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Effect of drying and storage on the degradation of carotenoids in orange-fleshed sweetpotato cultivars

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Key Words:	Ipomoea batatas (L.) Lam, carotenoid, storage, drying, cultivar

Effect of drying and storage on the degradation of carotenoids in orange-fleshed sweetpotato cultivars

Running title: Carotenoid degradation in OFSP

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Keywords: *Ipomoea batatas* (L.) Lam, carotenoid, storage, drying, cultivar.

Abstract: Ugandan orange fleshed sweetpotato cultivars were evaluated for their total carotenoid retention (as an estimate of provitamin A retention) after drying in solar dryers (tunnel dryer, plastic-covered-tents dryers with different light transmission properties) and directly in the sun. Cultivar effect was tested with six cultivars (Ejumula, Kakamega, SPK004/1, SPK004/1/1, SPK004/6 and SPK004/6/6) that differed in carotenoid content: Total carotenoid retention during drying was not dependent on the type of dryer (solar or

sun). Sweetpotato cultivar, however, had a significant effect on retention in drying ($p<0.05$). Carotenoid loss was generally correlated with high initial moisture content and high carotenoid content in fresh sweetpotato roots. Losses of provitamin A during drying were generally low (15% or less). Dried sweetpotato chips were also evaluated for their carotenoid content after four months of storage at room temperature in Uganda. Losses of provitamin A were high (about 70%) and this was not dependent on the use of opaque or transparent packaging. Losses of carotenoids during storage were therefore considered to be more of a nutritional constraint to the utilisation of dried sweetpotato than losses occurring during drying.

INTRODUCTION

Uganda is the world's third largest producer of sweetpotato (*Ipomoea batatas* (L.) Lam.) with 2.6 million tonnes per annum[1]. It is a staple food in many regions of the country, particularly in the North-Eastern and Southern-Western parts. Vitamin A deficiency, a major public health problem in developing countries[2] affecting 38% of the children under the age of five years in Uganda[3]. Vulnerable groups susceptible to the effects of vitamin A deficiency include pregnant and lactating women and those who are at risk from imunodeficiency, such as those suffering from HIV and AIDS[3]. Two recent studies in South Africa[4] and Mozambique[5] have demonstrated that consumption of orange fleshed sweetpotato (OFSP), rich in provitamin A, significantly increased the vitamin A status of children. White-fleshed sweetpotatoes are the most commonly cultivated in sub-Saharan Africa, while OFSP cultivars are rarer[6] or more recently introduced. Recent work with women and children in Tanzania[7] has however demonstrated that, for the majority of consumers, OFSP cultivars are equally as acceptable as the white fleshed ones.

Substitution of white-fleshed cultivars could make a significant contribution to reducing vitamin A deficiency in East Africa[8].

In addition to consumption of cooked fresh sweetpotato roots, dried sweetpotato products have the potential to increase year round food availability and also provide a source of income for farmers. Drying of sweetpotato is a traditional processing technique practiced in North-Eastern Uganda, and it is also a means of producing a tradable product for use in commercially-available composite flours or as a replacement of wheat flour in bakery products.

In Africa, a concern was that losses in carotenoids during the drying of OFSP were very high (Bouis H, HarvestPlus pers. comm.) and that this would limit the potential of processed OFSP products to contribute to alleviating vitamin A deficiency. Drying studies undertaken in Kenya[9] and Columbia[10] reported high losses of between 72 and 83% for sweet potato chips and between 41 and 62% in cassava respectively. Losses as low as 20% have been reported in Kenya[11] but the drying time was very short and under shade (5 hours). However, in the USA[12] and France[13] much lower losses of carotenoids during the drying of sweet potato of 5-6%, and 16% to 23% respectively were reported which suggests that if drying conditions can be consistently controlled that losses will not be so high. The scarce literature encountered on the extent of provitamin A losses in OFSP under African conditions shows a need for further research. On the other hand there is a need for quantification of provitamin A after drying in order to determine the nutritional value of the dried OFSP product compared to fresh roots; this would inform on whether the dried product can contribute to improving nutrition and heath and hence worth being promoted. Moreover, a clearer understanding of the causes of provitamin A losses (type of dryer;

environmental conditions; sweet potato variety etc) during drying of OFSP in developing countries would contribute to the development of improved processing and/or handling techniques, promotion and marketing.

Exposure to light, especially sun or ultra-violet light, has been reported to induce *trans-cis* photomerisation and photodestruction of carotenoids[14]. When exposed to sunlight radiation, provitamin A is more sensitive to ultra-violet (UV) rays, especially at wavelengths close to the maximum absorption of β-carotene of 450 nm; and, in general, short wavelengths less than 470 nm caused the most β-carotene degradation[15,16]. It has also been reported that screening from direct sun light had an impact on total carotenoid losses from mango and cowpea leaves[17]; total carotenoid losses were 94% and 63% in sun-drying; 84% and 51% under polythene-covered sheeting (non-UV resistant) and 73% and 44% under visqueen-covered (UV-resistant) sheeting respectively.

Degradation of provitamin A in sweet potato products during storage is important determine as this would decrease the nutritional impact of the product for food security. Typically at the household level dried sweetpotato is stored at ambient temperature for 4-6 months. A significant decrease was reported in *all-trans-*β-carotene content during storage of sweetpotatoes flakes for four months in either plastic or foil packaging. Losses were 43% in foil packaging, 46% laminate paper and 54% in plastic bag at room temperature[18]. Similar results were reported in Kenya[9] where *trans-*β-carotene content fell by 50% in sweetpotato chips of Kakamega and Jonathan cultivars stored at room temperature, whereas levels remained steady in chips stored for three months at -20ºC. However in another study in Kenya[19], storing dried slices from 24 sweetpotato cultivars in opaque paper bags under ambient conditions for 11 months resulted in lesser total-carotenoid

losses of 10%. Differences in room temperature during storage or packaging permeability to oxygen may explain these disparities. This raises a need for further investigation in recorded conditions.

The objectives of this study were (a) to quantify the losses of total carotenoids from OFSP chips dried in low-cost dryers in Uganda and subsequently stored, and (b) understand the main factors that influence losses, such as type of dryer, effect of different plastic coverage, sweetpotato cultivar and type of packaging of the stored product.

MATERIALS AND METHODS

Sweetpotato root samples

Sweetpotato roots were collected from three different locations: orange fleshed (Ejumula) and yellow-fleshed roots (Kakamega) that had already been released to farmers were harvested from a farm in Luwero District., Uganda. Four new cultivars under consideration for release at the time of the study SPK004/1 (Naspot 7), SPK004/1/1 (Naspot 8), SPK004/6 (Naspot 9O) and SPK004/6/6 (Naspot 10O), and Ejumula and Kakamega were obtained from the National Crop Resources Research Institute (NaCRRI) at Namulonge and from an experimental field in Bombo, Luwero District.

In all cases, mature roots were harvested after a growing season of six months. Roots were spread on the floor at ambient temperature inside a room to prevent rotting and were processed within 48 hrs of harvest. All cultivars (Table 1) have been previously reported to be susceptible to sweetpotato weevil and moderately resistant to *Alternaria* blight and Sweetpotato Virus Disease (SPVD) resulting of dual infections of Sweetpotato feathery

mottle virus vectored by aphids, and Sweetpotato chlorotic stunt virus vectored by whiteflies [20,21].

Handling and processing

Sweetpotato roots were trimmed, weighed, washed, and drained in the open air for about 30 minutes. Unpeeled roots were chipped using a rotary disc type chipper (Tonnet Company, Kampala, Uganda). Exposure to light was minimised by using black polythene bags to cover the samples. Chips (thickness 2 mm; width 5 mm; length 69 mm on average) were thoroughly mixed before drying.

Drying of sweetpotato chips

Sweetpotato chips were dried using dryers that varied in degree of exposure to direct sun light. Different types of coverage were selected to have different screening effects on UV-radiation for the tent dryers since it was hypothesised that UV- radiation would have a significant effect on carotene degradation. Details of the dryers are given below:

- Open air sun dryer
- Tent dryer with UV resistant polythene (Lumitherm BPI-Visqueen®, Herfordshire, UK)
- Tent dryer with non-UV resistant polythene (locally bought in the market in Uganda)
- Tent dryer with red resistant polythene (Allplass®, Hertfordshire, UK)
- Tunnel dryer (UV-resistant polythene sheeting of unknown origin).

The chips were spread over black plastic sheeting that absorbed the sun heat apart from the tunnel dryer where they were spread of cloth netting (mosquito mesh).

Transmittance of the polythene sheetings of tent-dryers (UV resistant, non-UV resistant and red) were measured by spectrophotometer measurement[22] between 200-800nm (Figure

1). A rectangular section of 1 cm width was placed in the centre of the spectrophotometric cuvette so that beam light could perpendicularly cross the plastic sheeting[22].

All dryers were positioned parallel East-West because of the incidence of the sun's radiation and prevailing wind. For the tent and tunnel dryers, air entered through the inlet placed at the base of the dryers while the moist warm air was evacuated through an outlet in the top corner.

Ambient temperature, humidity, wind speed and irradiance were recorded every 30 min when samples were on the dryers using on a Vantage Pro- meteorological station (Davis Instruments, California, USA). All samples were removed from dryers and placed under a shelter at night and when it rained. Temperature and humidity were recorded inside dryers using Tinytalk temperature/humidity sensors (RS Components Ltd, UK).

A loading density of 3.9 kg/m^2 was used when placing the sweetpotato chips on the dryers. The mean drying conditions were a temperature of 28.3ºC with a standard deviation of 5.6ºC and a mean humidity of 55.1% with a standard deviation of 23.8%. During drying, chips were weighed every four hours to estimate moisture loss. The end of drying was estimated by chips brittleness and sample weight.

Storage of the dried chips

Dried chips (> 1 kg per treatment for Ejumula and Kakamega cultivars) were collected, thoroughly mixed and split into samples of about 200g. Samples were stored under the following conditions: in a LPDE zipped polythene bags (VWR, Leicestershire, UK) protected from light; in knotted black polythene bags; in clear polythene bags placed under a window and so exposed to direct sunlight; or in sealed clear polythene bags stored inside

knotted black polythene bags. Black and clear polythene bags were bought from shops in Kawanda, Uganda. No information was available about the supplier.

Samples (200g) per treatment were taken after drying and after storage for 4 months (125 days) at ambient room temperature. The temperature and humidity was recorded every four hours using Tinytalk temperature/humidity sensors (RS Components Ltd, UK). A four month-storage for dried chips was chosen because it is a typical duration of storage for farmers in Uganda. Samples taken at each storage interval were kept in a freezer (-20°C) until analysed in triplicate.

Total carotenoids extraction and analysis

Carotenoid analysis was undertaken in Uganda (NARL, Kawanda) and in the UK (University of Greenwich).

Carotenoid Analysis in Uganda

Frozen fresh chips (500g) were defrosted at ambient temperature by soaking the plastic bag in tepid water. Fresh chips were then blended to a fine pulp using a Kenwood FP698 Multi Pro Food Processor.

Total carotenoid extraction and analysis were carried out following existing method[14].but with the following modifications: a portion of the homogeneous representative sample (1-6 g of fresh tissue or 0.5-2 g of flour) was re-hydrated for 20 minutes in 10 ml-desionised water and was homogenised with 50mL methanol: tetrahydrofuran (THF) (1:1) using a Polytron PT1200E (Kinematica, Switzerland) homogeniser for one minute. Total carotenoid content was determined using a Genesys 10UV /UV-visible spectrophotometer at 450 nm. Concentrations were determined by comparison to an external standard curve

using pure β-carotene (SIGMA, UK) and an absorption coefficient of β-carotene in PE of 2592[14].

Carotenoid analysis in the UK

Dried chips were transported to the UK by air flight and were immediately placed in a freezer on arrival. Although during transport to the UK over a 24 hour period, the dried chips did reached ambient temperature during transport over a 24 hour period outside the freezer, but the carotenoid degradation was negligible; a maximum of carotenoid loss of 0.88% was calculated for a sample stored at 25ºC for 24h (Bechoff A, unpublished). Samples were immediately placed in a freezer on arrival. Samples were stored in a freezer (-20ºC) for up to 2 months before analysis. Carotenoid content of samples stored in the freezer was checked over a 4 month period and there was no significant decrease in total carotenoid content ($p<0.05$).

Prior to analysis, chips were milled into flour. After careful mixing and sub-sampling using a grain divider, a quarter of the 200g was milled a Laboratory Mill (Models 3033 or 3600, Perten Instruments, Segeltorp, Sweden). Flour obtained was packed in zipped plastic bags from which excess air was removed manually. Flour samples were stored at -20°C for no more than two weeks before analysis.

The same extraction method was used in the UK by the same operator. Homogenisation was carried out using an Ultra-turax IKA Janke and a Kunkel Labortechnik at 8000 rpm/min. The total carotenoid content measured by Diode Array detector spectrophotometer (Hewlett Packard HP8452A).

Dry matter determination

Samples were collected for dry matter determination, before and after drying at the same time as carotenoids analysis. Determinations were made by drying triplicate 5g samples at 105ºC to constant weight (minimum 24h).

Statistical analyses

Analysis of variance (ANOVA) was carried out to determine whether there were significant differences between samples with one up to three factors; a significant difference between samples was determined using the Tukey test. Correlations were determined using Pearson tests on average losses. Inter-laboratory difference was tested by one way-ANOVA. All data were processed on SPSS 14.00 (SPSS UK Ltd. Woking Surrey) for Windows software.

RESULTS AND DISCUSSION

Provitamin A losses in solar and sun drying treatments

The inter-laboratory difference between the carotenoid extraction undertaken in the Uganda and UK laboratories (triplicate extractions of five dried samples of each of Ejumula and Kakamega roots) indicated that and there was no significant difference ($p<0.05$).

The drying of Ejumula and Kakamega (SPK004) sweetpotato cultivars was investigated. Total carotenoid losses were on average 7.3% in Ejumula and 10.7% in Kakamega (Table 2). The mean total carotenoid losses (for the two cultivars analysed jointly) were 10.9% in one replicate study (trial 1) and 7.1% in the other replicate study (trial 2). The two trials had different weather conditions: it was wet for trial 1 and dry, sunny and windy for trial 2.

Consequently drying times were reduced for trial 2 (7.2h on dryers in average) compared to trial 1 (11.9h in average). Shorter drying times may have resulted in lower levels of carotenoid loss. Low losses of *trans-β*-carotene were similarly reported in a recent study involving oven; solar and open sun drying of OFSP chips in Uganda[23]. *Trans-β*-carotene losses were respectively 12%; 9% and 16% for the Ejumula cultivar for a drying time and temperature of 10 h at 57ºC in oven drying; between 6-10 h in solar drying (45-63ºC) and sun (30-52ºC) respectively. In this present study, the low levels of carotenoid losses are in agreement with this more recently published finding.

Losses of total carotenoids from two cultivars of sweetpotato dried in dryers fitted with polythene sheeting were determined (Table 3). Independent of cultivar and dryer, losses of carotenoids during drying varied between 2.1% and 18.7% and dry matter contents in dried samples ranged between 88.0% and 92.4%.

Polythene sheeting presented different transmittance toward sun light. Red plastic sheeting absorbed at wavelengths between 300-600 nm which provitamin A is reportedly sensitive[15,16] (part of UVA and visible). UV-resistant plastic reduced most UV-wavelengths: between 200-240 nm (UVB and UVC) and between 260-370 nm (UVB, UVA). Simple polythene was not wavelength selective (Figure 1).

There was no effect on the loss of total carotenoids from the use of type of dryer and different types of polythene sheeting in spite of the various wavelength selectivities ($p<0.05$).

The greater provitamin A degrading effect of sun compared to solar drying has been previously reported by several authors[10,17,24] and these are in contrast to the current results.

Working with leafy vegetables[24], it has been demonstrated that solar-dried products retain significantly more *β*-carotene than sun-dried products. However, when analysing individual results from the paper, it appeared there were no significant differences between solar and sun drying on five out of seven leafy vegetables[24].

Previous reports[23,24] have indicated that solar drying with natural air convection was faster than sun drying. An explanation for the lack of differences in provitamin A retention between sun and solar dryers may be that in this study, as opposed to previous reports, sun drying was faster compared to solar drying. Furthermore, the lack of differences between dryers may have been because the UV irradiation affected only the surface and did not penetrate the inner tissue. The size and shape of chips may therefore have an impact on carotenoid loss[13]. Starch being the main component of sweetpotato may have also played a protective role in preventing carotenoid losses[25] and explain the lack of difference in-between the solar dryers and also sun drying.

The effect of trial and cultivar was significant (two-way ANOVA; $p<0.05$). The effect of trial (which means that not all the dryers behave the same way in the two replicates) can be explained by lack of control over environmental factors in sun and solar drying. The tunnel dryer had the most consistent results between the two replicates (for both cultivars), probably because it provides more protection from wind and other natural elements compared to the other dryers. The effect of cultivar is treated in the next part.

Effect of sweetpotato cultivar

Regarding total carotenoid determination in sweet potato cultivar, critics would say that it may not be the best means of measuring provitamin A because it does not estimate the level of *cis*-isomers of *trans-β*-carotene content and these can increase during processing,

especially at temperatures greater to 35ºC[26]. Significant increase of 13- *cis*-isomer was encountered on drum dried sweet potato[27]. However some authors[11,13,23,24] have found that there is no increase in cis isomerisation of *trans-β*-carotene after solar and sun drying. Moreover t*rans-β*-carotene was greater than 90% of total carotenoids in these cultivars[23]. Therefore total carotenoid determination could be an acceptable technique to estimate *trans-β*-carotene quite precisely on these Ugandan cultivars; no significant differences between total carotenoids and *trans-β*-carotene have been reported in Resisto, an orange fleshed sweetpotato cultivar having around 90% *trans-β*-carotene[28].

Total carotenoid losses from six OFSP cultivars dried in open sun drying at NaCRRI (Namulonge) and in Luwero District were on average 14.8% and 7.0% respectively (Table 4). The weather conditions were similar (high wind; low humidity and high solar radiation) for both trials but the drying times differed being half a day at the Namulonge location and half day plus a night at Luwero (Table 4). Because the samples from the two locations were not dried on the same day a comparison between the provitamin A losses is therefore not possible. Losses in carotenoids per cultivar in both locations are presented in Table 5.

Total carotenoid contents of fresh sweetpotato varied in the six cultivars between 78.5 and 300.5 $\mu g.g^{-1}$ at the NaCRRI and 41.7 and 223.1 $\mu g.g^{-1}$ in Luwero Distrct. These values are in agreement with the recent study[23] that described *trans-β*-carotene content varying between 108.1-261.9 $\mu g.g^{-1}$ on the same cultivars including Ejumula, Kakamega (SPK004), SPK004/1; SPK004/1; SPK004/6 and SPK004/6/6 more Sowola 9/94/9 also from the NaCRRI (Namulonge).

There were significant differences in fresh chip carotenoid content (before drying) associated with location (two-way ANOVA; $p<0.05$). This has been reported previously[29]. These differences were especially marked for the newly developed cultivars, SPK004/1 and SPK004/1/1 (Table 5). Sweetpotatoes grown on farmer's fields generally had lower levels of total carotenoids than those grown at the research station.

Independent of location, there was a significant influence of cultivar ($p<0.05$) on the levels of carotenoid loss. While the total carotenoid losses were not very consistent within cultivars, there was a correlation between initial dry matter content and carotenoid losses (Pearson coefficient $R=-0.518$; $p<0.05$) (Figure 2). For an equivalent drying time, cultivars with higher moisture contents tended to lose more carotenoids. Similar observations regarding the influence of dry matter content and carotenoid losses during drying have been made elsewhere: sweetpotatoes (dry matter content of 75.8 %) had greater β-carotene retention compared to carrots (90.5%) respectively 4.0–5.8%, and 48.9–67.5%[12]. These results were further confirmed by analysis of data presented by another author[19]. The effect of oven drying was tested on 24 white, yellow, purple and orange fleshed sweetpotato cultivars[19]. Total carotenoid content ranged between 2 and 632 $\mu g.g^{-1}$ dry basis and dry matter in fresh roots between 19 and 34% respectively. Losses of total carotenoids were variable among cultivars ranging between 0-80% with an average of 32%. Using the data presented[19], a significant correlation was observed between fresh dry matter and losses during drying in nine cultivars with total carotenoid content greater than 37 $\mu g.g^{-1}$ (Pearson coefficient $R=-0.687$; $p<0.05$). No correlation was observed on 12 other cultivars with carotenoid content lower than 37 $\mu g.g^{-1}$ [19].

The cultivars used in this present study demonstrated a positive correlation between initial total carotenoid content (in fresh chips) and carotenoid losses (Pearson coefficient $R=0.589$; $p<0.05$) (Figure 3). Cultivars with higher initial carotenoid content tended to lose more carotenoids during drying. The same trend was observed by analysis of other reported data[19] on 11 cultivars with total carotenoid content greater than 30 $\mu g.g^{-1}$ (Pearson coefficient $R=0.580$; $p<0.05$). As well as for the correlation between fresh dry matter and provitamin A losses, the correlation between initial carotenoid content and loss was stronger on cultivars with carotenoid contents greater than 37 $\mu g.g^{-1}$ (Pearson coefficient $R=0.713$; $p<0.05$); no correlation was observed on cultivars with lower carotenoid content[19].

Effect of storage on provitamin A retention

Because the levels of loss of carotenes associated with drying were much less than anticipated, changes during storage at ambient temperatures were investigated (Table 6). In all cases the levels of losses of carotenoids during storage were high under these conditions when compared to that lost during drying, averaging 68.2% with a range of 63.7 to 76.6%. The combined levels of loss from drying and storage (overall loss) ranged from 75.8 to 85.4% over four months of storage (Table 6).

Oxygen (in the air), temperature and relative humidity have been reported to be the main causes of carotenoid degradation in low moisture systems during storage and relationships between these factors have been reported[30]. The temperature and humidity in the room where the samples were stored was generally very constant and consistent during the periods of storage; the mean temperature and humidity were 23.1ºC and 70.5% respectively over an 8 month-period with minimum-maximum variations between 19.1-27.7ºC and 42.8-86.5% (Figure 4). The chips were stored in low density polythene (LDPE)

bags because this was the most common way of storing them in Uganda and other countries in Southern Africa. This type of packaging however did not offer a significant barrier to oxygen. In ambient temperature and relative humidity conditions during the period storage oxygen was proved to be the main factor of carotenoid degradation[30]. Packaging permeability to oxygen (in air) was demonstrated to have a critical influence on β-carotene retention in sweet potato flakes during storage[31]. It was reported that degradation of the carotenoids was significantly reduced during storage at 23°C for 210 days if oxygen was excluded. In our study, while the levels of losses in carotenoids were substantial, there were no differences in losses when the dried sweetpotato chips were stored in sealed clear bags, sealed clear bags in black bags or a knotted black bags (two-way ANOVA; $p<0.05$). This suggests that the packaging permeability to oxygen might have been a significant factor in causing these losses. Moreover this suggests that when stored at room temperature, restricting exposure to sun light did not influence the level of loss. The lack of effect of storage in the absence of light or dark has also been reported on the carotenoid loss of freeze-dried orange-peel, carrots and sweetpotato samples[32]. As compared with the effect of oxidation (packaged under nitrogen or air); the effect of photoisomerisation (can or clear bottle) was proved to be minor on mango puree[33].

Effects of temperature[32] and relative humidity that is related to water activity[34] on carotenoid degradation in dried sweet potato have been described. At higher temperatures carotenoids degrade more rapidly[26,32]. Water activity also had an influence on carotenoid retention during storage[34]. In our study, for both cultivars analysed collectively, losses were significantly higher where stored in zipped PE compared to all other packaging even though the moisture content was slightly lower in the zipped PE bag (90% compared to 88% in other types of packaging) and zipped PE bags were protected from light. A

possible explanation for these observations might be that water has a protective effect on the carotenoids and consequently a drier sample would result in higher carotenoid loss. Similar results have been reported on low moisture systems of microcrystalline cellulose containing β-carotene[30]; and research on dehydrated sweet potato have also proved that β-carotene degradation rate was faster at lower water activity[34]. Moreover recent but yet unpublished study of temperature related to water activity and oxygen on dried sweet potato was in line with these results (Bechoff A, unpublished).

In general levels of loss during storage in this study agreed with levels of loss encountered in literature which were around 50% or more after 4 months storage at ambient temperature/humidity and air on dried sweet potato chips[9] or flakes[18,31]

Effect of sweetpotato cultivar on provitamin A retention in storage

The levels of total carotenoids in chips made from Ejumula, Kakamega, SPK004/1, SPK004/1/1, SPK004/6 and SPK004/6/6 cultivars grown at NaCRRI, Namulonge after drying and after storage for four months is illustrated in table 7.

Although there was some variability between cultivars, levels of losses were high in all cultivars and averaged 70.4% after four months storage at room temperature (overall losses were 74.7%). Sample moisture contents increased during storage as previously observed on Ejumula and Kakamega in various packaging types (Table 6). There was no correlation between dry matter and total carotenoid content in fresh sweetpotatoes and losses in storage ($p>0.05$).

Levels of loss after 4 months from chips of the six cultivars (70.4%) are consistent with levels of loss observed previously in various packaging after 4 months (68.2%). Considerable losses therefore occur in storage leading to a poor quality product.

Estimation of vitamin A activity in OFSP chips

Vitamin A activities of various OFSP chips were estimated and summarised in Table 8. Chips made from most of the cultivars had a high vitamin A activity after drying (>4,000 RE.kg^{-1})[35] with an average of about 8,428 RE kg^{-1} [36], but after four months of storage none of the chips (regardless of cultivar) had vitamin A activities greater than 4,000 RE.kg^{-1}; the average was 2,281 RE kg^{-1}.

It is speculated that further losses occurring during the preparation of OFSP flour into finished product (for example, atapa (traditional Ugandan porridge cassava/sweetpotato), mandazi (traditional doughnut), or bread) would represent an estimated loss of a further 50% on a dry basis[9,19]. Nonetheless, most of the cultivars immediately after drying have the potential to provide a major part of FAO/WHO recommended daily requirements of children[34] assuming that 100 g of finished product was consumed. However, after storage for four months, none of the dried samples would provide a significant source of vitamin A to the diet. In addition to the loss of provitamin A activity, other constraints in the quality of the dried product need to be taken into account, such as, rancidity, browning, and presence of insects. From a nutritional and quality perspective, it would not be recommended to store dried OFSP under these conditions for more than two months.

CONCLUSION

A major conclusion from the work on drying and storage of sweetpotato in Eastern Africa was that sun drying is a relatively less important cause of loss of total carotenoid content than anticipated. An important finding was that the low-cost, controlled direct sun-drying (covering samples at night or in case of rain; and checking carefully the end of drying) was demonstrated to be as efficient as solar drying in terms of provitamin A retention. Mean losses were as low as 7.3% in Ejumula and 10.7% in Kakamega cultivars.

Sweetpotato cultivar had a significant effect on carotenoid losses in drying ($p<0.05$). An interesting fact is that carotenoid loss appeared to be related to the initial carotenoid and moisture content. Cultivars with higher initial moisture and carotenoid contents of cultivars occurred to be related to higher levels of carotene loss in drying.

Storage of OFSP chips had a far more significant effect on carotenoid content than drying; Losses over 70% were obtained after room storage for 4 months. Moreover levels of loss were consistent using various sweetpotato cultivars.

OFSP chips contained a significant amount of provitamin A immediately after drying and this could make a significant contribution to the diet. However, low-cost means of reducing provitamin A losses during storage (eg. pre-treatments such as salting and blanching) or limited shelf life are needed in order to increase the usefulness of drying as a processing technique in rural areas of Southern Africa. Losses of carotenoids during storage were therefore considered to be more of a constraint to the use of dried sweetpotato than losses during drying.

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Table 1. Source, flesh colour and yield of selected orange fleshed and yellow fleshed sweetpotato cultivars.

Cultivar	Original source	Flesh colour	Typical reported fresh root yield (tonnes per ha)
Ejumula	Eastern Uganda	Deep orange[20]	36.6[20]
Kakamega (SPK004)	Western Kenya	Yellow/light orange[20]	31[20]
SPK004/1	Bred from SPK004-Uganda	Yellow/light orange[21]	7.4-59.7[21]
SPK004/1/1		Yellow/light orange[21]	7.0-43.2[21]
SPK004/6		Orange[21]	4.6-50.4[21]
SPK004/6/6		Orange[21]	7.9-38.3[21]

Table 2. Total carotenoid loss (dry weight basis) related to processing trial, drying time and weather conditions for two cultivars combined (Ejumula and Kakamega) of sweetpotato dried on five types of dryers in Uganda

Trial	Wind Speed* (m/s)	T* (ºC)	RH* (%)	Solar Radiation* (W/m^2)	Drying on dryers time* (h)	Total drying time** (h)	Total carotenoid loss (%)		
							Ejumula	Kakamega	Average-trials
1	1.8(1.4)	27.3(2.6)	62.4(16.4)	496.0(230.3)	11.9(1.8)	59.5(11.2)	8.4(3.3)	13.4(4.4)	10.9 (4.7)
2	4.1(2.1)	31.2(2.6)	32.3(8.7)	781.9(183.2)	7.2(1.9)	16.9(10.0)	6.3(1.9)	8.0(3.0)	7.1 (2.7)
Average-varieties							7.3 (2.8)	10.7(4.8)	

Mean (standard deviation)
T=Temperature; RH= Relative Humidity.
**These parameters were measured during the total period of drying on dryers (day time). One measurement was taken each half hour.*
***Including time under shelter at night and when raining.*

Table 3. Losses in total carotenoids during solar-drying of Ejumula and Kakamega cultivars of sweetpotato dried in various solar and sun dryers under wet and dry weather conditions

Cultivar	Treatment	Dry matter content* (%)	Drying time** (h)	Total carotenoid content*** (μg.g^{-1} db)	Loss (%)
Trial 1: Wet weather					
Ejumula	Fresh	31.4	0.0	250.6(9.1)	-
	Red polythene	90.0	14.0	240.4(2.9)	4.1
	Local polythene	92.4	13.2	227.1(1.7)	9.4
	UV resistant polythene	90.9	12.6	230.1(3.0)	8.2
	Tunnel dryer	90.0	10.4	232.8(4.2)	7.1
	Sun drying	89.7	9.7	217.8(6.2)	13.1
Kakamega	Fresh	38.1	0.0	75.2(4.4)	-
	Red polythene	88.0	14.1	62.1(0.9)	17.4
	Local polythene	90.0	13.2	65.4(3.3)	13.0
	UV resistant polythene	89.3	12.6	61.1(0.4)	18.7
	Tunnel dryer	91.5	10.4	67.4(4.1)	10.4
	Sun drying	89.7	9.3	69.8(0.2)	7.2
Trial 2: Dry weather					
Ejumula	Fresh	30.9	0.0	306.3(2.4)	-
	Red polythene	89.7	9.3	291.7(5.8)	4.8
	Local polythene	90.9	7.5	290.9(6.1)	5.0
	UV resistant polythene	89.7	7.3	283.6(5.1)	7.8
	Tunnel dryer	91.0	5.7	279.6(5.0)	8.7
	Sun drying	91.1	4.8	291.2(6.6)	4.9
Kakamega	Fresh	33.5	0.0	100.3(1.8)	-
	Red polythene	89.6	10.2	91.7(1.7)	8.6
	Local polythene	90.1	8.6	91.2(1.4)	9.1
	UV resistant polythene	90.6	8.0	98.1(3.4)	2.1
	Tunnel dryer	89.5	5.7	91.0(0.3)	10.7
	Sun drying	91.1	4.9	90.6(6.6)	9.6

**Mean; standard deviation is not given because <1% on triplicate extractions*
***Exposure in dryers ***Mean (standard deviation) on triplicate extractions*

Table 4. Total carotenoid losses related to drying time and weather conditions in open air drying of six OFSP cultivars in Uganda.

Trial	Wind Speed* (m/s)	T* (ºC)	RH* (%)	Solar Radiation* (W/m^2)	Drying time on dryers (h)	Total drying time** (h)	Total carotenoid loss (%)
Namulonge	5.4 (2.0)	32.0(1.8)	31.7(12.6)	845.2(137.4)	4.9(0.2)	4.9 (0.2)	14.8(4.2)
Luwero	5.1(2.4)	32.0(1.6)	34.1(8.9)	752.3(277.9)	5.6(0.0)	24.5(0.0)	7.0(2.5)
Average							13.6 (4.7)

Mean (standard deviation)
T=Temperature; RH= Relative Humidity.
**These parameters were measured during the total drying time on dryers. One measurement was taken each half hour.*
***Including time under shelter at night and when raining.*

Table 5. Loss in carotenoids after open air sun-drying of different sweetpotato cultivars

Trial	Dry matter content in fresh roots (%)	Total carotenoid content (µg.g^{-1} db) before drying	Drying duration (h)	Dry matter content after drying (%)	Total carotenoid content (µg.g^{-1} db) after drying	Loss (%)
Namulonge						
Ejumula	31.5	300.5(5.1)	4.7	92.9	236.3(1.7)	**21.4**
Kakamega	32.1	107.9(1.2)	4.7	92.3	96.5(2.9)	**10.6**
SPK004/1	32.9	96.2(0.4)	4.7	92.6	84.4(2.2)	**12.2**
SPK004/1/1	30.3	78.5(6.1)	5.0	92.3	69.4(1.4)	**11.6**
SPK004/6	28.4	188.5(7.6)	5.2	92.4	160.0(2.3)	**15.1**
SPK004/6/6	28.8	172.9(1.9)	5.1	92.8	142.0(1.2)	**17.9**
Luwero						
Ejumula	32.4	223.1(4.3)	5.7	91.3	194.5(5.6)	**12.8**
Kakamega	32.7	94.7(3.3)	5.7	91.6	101.2(3.5)	**-6.8**$^{\int}$
SPK004/1	31.7	47.9(1.5)	5.6	91.6	41.7(3.4)	**13.0**
SPK004/1/1	33.1	41.7(4.1)	5.6	91.7	42.2(1.0)	**-1.1**$^{\int}$
SPK004/6	33.8	159.6(11.7)	5.6	91.6	152.7(2.9)	**4.3**
SPK004/6/6	22.8	168.1(2.3)	5.6	92.0	139.1(5.0)	**17.2**

**Mean; standard deviation is not given because <1% on triplicate extractions*
***Exposure in dryers ***Mean (standard deviation) on triplicate extractions*
$^{\int}$*Negative values do not differ significantly from total carotenoid content in fresh chips*

Table 6. Losses of total carotenoids during the storage of OFSP dried chips at ambient temperature in polyethylene (PE) bags for 4 months (125 days).

Cultivar	Treatment	Dry matter content* (%)	Total carotenoid content ** ($\mu g.g^{-1}$ db)	Loss in storage (%)	Overall loss (%)
Ejumula	Before storage	91.3	199.8(5.4)		
	Zipped PE bag	90.4	46.7(4.5)a	76.6	85.4
	Sealed clear PE bag in black PE bag	88.4	64.2(1.0)b	67.9	79.9
	Black PE bag with simple knot	88.4	58.2(4.6)b	70.9	81.8
	Sealed clear PE bag	88.1	69.5(5.7)b	65.2	78.3
Kakamega	Before storage	91.3	52.4(3.6)a		
	Zipped PE bag	90.3	12.0(0.8)b	77.2	84.8
	Sealed clear PE bag in black PE bag	88.8	18.0(0.5)b	65.7	77.2
	Black PE bag with simple knot	88.7	19.0(1.0)b	63.7	75.8
	Sealed clear PE bag	88.0	18.5(1.0)b	64.7	76.5

**Mean; standard deviation is not given because <1% on triplicate extraction*

***Mean (standard deviation) on triplicate extractions. Values in the same column (same cultivar) followed with different letters are significantly different; ANOVA two ways Tukey test.*

Table 7. Levels of total carotenoids (µg/g on a dry weight basis) in dried sweetpotato chips of six cultivars grown at Namulonge stored at ambient temperature for four months (125 days) in locally purchased black polythene bags.

Cultivar	Dry matter content immediately after drying* (%)	Dry matter content after 4 month-storage* (%)	Total carotenoid content after 4 month-storage** ($\mu g.g^{-1}$ db)	Loss after 4 month-storage (%)
Ejumula	92.9	88.0	58.5(1.7)	75.3
Kakamega	92.3	87.9	29.2(0.7)	69.8
SPK004/1	92.6	88.1	29.1(0.7)	65.5
SPK004/1/1	92.3	88.0	21.5(1.0)	68.9
SPK004/6	92.4	87.8	48.4(1.0)	69.7
SPK004/6/6	92.8	88.1	38.0(0.6)	73.2

**Mean; standard deviation is not given because <1% on triplicate extraction.*
***Mean (standard deviation) on triplicate extractions.*

Table 8. Estimation of vitamin A activity in flours made from OFSP cultivars after drying and storage for four months at room temperature (RE. kg^{-1} product on a fresh weight basis).

Cultivar	Estimated vitamin A activity RE. kg^{-1} product on a fresh weight basis*	
	Freshly dried chips	Stored chips (4 month)
Ejumula	15,202	3,561
Kakamega	6,163	1,774
SPK004/1	5,413	1,777
SPK004/1/1	4,430	1,313
SPK004/6	10,235	2,942
SPK004/6/6	9,124	2,317

**1 RE=13 µg of all-trans-β-carotene[36]. All-trans-β-carotene content is estimated to 90% mean total carotenoids content[14,23.] RE= Retinol Equivalents. Recommended daily requirements (RDA) of 2-6 year-olds is 400 RE.[35]*

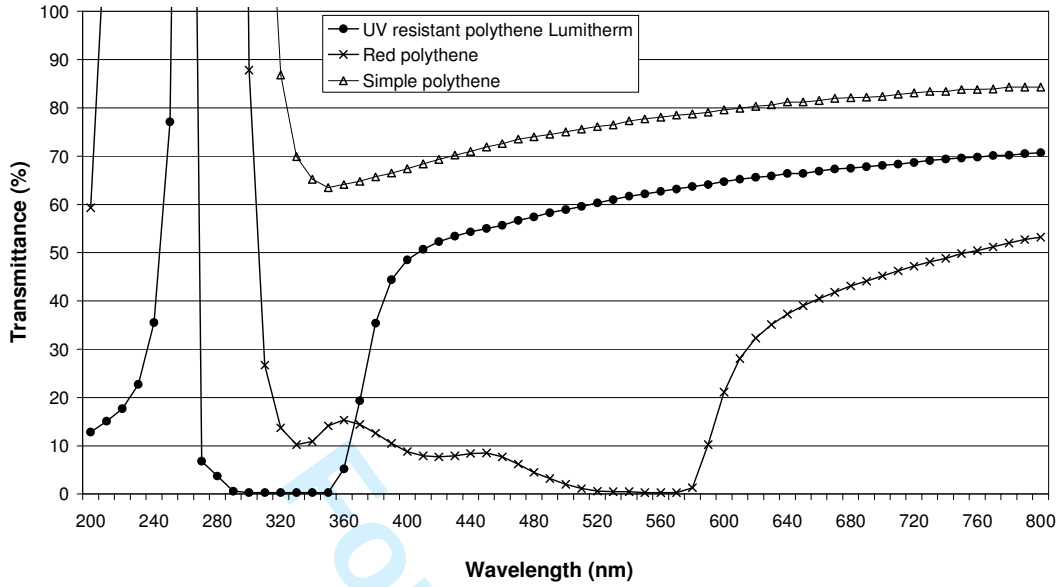

Figure 1. UV/visible spectrum of polythene sheeting used in drying studies.

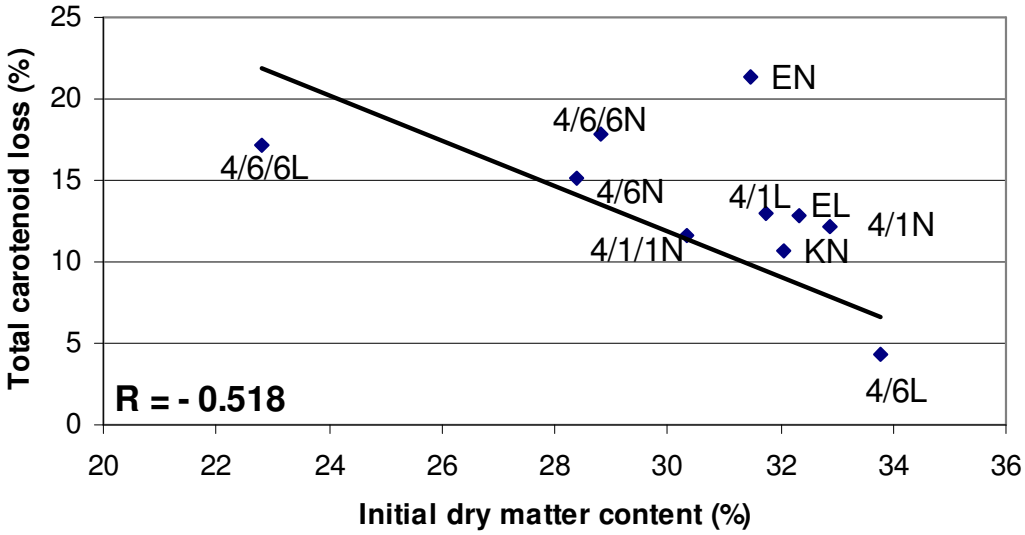

Figure 2. Relationship between initial dry matter content and total carotenoid loss in drying for six sweetpotato cultivars obtained from Namulonge and Luwero.

One point represents the average result per sample (12). Each sample was analysed in triplicate.

The abbreviations are: E, Ejumula; K, Kakamega; 4/1, SPK004/1; 4/1/1, SPK004/1/1; 4/6, SPK004/6; 4/6/6, SPK004/6/6; N, Namulonge; L, Luwero.

Cultivars KL and 4/1/1L with negative loss are not represented on the figure but taken into account in the calculation of the coefficient of correlation (R).

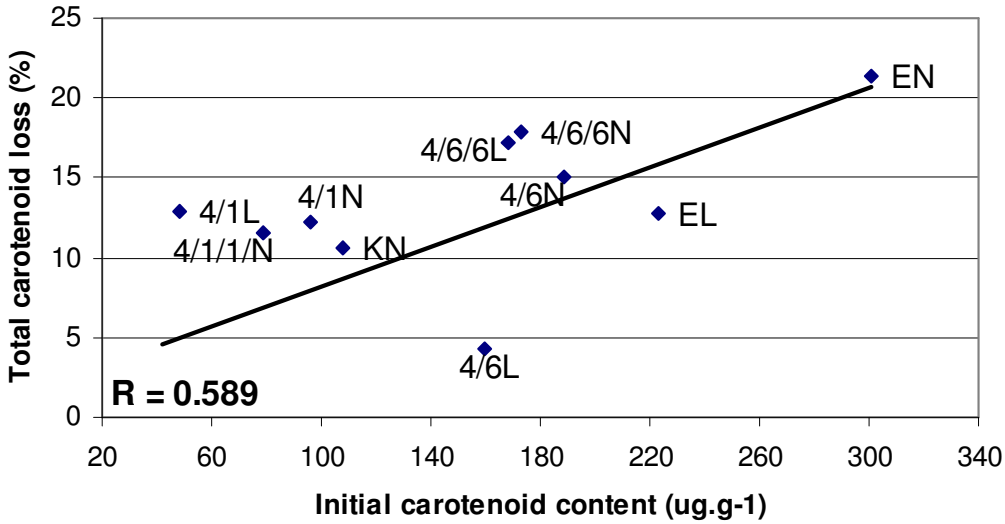

Figure 3. Relationship between initial total carotenoid content (dry basis) and total carotenoid loss in drying for the sweetpotato cultivars from harvested from Namulonge and Luwero. *One point represents the average result per sample (12) . Each sample was analysed in triplicate.*

One point represents the average result per sample (12). Each sample was analysed in triplicate.

The abbreviations used are: E, Ejumula; K, Kakamega; 4/1, SPK004/1; 4/1/1, SPK004/1/1; 4/6, SPK004/6; 4/6/6/, SPK004/6/6; N, Namulonge; L, Luwero.

Cultivars KL and 4/1/1L with negative loss are not represented on the figure but taken into account in the calculation of the coefficient of correlation (R).

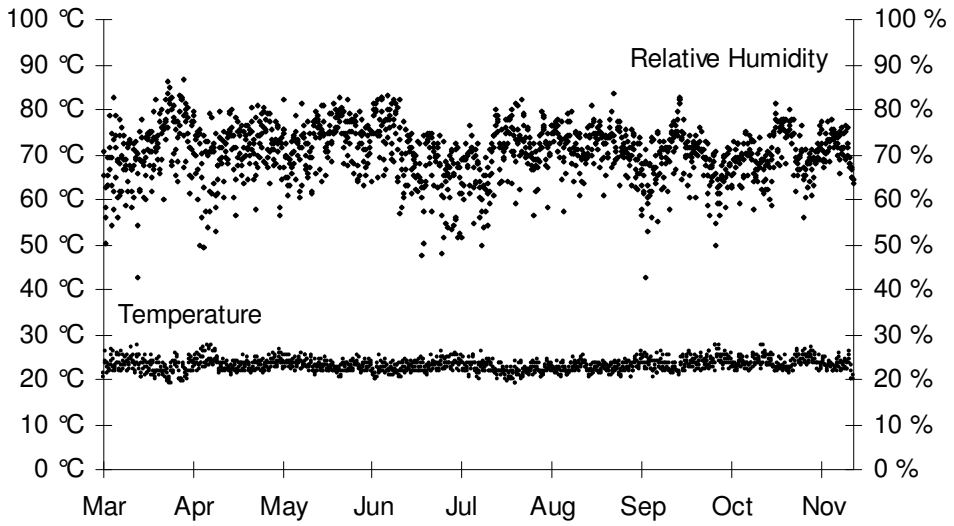

Figure 4. Variation in temperature and relative humidity with storage for sweet potato chips stored over 8 months (record was every 4h using Tinytalk temperature/humidity sensors)