Understanding carotenoid losses in orange-fleshed sweet potato in drying and storage

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ABSTRACT

Biofortified orange-fleshed sweet potato (OFSP) is being promoted to tackle vitamin A deficiency, a serious public health problem affecting children and pregnant/lactating women in sub-Saharan Africa. The aim of the study was to quantify and understand the factors influencing provitamin A losses in OFSP dried chips. Losses were determined after drying and storage. A preliminary pilot-scale study demonstrated that carotenoid levels were not significantly different after either solar or sun drying. Field conditions using locally-promoted varieties in Uganda and Mozambique showed losses associated with drying were less than 40%. Flour made from OFSP could therefore be a significant source of provitamin A. In contrast, storage of chips at room temperature in Uganda for four months resulted in high losses of pro-vitamin A (*ca*. 70% loss from the initial dried product). Low-cost pretreatments, such as blanching, antioxidants and salting, did not improve carotenoid retention during storage. To understand the cause of the losses, dried sweet potato chips were stored under controlled conditions of temperature (10; 20; 30; or 40ºC), aw (0.1; 0.3; 0.5 or 0.7) and oxygen (0 [under nitrogen]; 2.5; 10 or 21% [air]). Losses in provitamin A were the least during storage at the lowest temperature and oxygen level and at the highest humidity level. Enzymatic catabolism of β-carotene in the flour was considered unlikely because of low peroxidase activities at low water activities and the loss of peroxidase activity during storage.

Keywords: orange-fleshed sweet potato, carotenoid degradation, drying, storage

INTRODUCTION

Carotenoids are organic pigments found in plants that play an important role as vitamin A precursors in the human diet. In contrast to most plant foods, 80% of the carotenoid content of orange-fleshed sweet potato (OFSP) is trans-β-carotene (Bechoff et al., 2009a; Bengsston, et al., 2008). Such varieties could contribute to tackling vitamin A deficiency, a main public health issue in the developing world (Bechoff et al., 2009a; Bengsston et al., 2008). Sweet potato is a very valuable crop widely consumed in sub-Saharan Africa (Woolfe 1992). Sun drying of sweet potatoes is a traditional practice. Roots are either sliced or crushed and then dried on rocks. These are stored in granaries; re-hydrated and boiled to be eaten like fresh roots, or milled into flour. There are efforts through the HarvestPlus Challenge Program to promote the use of orange-fleshed varieties with high β-carotene content. In order to tackle

vitamin A deficiency in sub-Saharan African by increased consumption of OFSP, CIP and HarvestPlus Challenge Program have launched trials to incorporate OFSP in various recipes of African foodstuffs (Namanda et al., 2005; Owori et al., 2007). Food processing, drying and storage have been previously reported to have a major effect on pro-vitamin A retention because of the nature of unsaturated, unstable provitamin A carotenoids that are easily degraded by light, oxygen, ultra-violet and heating leading, to significant losses (Rodriguez Amaya 1997). It is therefore essential to optimise Orange Flesh Sweet potato (OFSP) processing in order to achieve products with high nutritional quality. Few data are found on carotenoid retention from sweet potato after drying and storage and the effect of direct sun drying compared to solar drying.

MATERIALS AND METHODS

Sweet potato varieties were obtained from partner farmers in Uganda and from Namulongue Agricultural Research Station of National Agricultural Research Organisation in Uganda and farmers partners with World Vision International in Mozambique. For preliminary trials in France, roots were of an imported American variety (Rubina®, Agrexco).

Roots were chipped using hand rotary disc chipper or sliced by hand. Dryers used were hot air dryer and greenhouse fan-operated solar dryer in France; tunnel and tent dryers in Uganda and tunnel dryer, shade in Mozambique. Open air sun dryers were used as a comparison with other dryers in each location. Chips were dried up to 10% moisture in average. After drying, chips were stored using locally bought polythene or propylene bags or traditional bags made of jute.

Total carotenoids content was determined on sweet potatoes grown in Uganda and Mozambique by visible spectrophotometry (UV-visible spectrophotometer) using the method of Rodriguez-Amaya and Kimura (2004). For preliminary trials in France, the method of Dhuique-Mayer et al. (2005) was used. Trans-β-carotene content was measured by HPLC using the analysis method of Dhuique Mayer et al. (2005) on preliminary samples (OFSP from USA) and samples stored in controlled conditions. Samples were extracted in duplicate or triplicate. Readings were made at a wavelength of 450nm.

Losses (%) in total carotenoid (or trans-β-carotene) content were calculated following the equation (1):

$$\%loss = 1 - \frac{C}{C_0} \qquad (1)$$

Where: C: Carotenoid content after drying (or storage) expressed in $\mu g.g^{-1}$ dry weight; C_0: Carotenoid content before drying (or storage) expressed in $\mu g.g^{-1}$.

Carotenoid degradation followed a first order degradation during storage (Equation 2).

$$\ln \frac{C}{C_0} = -kt \qquad (2)$$

Where: k: constant degradation (day^{-1}); t: storage time (days).

The carotenoid degradation at various temperatures was modelled using the Arrhenius equation (3).

$$k = k_\infty e^{-\frac{Ea}{RT}}$$

(3)

Where: Ea: activation energy ($kJ.mol^{-1}$); R: gas constant = 8.314 $J \cdot K^{-1}.mol^{-1}$. In order to validate the Arrhenius carotenoid degradation model in laboratory conditions, dried samples (Ejumula variety) were stored for 88 or 125 days at ambient room temperature (recorded temperature).

Statistical analyses on the analysis of variance were performed using SPSS 14.0 or 15.0. Significant differences per variety between samples ($p<0.05$) were given by Tukey test and are indicated by different letters in the same column (a, b, c).

RESULTS AND DISCUSSION

Preliminary trials

Losses in total carotenoid content and trans-β-carotene content using different dryers are reported in Table 1.

Table 1. Comparison of losses of total carotenoids and trans-β-carotene after drying sweet potato by three different dryers

Treatment	Drying time (h)	Spectrophotometer Total carotenoids (ug/g)	Total carotenoid loss (%)	HPLC trans-β-carotene (ug/g)	trans-β-carotene loss (%)
Fresh	-	372±9a	-	293±13a	-
Hot air dried	2	324±17b	13	247±23b*	16
Solar dried	8	294±17bc	21	226±17bc*	23
Sun dried	8	250±8c	33	193±15c	34

Mean±standard deviation of duplicate* or triplicate extraction.

No significant difference was observed between drying by greenhouse solar dryer and direct sun in term of β-carotene and total carotenoids. Cross flow drying (hot air drying) significantly retained a higher content of β-carotenes and total carotenoids than sun-drying.

Field work in Uganda

On both varieties grown in Uganda (Ejumula and Kakamega analysed jointly), no significant difference was observed between retention of carotenoids in tent, tunnel or sun dryers with total carotenoid losses of 9.0; 9.2 and 8.7% respectively. This is contradictory to studies that reported that sun drying was more damaging than solar drying (Rodriguez Amaya 1997, Mulokozi and Svanberg 2003) but agreed with levels of loss in the recent study by Bengsston et al. (2008) working on Ugandan OFSP.

Carotenoid losses were high during storage as opposed to after drying (Table 2).

Table 2: Total carotenoids losses 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	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	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.

Dried chips stored for 4 months had important losses for both varieties (Ejumula and Kakamega) with an average of 67%. Samples of dried sweet potato stored in clear polythene bags placed under the window did not demonstrate any difference in terms of loss in carotenoids as compared with opaque (black bag) that was either sealed or tied with simple knot. This agreed with results from Vasquez-Caicedo et al. (2007) about the impact of packaging and storage on pro-vitamin A retention of mango puree.

Field work in Mozambique

Shade drying significantly retained more total carotenoids compared to sun and solar drying in Mozambique with 3.3%, 10.0% and 12.2% respectively for MGCL01 and Resisto varieties analysed jointly.

Carotenoid losses were high during storage in accordance with results in Uganda (Table 3).

Table 3. Total carotenoids losses after drying in Mozambique on two varieties in dry weather

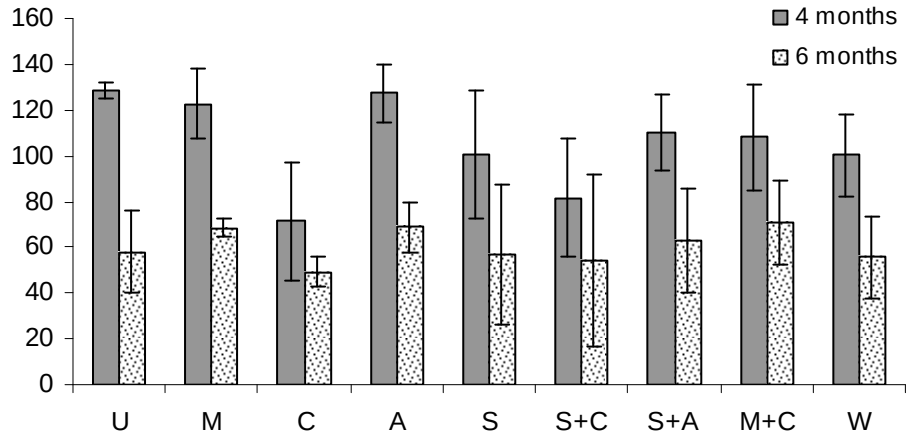
	thin	thick	slices
MGCL01	86.6%	88.2%	89.7%
Resisto	76.8%	79.3%	81.9%

Chipping did not have an effect but variety had (ANOVA; $p<0.05$).

Effect of pre-treatment

The effect of pre-drying treatment by different chemicals was tested (Figure 1).

Figure 1. Total carotenoids losses after pre-treatment on dried and stored Ejumula variety for 4 and 6 months



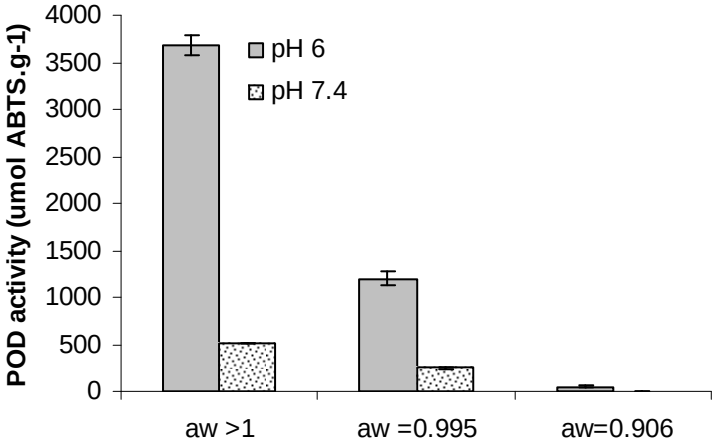
Where: U: untreated; M: 0.5% sodium metabisulphite; C: 0.5% citric acid; A: 1% ascorbic acid; S: 1% salt; W: deionised water.

Pre-treatment did not reduce carotenoid loss. After four months of storage, deionised water treated samples had lower total carotenoid content than untreated that had lower carotenoid content than untreated ones. After six months of storage, there was no difference between samples.

Effect of enzymes

The effect of enzymatic activity (peroxidase) on carotenoid degradation was tested (Figure 2).

Figure 2. Peroxidase activity related to water activity (adjusted with glycerol concentration). Peroxidase activity (µg ABTS.g^{-1} sweet potato on a fresh basis*)



*mean of 3 measurements (error bars refer to standard deviation).

Peroxidase activity decreased with water activity (Figure 2) and with storage time (data not shown). Globally the effect of peroxidase on carotenoid degradation was unlikely.

Storage study under controlled conditions

The effect of temperature, water activity (aw) and oxygen was measured on Ejumula chips stored under controlled conditions of temperature (10; 20; 30; or 40ºC), aw (0.1; 0.3; 0.5 or 0.7) and oxygen (0 [under nitrogen]; 2.5; 10 or 21% [air]) (Figure 3).

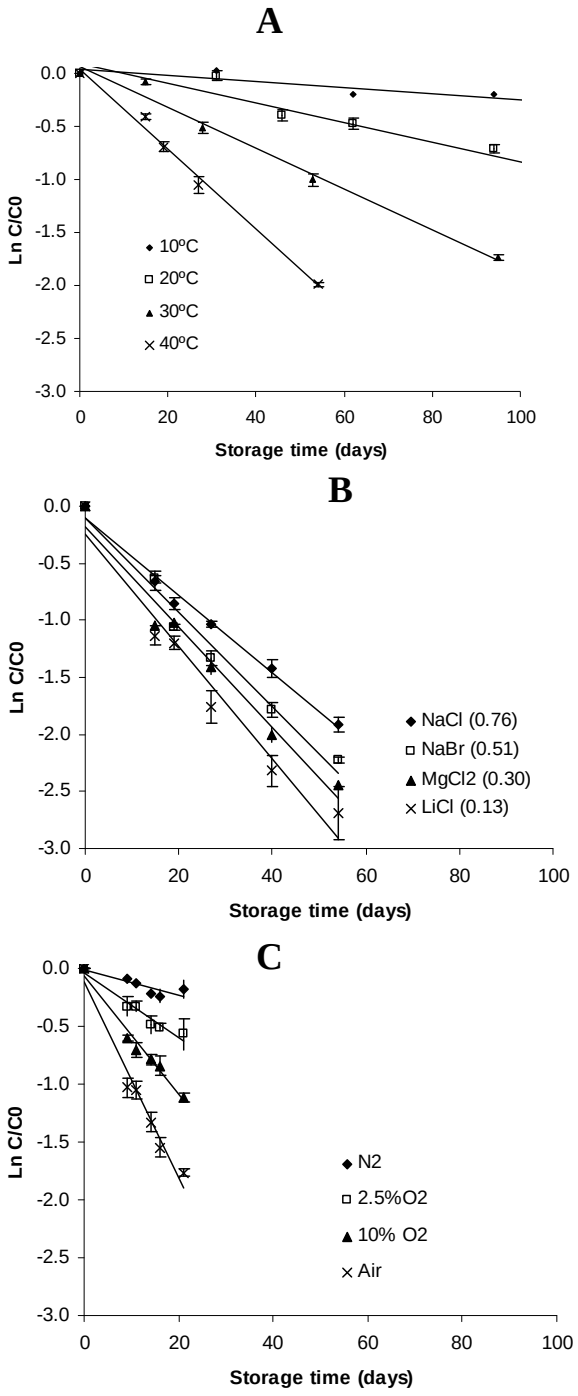


Figure 3. Trans-β-carotene degradation kinetics influenced by temperature between 10-40ºC (A); and water activity (B) and oxygen (C) at 40ºC on a fresh matter basis.

Losses in provitamin A were the least during storage at the lowest temperature and oxygen level and at the highest humidity level.

Carotenoid degradation influenced by temperature was validated using the Arrhenius model (Table 4)

Table 4. Validation of Arrhenius model for a sample of dried Ejumula sweet potato chips stored under ambient anisotherm conditions during 88 days in the UK[a] and during 125 days in Uganda[b] on a fresh weight basis. Oxygen level 21% (air).

			Initial	Final		
		Storage time (days)	($\mu g.g^{-1}$)[c]	Experimental[c] ($\mu g.g^{-1}$)	Predicted by Arrhenius model ($\mu g.g^{-1}$)	Difference (%)
Sample stored in UK[a]	Trans-β-carotene	88	181.2 (5.9)	74.6 (5.1)	72.0	3.5
	Total carotenoids		250.3 (1.1)	94.4 (1.1)	90.3	4.3
Sample stored in Uganda[b]	Total carotenoids	125	219.6 (1.6)	51.4 (1.5)	46.6	9.3

[a] This present study (Calculated a_w: 0.460 (0.012) from chips dry matter (90.4 (0.3) g/100g)
[b] Bechoff et al. (2009b) (a_w from BET model: a_w: 0.400 (0.255); range: [0.22-0.58] from chips dry matter 90.5 (3.5)g/100g; range ([88-92.9g/100g]). [c]Mean of triplicate (standard deviation).

For the total carotenoids and trans β-carotene under anisothermic conditions, the difference between the experimental value and value predicted by the model was 4.3% and 3.5% respectively. The robustness of the model was further tested by using it to predict the carotenoid content a a dried sweet potato sample (Ejumula) that had been stored in Uganda at ambient temperature in LPDE bags (permeable to oxygen) for 125 days in Uganda (Bechoff et al., 2009b). Similarly, the model was also accurate in it predictions where for total carotenoids under anisothermic conditions with a difference between the experimental value and model of 9.3%. Therefore it can be concluded that the model developed under samples stored under controlled laboratory conditions was robust enough to apply to samples stored under field conditions in Uganda and elsewhere.

CONCLUSIONS

The major conclusions from this work were:

- There were few carotenoid losses after drying of OFSP
- There were high carotenoid losses after storage of OFSP
- The chip size and pre-treatment failed to reduce carotenoid degradation in storage.
- The enzymatic degradation was unlikely because peroxidase activity was low or negligible after storage and at low water activities.
- Oxygen and temperature strongly influenced carotenoid degradation.
- In conclusion, there was no low-cost solution to preserve provitamin A. Further work should focus on special packaging (*eg.* vacuum) and low temperature for storage

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