing potato tubers. The Plant Journal, 19, 119-129.

Grace, M. H., Yousef, G. G., Gustafson, S. J., Truong, V.-D., Yencho, G. C. & Lila, M. A. (2013). Phytochemical changes in phenolics, anthocyanins, ascorbic acid, and carotenoids associated with sweetpotato storage and impacts on bioactive properties. Food Chemistry 145, 717–724.

Hagenimana, V. & Low, J. (2000). Potential of orange-fleshed sweet potatoes for raising vitamin A intake in Africa. Food and Nutrition Bulletin, 21, 414-418.

Kapinga, R., Anderson, A., Crissman, C., Zhang, D., Lemaga, B. & Opio, F. (2005). Vitamin A partnership for Africa: A food based approach to combat vitamin A deficiency in sub-Saharan Africa through increased utilization of orangefleshed sweetpotato. Chron Horticult, 45, 12-4.

La Bonte, D. R. & Wright, M. E. (1993). Image analysis quantifies reduction in sweetpotato skinning injury by preharvest canopy removal. Hortscience, 28, 1201.

Morrison, T. A., Pressey, R. & Kays, S. J. (1993). Changes in α- and β-amylase during Storage of Sweetpotato Lines with Varying Starch Hydrolysis Potential. Journal of the American Society for Horticultural Science, 118, 236-242.

Muzhingi, Yeum, Qin & Tang (2008). Determination of carotenoids in yellow maize, the effects of saponification and food preparations. International journal for vitamin and nutrition research, 78, 112-120.

Ravi, V., Aked, J. & Balagopalan, C. (1996). Review on tropical root and tuber crops I. Storage methods and quality changes. Critical Reviews in Food Science and Nutrition, 36, 661-709.

Ray, R. C. & Ravi, V. (2005). Postharvest spoilage of sweetpotato in tropics and control measures, critical reviews in food science and nutrition. 45, 623-644.

Rees, D., Kapinga, R., Mtunda, K., Chilosa, D., Rwiza, E., Kilima, M., Kiozya, H. & Munisi, R. (2001). Effects of damage on market value and shelf-life of sweetpotato in urban markets of Tanzania. Tropical Science., 41, 1-9.

Riso, P. & Porrini, M. (1997). Determination of carotenoids in vegetable foods and plasma.

International journal for vitamin and nutrition research. Internationale Zeitschrift fur Vitamin-und Ernahrungsforschung. Journal international de vitaminologie et de nutrition, 67, 47-54.

Rodriguez-Amaya, D. B. (1997). Carotenoids and food preparation: the retention of provitamin A carotenoids in prepared, processed and stored foods, Citeseer.

Rukundo, P., Shimelis, H., Laing, M. & Gahakwa, D. (2013). Storage root formation, dry matter synthesis, accumulation and genetics in sweetpotato. Australian Journal of Crop Science, 7, 2054-2061.

Scott, L. B. & Mathews, W. A. (1957). Carbohydrate changes in sweet potatoes during curing and storage. Proceedings. American Society for Horticultural Science, 70, 407-18.

Takahata, Y., Noda, T. & Sato, T. (1995). Changes in carbohydrates and enzyme activities of sweetpotato lines during storage. Journal of Agricultural and Food Chemistry, 43, 1923-1928.

Tomlins, K., Ndunguru, G., Rwiza, E. & Westby, A. (2002). Influence of pre-harvest curing and mechanical injury on the quality and shelf-life of sweet potato (Ipomoea batatas (L.) Lam) in East Africa. Journal of Horticultural Science & Biotechnology, 77, 399-403.

Tomlins, K., Owori, C., Bechoff, A., Menya, G. & Westby, A. (2012). Relationship among the carotenoid content, dry matter content and sensory attributes of sweet potato. Food Chemistry, 31, 14-21.

Tumuhimbise, G., Namutebi, A. & Muyonga, J. (2010). Changes in microstructure, beta carotene content and In Vitro bioaccessibility of orange-fleshed sweet potato roots stored under different conditions. African Journal of Food, Agriculture, Nutrition and Development, 10.

Van Jaarsveld, J. P., Faber, M., Tanumihardjo, A. S., Nestel, P., Lombard, J. C. & Benadé, J. S. A. (2005). β-Carotene–rich orange-fleshed sweet potato improves the vitamin A status of primary school children assessed with the modified-relative-dose-response test. American Journal of Clinical Nutrition 81, 1080 –1087.

Vimala, B., Nambisan, B. & Hariprakash, B. (2013). Variability of Carotenoids and Dry Matter Content in Orange-fleshed Sweet Potato (Ipomoea batatas (L.) Lam.) During Storage. Journal of Root Crops, 37, 182.

Vimala, B., Sreekanth, A., Binu, H. & Wolfgang, G. (2011). Variability in 42 Orange-Fleshed Sweet Potato Hybrids for Tuber Yield and Carotene & Dry matter Content. Geneconserve, 40, 190-200.

Woolfe, J. A. (1992). Sweet potato: An untapped food resource, Cambridge University Press.

Cambridge, UK.

World Health Organization (2009). Global prevalence of vitamin A deficiency in populations at risk 1995–2005. WHO global database on Vitamin A deficiency. Geneva, World Health Organization, Geneva, Switzerland, WHO Press.

Zhang, Z., Wheatley, C. C. & Corke, H. (2002). Biochemical changes during storage of sweet potato roots differing in dry matter content. Postharvest Biology and Technology, 24, 317-325.

Table 1: Compositional quality (dry matter basis) of roots either cured/uncured and then stored under heap or sand box storage for nine weeks in 2014

	Root compositional quality (%)					
Cultivar	Fructose	Glucose	Sucrose	Starch	Dry matter	β-carotene
Apomuden	4.23 ± 0.21[a]	6.78 ± 0.32[a]	21.05 ± 0.93[a]	46.16 ± 1.00[b]	25.62 ± 0.48[b]	28.29 ± 0.68[a]
"Nangungungu"	1.93 ± 0.21[b]	3.19 ± 0.32[b]	18.97 ± 0.93[a]	54.81 ± 1.00[a]	32.89 ± 0.48[a]	17.20 ± 0.68[b]
p-value	< 0.001	< 0.001	0.125	< 0.001	< 0.001	< 0.001
Curing type						
Field-piled	3.19 ± 0.25[a]	5.28 ± 0.40[a]	22.15 ± 1.14[a]	49.00 ± 1.23[a]	29.55 ± 0.59[a]	24.96 ± 0.83[a]
In-ground	3.17 ± 0.25[a]	5.01 ± 0.40[a]	20.45 ± 1.14[ab]	49.73 ± 1.23[a]	27.79 ± 0.59[ab]	22.26 ± 0.83[ab]
Uncured	2.89 ± 0.25[a]	4.66 ± 0.40[a]	17.42 ± 1.14[b]	52.81 ± 1.23[a]	30.42 ± 0.59[b]	21.01 ± 0.83[b]
p-value	0.635	0.549	0.021	0.093	0.011	0.007
Storage type#						
Before	3.36 ± 1.69[a]	5.28 ± 2.75[a]	19.18 ± 4.60[a]	52.50 ± 7.09[a]	29.64 ± 3.82[a]	24.47 ± 6.44[a]
Heap¥	*	*	*	*	*	*
Sand Storage	1.80 ± 1.19[a]	4.69 ± 1.68[a]	20.83 ± 4.22[a]	48.47 ± 5.28[a]	28.86 ± 4.48[a]	21.02 ± 6.67[a]
p-value	0.258	0.445	0.270	0.063	0.595	0.124

Values (least square means SEM, $n = 3$). Least square means in the same category in a column with the same letter are not significantly different ($p > 0.05$)
#Values (least square means ± SD, $n = 3$)
¥No values because all roots stored in the heap rotted got rotten before samples were taken for analysis

Table 2: Compositional quality (dry matter basis) of roots either cured/uncured and then stored under heap or sand box storage for eight weeks in 2015

	Root compositional quality (%)					
Cultivar	Fructose	Glucose	Sucrose	Starch	Dry matter	β-carotene
Apomuden	3.74 ± 0.11^{a}	6.19 ± 0.15^{a}	20.74 ± 0.33^{a}	46.30 ± 0.41^{b}	25.06 ± 0.23^{b}	13.80 ± 0.22^{a}
"Nangungungu"	1.95 ± 0.11^{b}	3.53 ± 0.15^{b}	16.74 ± 0.33^{b}	56.16 ± 0.41^{a}	30.43 ± 0.23^{a}	11.33 ± 0.20^{b}
p-value	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Curing type						
Field-piled	3.20 ± 0.14^{a}	5.18 ± 0.19^{a}	17.98 ± 0.41^{b}	51.67 ± 0.51^{a}	28.19 ± 0.28^{a}	12.33 ± 0.27^{a}
In-ground	2.52 ± 0.14^{ab}	4.58 ± 0.19^{a}	18.47 ± 0.41^{ab}	51.39 ± 0.51^{a}	27.67 ± 0.28^{a}	12.51 ± 0.26^{a}
Uncured	2.80 ± 0.14^{b}	4.82 ± 0.19^{a}	19.78 ± 0.41^{a}	50.64 ± 0.51^{a}	27.37 ± 0.28^{a}	12.85 ± 0.25^{a}
p-value	0.003	0.075	0.007	0.343	0.092	0.352
Storage type						
Before	3.61 ± 0.23^{a}	6.22 ± 0.31^{a}	15.27 ± 0.62^{b}	52.16 ± 1.05^{a}	26. 08 ± 0.55^{b}	13.83 ± 0.32^{a}
Heap	2.35 ± 0.23^{b}	3.97 ± 0.31^{b}	20.79 ± 0.62^{a}	50.99 ± 1.05^{a}	29.59 ± 0.55^{a}	11.23 ± 0.34^{b}
Sand box	2.57 ± 0.23^{b}	4.39 ± 0.31^{b}	20.16 ± 0.62^{a}	50.55 ± 1.05^{a}	27.57 ± 0.55^{b}	12.42 ± 0.32^{c}
p-value	< 0.001	< 0.001	< 0.001	0.531	< 0.001	< 0.001
Cultivar*Storage						
Apomuden Heap	3.70 ± 0.16^{a}	6.07 ± 0.21^{a}	21.80 ± 0.47^{a}	45.77 ± 0.59^{a}	25.60 ± 0.30^{a}	13.65 ± 0.34^{a}
Apomuden Sand box	3.70 ± 0.16^{a}	6.31 ± 0.21^{a}	19.70 ± 0.47^{b}	46.84 ± 0.59^{a}	24.60 ± 0.30^{a}	13.94 ± 0.29^{a}
"Nangungungu" Heap	1.86 ± 0.16^{a}	3.39 ± 0.21^{a}	16.35 ± 0.47^{c}	56.94 ± 0.59^{b}	31.40 ± 0.31^{a}	10.74 ± 0.29^{a}
"Nangungungu" Sand box	2.03 ± 0.16^{a}	3.67 ± 0.21^{a}	17.13 ± 0.47^{c}	55.38 ± 0.59^{b}	29.50 ± 0.31^{a}	11.92 ± 0.29^{a}
p-value	0.806	0.930	0.004	0.030	0.171	0.141

Values (least square means ± SEM, n = 3). Least square means in the same nutrient category per treatment in a column with the same letter are not significantly different ($p > 0.05$)

Table 3: Combined effects of cultivar and storage time on the root compositional quality (dry matter basis) in 2015

Cultivar type*Month		Root compositional quality					
		Fructose	Glucose	Sucrose	Starch	Dry matter	β-carotene
		%					
Apomuden	0	4.83 ± 0.20^{a}	8.13 ± 0.26^{a}	18.13 ± 0.58^{bc}	45.42 ± 0.73^{cd}	22.70 ± 0.37^{d}	16.03 ± 0.36^{a}
	1	3.37 ± 0.20^{b}	5.26 ± 0.26^{b}	21.29 ± 0.58^{a}	48.26 ± 0.73^{c}	26.40 ± 0.37^{c}	12.42 ± 0.36^{b}
	2	3.02 ± 0.20^{bc}	5.18 ± 0.26^{b}	22.81 ± 0.58^{a}	45.24 ± 0.73^{d}	26.20 ± 0.37^{c}	12.94 ± 0.43^{b}
"Nangungungu"	0	2.40 ± 0.20^{cd}	4.32 ± 0.26^{b}	12.41 ± 0.58^{d}	58.9 ± 0.73^{a}	29.50 ± 0.37^{b}	11.71 ± 0.35^{bc}
	1	1.81 ± 0.20^{d}	3.08 ± 0.26^{c}	17.33 ± 0.58^{c}	55.60 ± 0.73^{b}	30.10 ± 0.37^{ab}	10.90 ± 0.35^{c}
	2	1.63 ± 0.20^{d}	3.18 ± 0.26^{c}	20.47 ± 0.58^{b}	53.97 ± 0.73^{b}	31.70 ± 0.37^{a}	11.39 ± 0.35^{bc}
p-value		0.020	0.001	0.017	< 0.001	< 0.001	< 0.001

Values (least square means ± SEM, *n* = 3). Least square means in the same category in a column with the same letter are not significantly different (p > 0.05)

Table 4: Combined effects of curing and storage time on the root compositional quality (dry matter basis) in 2015

Curing type*Month		Root compositional quality					
		Fructose	Glucose	Sucrose	Starch	Dry matter	β-carotene
		%					
Field-piled	0	4.96 ± 0.24^{a}	7.71 ± 0.32^{a}	16.34 ± 0.71^{d}	49.50 ± 0.89^{cd}	26.51 ± 0.46^{a}	13.72 ± 0.45^{a}
	1	2.12 ± 0.24^{b}	3.64 ± 0.32^{d}	17.49 ± 0.71^{cd}	54.32 ± 0.89^{a}	29.21 ± 0.46^{a}	11.06 ± 0.45^{a}
	2	2.53 ± 0.24^{b}	4.15 ± 0.32^{cd}	20.09 ± 0.71^{bc}	51.19 ± 0.89^{abcd}	28.85 ± 0.46^{a}	12.22 ± 0.51^{a}
In-ground	0	2.73 ± 0.24^{b}	5.30 ± 0.32^{bc}	14.55 ± 0.71^{d}	53.09 ± 0.89^{abc}	25.55 ± 0.46^{a}	14.15 ± 0.43^{a}
	1	2.74 ± 0.24^{b}	4.33 ± 0.32^{bcd}	19.71 ± 0.71^{bc}	51.40 ± 0.89^{abcd}	28.17 ± 0.46^{a}	11.44 ± 0.43^{a}
	2	2.10 ± 0.24^{b}	4.12 ± 0.32^{cd}	21.14 ± 0.71^{ab}	49.67 ± 0.89^{cd}	29.30 ± 0.46^{a}	11.95 ± 0.48^{a}
Uncured	0	3.15 ± 0.24^{b}	5.62 ± 0.32^{b}	14.91 ± 0.71^{d}	53.90 ± 0.89^{ab}	26.17 ± 0.46^{a}	13.74 ± 0.43^{a}
	1	2.91 ± 0.24^{b}	4.55 ± 0.32^{bcd}	20.73 ± 0.71^{ab}	50.06 ± 0.89^{bcd}	27.36 ± 0.46^{a}	12.49 ± 0.43^{a}
	2	2.36 ± 0.24^{b}	4.28 ± 0.32^{bcd}	23.69 ± 0.71^{a}	47.95 ± 0.89^{d}	28.60 ± 0.46^{a}	12.33 ± 0.43^{a}
p-value		<0.001	<0.001	0.003	<0.001	0.157	0.339

Values (least square means ± SEM, $n = 3$). Least square means in the same category in a column with the same letter are not significantly different ($p > 0.05$)