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Abstract: Different drying treatments, cross flow, greenhouse solar, and open-air sun, were applied to an American orange-fleshed sweetpotato variety. Trans-β-carotene losses in flour made from dried chips varied between 16 and 34% in all treatments. Hot air cross flow drying retained significantly more provitamin A than sun drying. Solar and sun drying were not significantly different in terms of provitamin A retention. The shape of the sweetpotato pieces (chip or crimped slice) influenced provitamin A retention during sun-drying; crimped slices retained more provitamin A. Other minor provitamin A compounds in fresh sweetpotato included 13-cis and 9-cis-β-carotene and β-carotene 5,6-epoxide. No significant increase in the cis-isomers was observed after drying.

Vitamin A activity in flours was found to be greater than 1,500 RE (β-carotene:retinol; 13:1) per 100g including in sun-dried samples. Flour from orange-fleshed sweetpotato therefore has potential as a significant source of provitamin A.

* Cover Letter

The Editor
Journal of Food Engineering

Dear Sir

Please find attached our publication entitled "Effect of hot air, solar and sun drying treatments on provitamin A retention in orange-fleshed sweetpotato" that we would like to submit to the Journal of Food Engineering.

With kind regards

Professor Andrew Westby
Director of Research
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Bhesh Bhandari
Editor
Journal of Food Engineering

24 October 2008

Dear Sir

Many thanks for the review of our manscript entitled “Effect of hot air, solar and sun drying treatments on provitamin A retention in orange-fleshed sweetpotato”. We are grateful to the referees for their comments. We have revised the paper in the light of the comments from the second referee and our revised paper is attached.

We have indicated in the text below how we have dealt with each of the comments made.

Many thanks again

Andrew Westby
Director of Research
Natural Resources Institute

Author's responses on reviewers' comments:

Reviewer #1: the work is valuable, interesting, well prepared and written, and therefore I recommend its publication in the present form.

Thank you for this very positive review

Reviewer #2: Authors present an interesting paper on the effect of Effect of hot air, solar and sun drying treatments on provitamin A retention in orange-fleshed sweetpotato; attention should be given to the following points:

Thank you for these very helpful comments

Drying experiments should be described with more detail and the delivery of information such as moisture of the outlet air must be avoided since it is not used towards the objectives of the paper.

In order to provide a clearer view on the drying process the former Table 1 has been replaced by schematic diagrams of the cross flow dryer and the greenhouse solar dryer (Figures 1 and 2). Velocity of air over the samples has been added on the diagrams and outlet humidity (which caused confusion) has been removed. Description of open air sun drying has been added (lines 119-121)

Regarding evaluation of dimensions of samples (LINES 74-84), the estimations presented by authors need to be determined more precisely, possibly using an image analysis system and suitable software (Image J for instance). Moreover, proper evaluation of effects of drying air onto samples must consider the variation of dimensions of samples during drying and not only at initial conditions (Please see Table 4)

Samples have been measured using the suggested image analysis system (Image J) that was downloaded from the internet. Three different photographs showing the samples at the initial stage; during drying (after 2h) and at the end of drying have been analysed using the ROI macro to measure slices' area individually (lines 123-132). Distribution of visible surface area has been plotted in Figure 3 and commented upon in the results (lines 249-252). The effect of visible surface area reduction has been shown in Figure 4 and commented in the results (lines 254-262) and mentioned in the conclusion (line 375).

The actual velocity of air over the sample should be provided; airflow through inlet air pipe is of little use and no relevant information can be derived from these data.
If air leaves chamber at 19-100% relative humidity, samples surely received very different thermal treatment when subjected to drying. What do authors inferred from such differences? Air at 100% RH does not dry

and may even wet samples. Important differences toward moisture removal rates surely arise due to this.

Velocity of air over the sample has been given in Figures 1 and 2. Air at 100% was the outlet air after drying the sample; this has been removed from the text.

At the start of drying very humid air is expelled from the dryer as samples dried then it would be anticipated that drier air would be expelled from the equipment.

Authors surely are aware of the fact of actual air drying is carried out at higher temperatures than those used in their experiments, how do they justify the use of such low temperatures in this type of drying?

The drying temperature used in cross flow dryer (42ºC) was chosen because it is close to that of the greenhouse solar dryer (38ºC)(lines 92-94).

A very good comparison between damage to B carotene was performed, however, authors should expand on the discussion of radiation vs convection effects.

We added a comment on the possible effects of sun radiation (line 260-262), but we feel that this as far as we can go with the data available from this particular study.

In my opinion, authors need considering most of the above comments for his paper to be published in JFE.

Effect of hot air, solar and sun drying treatments on provitamin A retention in orange-fleshed sweetpotato

Running title: Effect of drying on provitamin A in OFSP

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Keywords: Carotenoids, provitamin A retention, drying, sun, solar, hot air, vitamin A activity, sweetpotato

Abstract: Different drying treatments, cross flow, greenhouse solar, and open-air sun, were applied to an American orange-fleshed sweetpotato variety. *Trans-β*-carotene losses in flour made from dried chips varied between 16 and 34% in all treatments. Hot air cross flow drying retained significantly more provitamin A than sun drying. Solar and sun drying were not significantly different in terms of provitamin A retention. The shape of the sweetpotato pieces (chip or crimped slice) influenced provitamin A retention during sun-drying; crimped slices retained more provitamin A. Other minor provitamin A

compounds in fresh sweetpotato included *13*-cis and *9-cis-β*-carotene and *β*-carotene *5,6*-epoxide. No significant increase in the *cis*-isomers was observed after drying. Vitamin A activity in flours was found to be greater than 1,500 RE (*β*-carotene:retinol; 13:1) per 100g including in sun-dried samples. Flour from orange-fleshed sweetpotato therefore has potential as a significant source of provitamin A.

INTRODUCTION

Sweetpotato *(Ipomoea batatas* (L.) Lam.) is an important food crop. It is cultivated in more than 100 countries and ranks third in terms of world root and tuber crops production (FAOstat 2006). In Africa white-fleshed varieties are currently mainly grown. However, recent studies by van Jaarsveld *et al.* (2005) in South Africa and Low *et al.* (2007) in Mozambique demonstrated that consumption of orange-fleshed sweetpotato (OFSP) significantly increased the vitamin A status of children. OFSP could therefore potentially contribute to tackling vitamin A deficiency in African countries, if orange-fleshed varieties were to replace traditional white ones.

Sweetpotatoes are traditionally sun-dried in Africa for consumption in the dry season when fresh roots are not available. Roots are crushed or chipped and then dried for several days on stones or on dried cow dung. Dried pieces can be re-hydrated or milled into flour to be used in porridge. In urban areas, flour can also be used in a variety of baked products to partially replace wheat flour.

Few studies have been reported on *β*-carotene retention in dried sweetpotato. Hagenimana *et al.* (1999) found that drying fresh slices from 24 sweetpotato varieties in a forced air oven at 60ºC for 12 hours reduced total carotenoids content by 30%. Kósambo (2004) similarly reported that drying fresh slices of 13 OFSP varieties from Kenya in an electric cabinet dryer at 58ºC for 4 hours caused an average loss of 35% in *trans-β*-carotene content. Losses in cabinet drying and open air sun drying respectively were 28% and 83% on SPK004 and 47% and 72% on Jonathan varieties (Kósambo 2004). Lower retention in open air sun drying was explained by the destructive effect of sunlight and the non-controlled environmental conditions argued Kósambo (2004). Both van Hal (2000) and Kósambo (2004) reported that artificial cabinet drying generally retained more provitamin A than natural sun drying.

With recent increased interest in using OFSP as a biofortification route to reducing vitamin A deficiency in sub-Saharan Africa, combined with the seasonality of the crop, there is renewed interest in the effect of drying on provitamin A retention. The studies reported in this paper aim to clarify the extent and nature of provitamin A losses during drying at low temperature.

MATERIALS AND METHODS

Raw material

Sweetpotato roots having red skin and deep orange flesh imported from the United States of America were purchased locally in Montpellier, France (Rubina® Agrexco Carmel Rungis, France). No information was available on the variety, exact location, harvest batch and transport, but roots were all purchased in a single batch and stored in a conditioning room (14ºC) during the analysis time (1 month).

Sample preparation for drying

Roots were peeled and chipped/sliced using electrical equipment: CL 50 Robocoupe (Vincennes, France) for crimped slices and A200 Hobart (Marne la Vallee, France) for chips. Precautions were taken to protect samples from light, such as by the use of foil and low light conditions during handling.

Drying of chips

Crimped slices and chips were dried in three dryers described below. Drying times were estimated by weighing the product at regular intervals to an estimated moisture content of 10-11%.

Cross flow dryer

The cross flow dryer made in wood, called SCec-T®, was developed by CIRAD for the drying of granular products such as couscous in West Africa (Méot *et al.* 2007). The air heating system consisted of a butane gas jet and a centrifuge fan (Gomez Eslava 2005). Experiments were carried out indoors. Two temperature probes were positioned between trays and one temperature/humidity probe was placed in the outlet (Gomez Eslava 2005). Hot air arrived through a pipe (ϕ200cm) underneath the drying trays with an air temperature between 24 and 45°C (average 42°C). Low temperature (mean temperature 42ºC) cross flow drying was used for a comparison to be made with solar drying (mean temperature 38ºC).

Temperature, humidity, and air velocity through the sample are presented in Figure 1.

The inlet pipe had three holes (ϕ100 mm) that let air rise and cross flow the food product placed on three overlaid trays (0.94 m x 0.6 m= 0.564 m² for each tray). The air velocity through the product was 0.28 $m.s^{-1}$. The external ambient temperature ranged between 24 and 30°C and relative humidity between 33 and 59% (Figure 1). A 3-mm layer of chips or crimped slices was placed on the trays with an initial loading density of 8 $kg.m^{-2}$ for chips and 15 $kg.m^{-2}$ for crimped slices (Table 1).

Greenhouse solar dryer and open air-sun drying

Solar drying is achieved by direct sun radiation and greenhouse effect. A polythene film covered the solar dryer similar to a greenhouse (Gomez Eslava 2005) of 6 m long x 2.5 m wide. A fan was used to force air into the dryer. Five wire mesh trays (2 x 0.94 m) placed 30 cm above the ground, were loaded with a 2 mm layer of crimped sliced or chipped sweet potato placed on terylene tissue. Two temperature probes and one temperature/humidity probe were placed between the trays to measure temperature and outlet air humidity. The temperature/humidity within the solar dryer ranged from 27 to 50°C /14 to 52% compared to the external ambient range of 24 to 36°C/24 to 52% (Figure 2). Air velocity was 0.04$m.s^{-1}$. Solar irradiance (Pyranometer Cimel CE 180 (Paris, France)) ranged between 421 and 1005 $W.m^{-2}$ (9 am to 2 pm) depending on the course of the sun with an average of 751 $W.m^{-2}$. Temperature and humidity as well as air velocity through sample are presented in Figure 2. Tray loading densities were 3.5 $kg.m^{-2}$ for both chips and crimped slices.

Open air sun drying was carried out concurrently with solar drying and using the same tray loading density (Table 1). Wire mesh trays (0.43x 0.45 m) were placed in the sun on a stand 10 cm above ground level.

Dimensions of chip and slice samples

Three photographs of samples (chips and slices together) in open air drying at the start of drying; after two hours and at the end of drying were analysed using Image J 1.40g Software (National Institute of Health, USA). Using the width of the drying tray as known measurement, pixels values were converted into distance units (cm) (11 pixels=1 cm in the three photographs). On each picture thirty chips and slices were selected individually and their visible surface area calculated using ROI (Region of Interest) manager macro in Image J software. Area measured using the Image J software was in agreement with earlier estimation by calliper measurement (0.01 mm precision) done on ten chips/slices at initial time.

Moisture and water activity determination

Dry matter contents were determined by drying triplicate 5 g samples at 105ºC to constant mass (AOAC 1984). Water activity (Aw) was determined in duplicate on finely blended flour samples using an Aqualab (Decagon, Pullman, WA, USA) controlled with a sodium chloride standard solution (Aw=0.75).

Sample preparation for provitamin A analysis

Fresh samples were prepared according to Rodriguez Amaya and Kimura (2004). Five raw roots were randomly picked, peeled, quartered. Two opposites sections were combined and blended to a fine pulp using a Thermomix multi-purpose household food processor (Vorwerk, Germany). All operations were carried out under dim light. The samples were thoroughly mixed and packed into 100 ml closed plastic boxes wrapped in black plastic and stored at -20ºC before analysis (1 month maximum).

After drying, chips or slices were collected tray by tray and milled into coarse flour using a Thermomix food processor (Vorweck, Germany). Flour was packed into sealed plastic bags under vacuum and stored at -20ºC. Samples were further milled into a fine flour (< 250 µm) on the Laboratory Mill 3100 (Perten Instruments, Roissy, France) before analysis.

Provitamin A carotenoid analysis

Carotenoid extraction was carried out according to Dhuique-Mayer *et al.* (2005) which was based on Taungbodhitham *et al.* (1998). A sub-sample from the homogeneous representative sample, 2 g for fresh and 1 g for dried samples was extracted. Sub-samples were extracted in triplicate on the same day. Extraction was conducted under low light conditions to limit carotenoid losses.

Carotenoids were analysed by reverse-phase high-performance liquid chromatography using a Agilent 1100 system with photodiode array detection (Massy, France) according to the previously published method of Dhuique-Mayer *et al.* (2005). Carotenoids were separated through a C_{30} reverse phase column (250 x 4.6 mm i.d. 5µm YMC (EUROP GmbH) with a flow rate of $1 ml.min^{-1}$, a column temperature at 25ºC and an injection volume of 20 µl. Absorbance was measured with Agilent Chemstation Plus software at 450 nm (beta carotene in Petroleum Ether). Quantification of carotenoids was achieved using calibration curves with *β*-carotene at five concentration levels (4.38, 15.34, 30.69, 46.08, 61.38 mg/L). The curve passed through the origin and had a coefficient of correlation of 0.9986.

Samples from the same extract were analysed on a spectrophotometer UVIKON 933 UV/Visible double beam to measure absorbance at 450 nm. Samples were diluted in

Petroleum Ether; 100 µl/10ml for fresh samples and 50 µl/10ml for dried samples. Concentrations were determined by comparison to a standard curve using pure *β*-carotene from Extrasynthese, Genay, France. Concentration was calculated by Lambert Beer law from the absorbance (Britton *et al.* 1995).

Statistical analyses

Normality of distribution of sample visible surface area was verified by Kolmogorov-Smirnov test used for small sample size (n=30). Analysis of variance (ANOVA one way - homogeneity of variance test) was carried out to determine whether there were significant differences between means; a significant difference between means was determined by a Tukey test. An independent sample T Test was carried out to determine significant differences between provitamin A compounds before and after drying. All data were integrated on SPSS 14.00 for Windows.

RESULTS AND DISCUSSION

Quality of flour

Flour from dried sweetpotato was evaluated for its moisture content and water activity in order to assess its quality for storage. Tray loading and drying time for each treatment and the moisture contents and water activities (Aw) of flours are shown in Table 1.

The flour moisture content was between 9.8 and 11.2%. Flour water activity that ranged between 0.38 and 0.45 should favour carotenoid stability. It was demonstrated on dehydrated carrots in different conditions that better stability of carotenoids was obtained with water activity of 0.43 (Arya *et al.* 1979) and between 0.31-0.54 (Lavelli *et al.* 2007). Moreover water activity below 0.7 also limits the risk of microbial deterioration and the lowest lipid oxidation is found between 0.2-0.4 (Rahman and Labuza 1999). The water activities of the dried sweetpotato flours were therefore considered suitable for storage.

Influence of drying treatment on provitamin retention

Provitamin A losses influenced by drying treatment are reported in the Table 2 for chipped sweetpotatoes.

Losses with the different drying techniques ranged from 13 to 33% in total carotenoids content and 16 to 34% in *trans-β*-carotene content. Losses were low for all treatments including sun drying. Levels of loss in sun drying were in contrast to the high levels of loss reported (72 to 83%) previously by Kósambo (2004).

Drying by hot air gave significant higher retention than sun drying (respectively 13% compared to 33% in total carotenoids content and 16% compared to 34% in *trans-β*-carotene content) in chips. There was no significant difference between drying by hot air and solar drying.

Negi and Roy (2000) also reported that solar drying was equivalent to cabinet drying at 65°C in terms of provitamin A retention in various leafy vegetables (savoy beet, amaranth and fenugreek). However in other studies retention in solar drying was significantly less in comparison with artificial drying: the same authors found in another study that solar drying was found to induce more *β*-carotene losses than cabinet drying at 65°C in savoy beet and amaranth leaves (Negi and Roy 2001). Solar drying results can be variable because it depends on the prevailing environmental conditions. In this study, temperature in the solar dryer was similar to the hot air dryer (42ºC). However the hot air cross flow dryer had a better drying performance; higher tray loading and quicker drying (8 kg.m^{-2}; 2 h) compared to solar dryer (3.5 kg.m^{-2}; 8 h) (Table 1). No significant difference between solar and sun drying was observed for samples dried under the same conditions (3.5 kg.m^{-2}; 8 h). Similar results were reported by Mulokozi and Svanberg (2003) working with leafy vegetables, where on the whole solar drying retained more provitamin A carotenoids than open-sun drying. However when analysing individual results, it appeared there were no significant differences between solar and sun drying on five out of seven leafy vegetables.

The low levels of losses obtained in this study with sun drying may be partially explained by environmental factors: the weather was hot and dry during the study with an ambient average of 29°C/39%, which allowed quick drying (8h).; the weather was also windy during the experiment which allowed rapid sun-drying. Traditionally in sub-Saharan Africa, sweetpotato pieces are sun-dried for 2-3 days. Chavez *et al.* (2007) reported 62.1% losses in sun dried cassava dried for 2-3 days up to a moisture content of 12%. However a recent study by Bengtsson *et al.* (2008) using Ugandan sweetpotato varieties confirmed the results of this study. Losses of *trans-β*-carotene in oven; solar and open sun drying on OFSP chips were respectively 12%; 9% and 16% in Ejumula variety from Uganda dried up to 10% moisture. Drying times and temperature were 10 h at 57ºC in oven drying; and between 6-10 h in sun (30-52ºC) and solar drying (45-63ºC). Bengtsson *et al.* (2008) indicated that there were no significant differences of retention between oven; solar and sun drying, contrary to previous publications. Bengtsson *et al.* (2008) likewise commented that a quick drying may result in higher retention.

Influence of either chipping or slicing on provitamin A content

The influence of chip size on total carotenoids content under solar and sun drying carried out under the same conditions (same time and loading density) was investigated (Table 3).

The distribution of mean sample visible surface area over 30 chips or crimped slices during drying followed a normal distribution (Figure 3). “shrinkage” of the visible surface area of the samples during drying was more marked for chips (51.2% of the initial area) compared to crimped slices (70.5% of the initial area) (Figure 4).

When drying chips, there was a significant difference between sun and solar drying in terms of provitamin A content under the same conditions. The difference was, however, not significant in crimped slices. Although data are only available for sun-dried samples, it would appear that chips that had the greatest carotenoid loss also had the greatest degree of “shrinkage”. It can be therefore hypothesised that there is relationship between the degree of “shrinkage” and carotenoid degradation, but this needs further investigation. It is possible that there could be a relationship between cellular collapse caused by “shrinkage” and susceptibility of degradation of provitamin A by sun radiation, but more research would be needed to understand this more fully.

Identification of provitamin A carotenoids

Several carotenoids were observed on the chromatogram of fresh sweetpotato (16; 17; 24; 25; 30; 32; 33; 34; 37; 39 minute retention times) (Figure 5). Carotenoids were identified by diode array by their three-peak spectrum at three wavelengths.

Trans-β-carotene peak appeared at 37 minutes (peak 4). The spectrum of maximum absorption wavelength was 428-452-478 nm in ethanol/hexane, slightly staggered by 2.5 mm compared to literature and % III/II= 13% was in accordance with literature (Rodriguez Amaya and Kimura 2004). (%III/II is an indicator of fine spectral structure calculated as ratio of longest-wavelength absorption peak III and that of the middle absorption peak II). Apart from *trans-β*-carotene (peak 4), peaks 1 and 2 were clearly defined (retention time 16 and 30 minutes). Peak 1 did not appear constantly on all samples analysed; the peak 1 was definitely not a carotene: its retention time far from apolar *β*-carotene indicated a more polar molecular structure such as xanthophylls.

Peak 2 was firstly thought to be *β*-cryptoxanthin because the retention time was identical to the *β*-cryptoxanthin standard when co-injected (retention time 30 minutes). However the calculation of the %III/II of peak 2 (%III/II= 46%) was contradictory with *β*-cryptoxanthin's %III/II equal to 20%. On the other hand it was in agreement with *β*-carotene 5,6 epoxide's %III/II equal to 57% (Rodriguez and Rodriguez-Amaya 2007). It is to note that the molecular weights of *β*-cryptoxanthin and β-carotene 5,6 epoxide are the same (552g.mol^{-1}) which make the identification difficult. Furthermore it was found that β-carotene 5,6-epoxide was present in the fresh roots of Kakamega sweetpotato variety (Kosambo *et al.* 1998); on the other hand β-cryptoxanthin was not mentioned as part of the carotenoids of sweetpotato in literature.

The amounts of both compounds, peaks 1 and 2, were small (less than 10% total carotenoids).

Other compounds were less clearly defined; the peak 3 (retention time 34 minute) fitted a typical curved-*cis* and was identified as *13-cis-β*-carotene by co-injection of *13-cis* standard. Peak 5 appearing after all-trans-β carotenoids (retention time 39 minutes) was likely to be *9-cis-β*-carotene (Lessin *et al*. 1997; Rodriguez-Amaya and Kimura 2004; Kimura *et al*. 2007). No *α*-carotene was identified from raw sweetpotato.

Quantification of provitamin A carotenoids

The percentage of *trans-β*-carotenes and minor carotenoids identified are reported in Table 4 for fresh and dried sweetpotato in the drying treatments jointly analysed.

The contents of *trans-β*-carotene and minor compounds: isomers and *β*-carotene 5,6 epoxide were found to be similar in both fresh and dried samples. These results differ from other previous studies that have indicated that under stressful conditions, such as heating, UV exposure and storage, *trans*-carotenoids tend to isomerise into *cis*-carotenoids. There may be several reasons for these observations. Raw roots already contain smaller amounts of *13-cis* isomers if they were stored too long (Chandler and Schwartz 1988). The presence of small amounts of 9-*cis* and 13-*cis* in Rubina sweetpotato raw roots could be explained by long root storage time after harvest; these were roots grown in USA and purchased in France. Drying temperatures were not very high (<45°C on average) and drying was quick. The quantity of isomer formed was found to be related to the heat and length of treatment (Chandler and Schwartz 1988; Doering *et al.* 1995). This may explain why carotenoids losses during drying were low (13-40%). In addition, isomerisation in dried samples may need harsher processing conditions to occur. These results were consistent with a study by Mulokozi and Svanberg (2003) on leafy vegetables submitted to solar and sun drying in Tanzania where all trans-β carotene *13-cis* and *9-cis* isomers were similarly affected by sun and solar drying. *13-cis* and *9-cis* isomers represented 5% and

15% of *β*-carotene respectively in Mulokozi and Svanberg (2003) whilst 3% and 6% respectively in this study. Mulokozi and Svanberg (2003) formulated the hypothesis that "the stereo-isomeric forms of *β*-carotene could be strongly correlated with each other on light exposure and storage"; which means that instead of isomerising, *trans-β*-carotene could have been converted into oxidative products as well as their isomers. This hypothesis was corroborated by the fact that ratio of *trans-β*-carotene, *13-cis*, *β*-carotene 5,6 epoxide and *9-cis* are the same in fresh and dried samples. This result was confirmed by Kidmose *et al.* (2007) on shade dried OFSP; same amount of *13-cis-β*-carotene was found in root and flour made from dried chips (representing 1% of *trans-β*-carotene). An interesting and recent work by Hiranvachat *et al.* (2008) showed that a minimum of 5h at constant temperature of 60ºC was necessary to induce formation of *13-cis-β*-carotene in oven-dried diced carrot. The absence of isomerisation could therefore be explained since the average temperature in the three dryers was around 40ºC and never went beyond 50ºC. Oxidation occurs through a free radical process and loss of water during drying has proved to be a risk factor (Chandler and Schwartz 1988). Therefore loss of carotenoids (by oxidation) would have occurred rather than isomerisation.

The percentage of *β*-carotene 5,6 epoxide was significantly lowered after drying. This could result from quicker degradation of *β*-carotene 5,6 epoxide than *β*-carotene. A combination of factors (light, heat, exposure to oxygen) could have degraded *β*-carotene 5,6 epoxide slightly more rapidly than trans-*β*-carotene and stereo-isomers.

Vitamin A activity

Vitamin A activity was calculated using the recent conversion factor of Haskell *et al.* (2004), who demonstrated that bioavailability in fresh sweetpotato puree was *β*-carotene: retinol 13:1. This updated the previous estimation of 6:1 by NAS/NRC (1974). Bioavailability of *cis*-isomers is estimated as half of *trans*-*β*-carotene and that of *β*-carotene 5,6 epoxide would represent also half of *β*-carotene activity because it has only one un-substituted *β*-ionone ring instead of two. Carotenoids contents from minor provitamin A carotenoids and *trans*-*β*-carotene and an estimation of vitamin A activity are summarised in Table 5.

Estimated vitamin A activity ranged between 1,596 and 2,012 RE per 100g flour and was 2,382 RE per 100g on fresh roots (dry basis). All flours, including sun-dried (1,596 RE), provided a substantial amount of vitamin (about 400% of daily nutritional requirements). These estimations do not take into account further significant losses occurring during the preparation of finished products from the orange-fleshed sweetpotato flours. An example of finished product is a traditional doughnut commonly eaten in Uganda called mandazi. Mandazis are usually prepared using wheat flour, but up to 30% of it can be substituted with sweetpotato flour (Owori and Hagenimana 2000). These authors reported that dried chips of Zappalo sweetpotato variety with a vitamin A activity of 1,170 RE per 100 g (db) resulted in a mandazi with vitamin A activity of 157 RE per 100g (fb) (Hagenimana *et al.* 1999). One hundred grams of the finished product could therefore meet 40% of the recommended intake of provitamin A for children. Another example is porridge made from sweetpotato-sorghum composite flour (70%:30%). Kosambo (2004) reported that dried chips of Jonathan sweetpotato variety with a vitamin A activity of 853 RE per 100g (db) resulted in porridge with vitamin A activity of 448 RE (db); considering a moisture content of 75% due to addition of water, one hundred grams of porridge (fb) would meet 30% of the recommended intake of provitamin A for children. In this present study greater vitamin A activities in flour of 1946 RE on average compared to Owori and Hagenimana (2000) and Kosambo (2004) should favourably result in greater vitamin A content in finished products. Products such mandazi and porridge made from orange-fleshed sweetpotato could therefore contribute significantly to vitamin A intake in the diet.

CONCLUSION

The effects of drying treatment and chip size on provitamin A losses in OFSP were investigated. Low levels of loss varying between 16 and 34% in *trans-β*-carotene were obtained for all the treatments. The significant findings are that sun-drying was not so damaging to provitamin A content compared to solar and hot air drying. Another finding was chip shape had an influence on retention: sun-dried samples exhibited significantly lower retention on chips but retention was greater with crimped slices. Crimped slice bulkiness or lesser degree of "shrinkage" may have protected them from damage from the sun's rays and oxidation. These low levels of loss may be attributed by quick drying (8h) due to the favourable dry, hot and windy climatic conditions. Contrary to expectations, there was not an increase in isomerisation (formation of *9-cis* and *13-cis-β*-carotenes) due to drying. A similar result was found on a study on sun and solar dried leafy-vegetables by Mulokosi and Svanberg (2003) and Kidmose *et al.* (2007), who suggested that all stereo-isomers; *trans-β*-carotene, *9-cis* and *13-cis*, are likely to be oxidised following the same trend. OFSP flour therefore gave promising results with respect to provitamin A retention. Because of the high *β*-carotene content of fresh roots (close to 300 $\mu g.g^{-1}$ db) and its high retention even in low cost-sun-drying treatment, orange-fleshed sweetpotato demonstrates a potential for a significant contribution to vitamin A in the diet.

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Figure

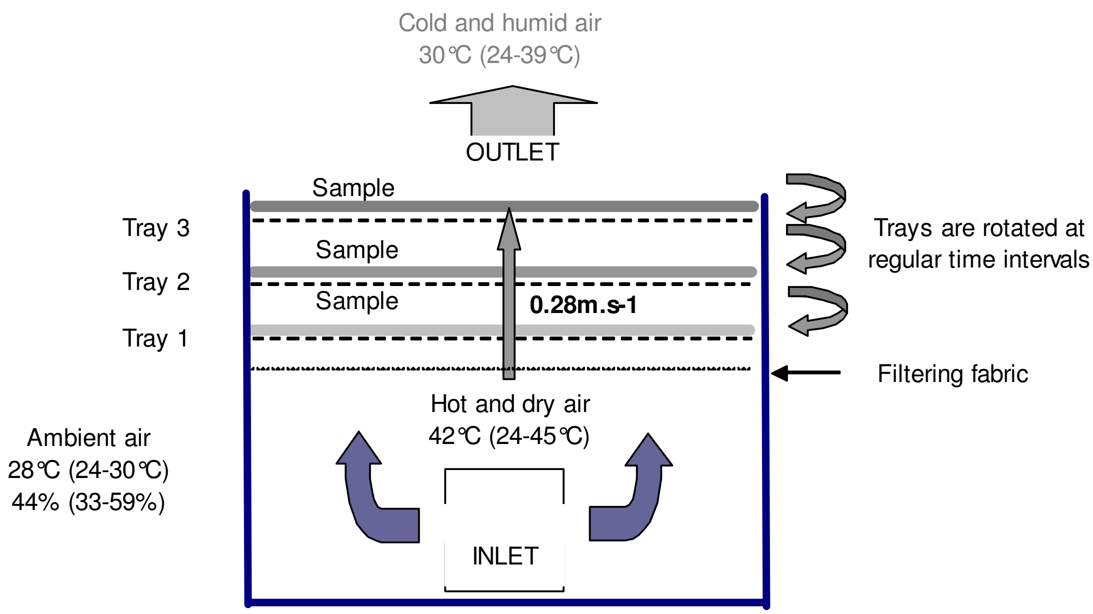

Figure 1: SCec-T® cross flow dryer
Temperature/ humidity: mean (min-max)

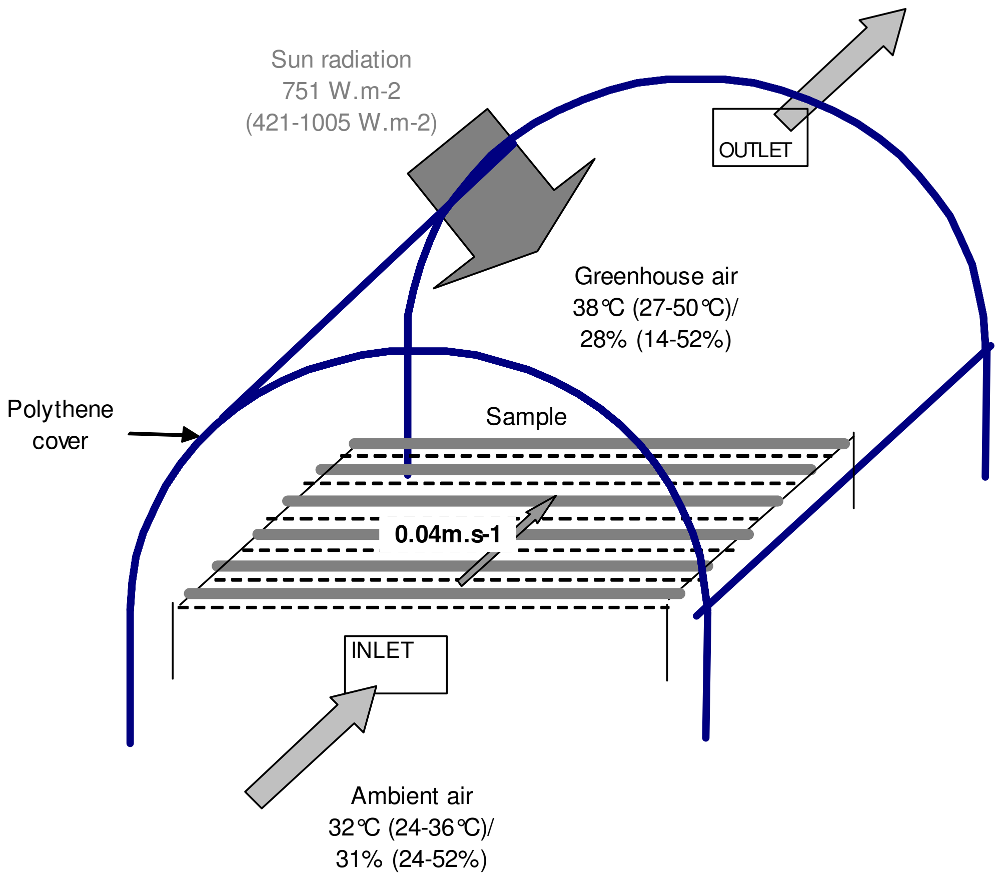

Figure 2: SCec-Serre® greenhouse solar dryer
Temperature/ humidity: mean (min-max)

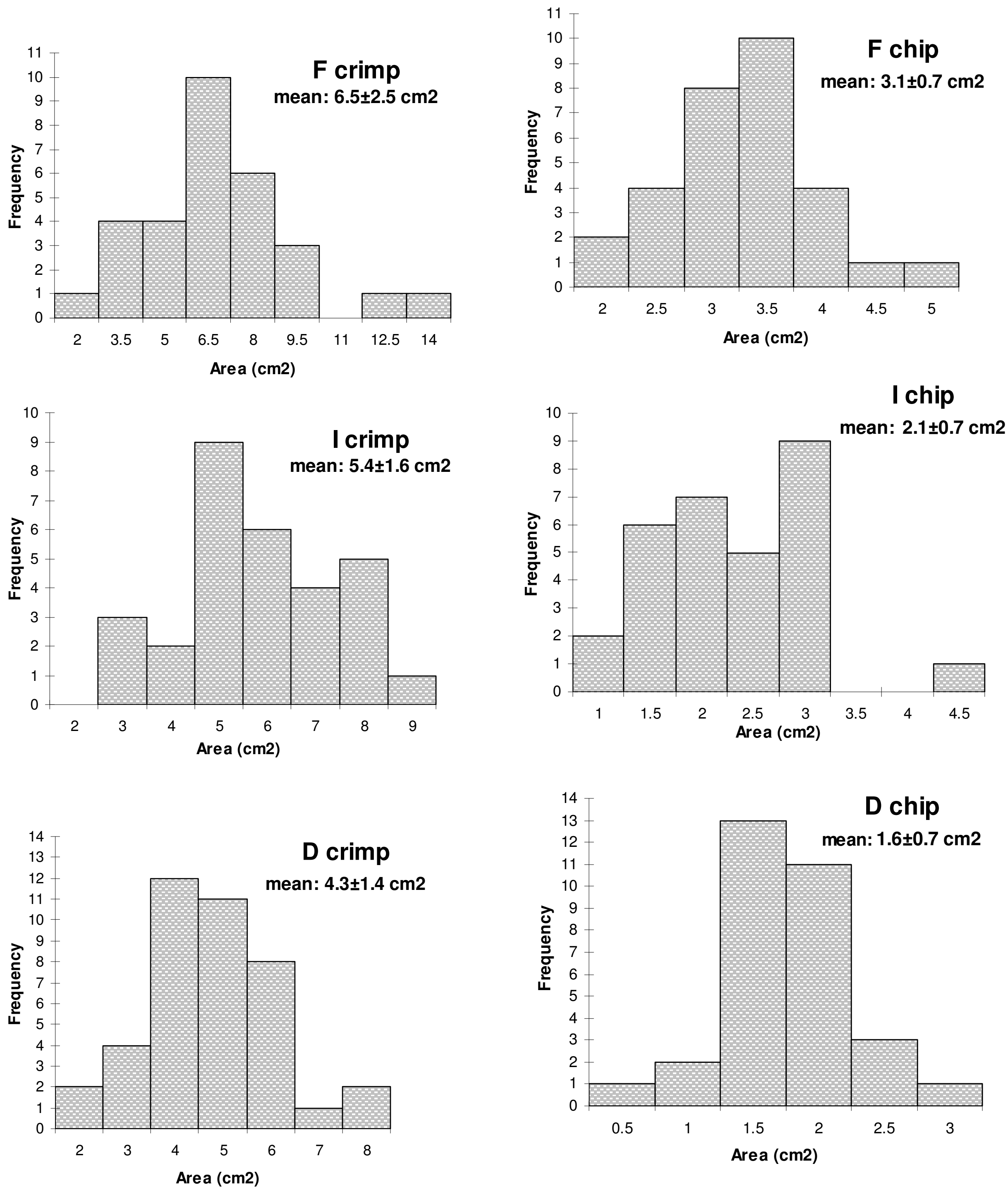

Figure 3: Distribution of grated chip and crimp slice visible surface areas during open air-sun drying. F=fresh; I=after two hours of drying; D=dried. Each histogram represents the area of 30 samples. mean ± standard deviation.

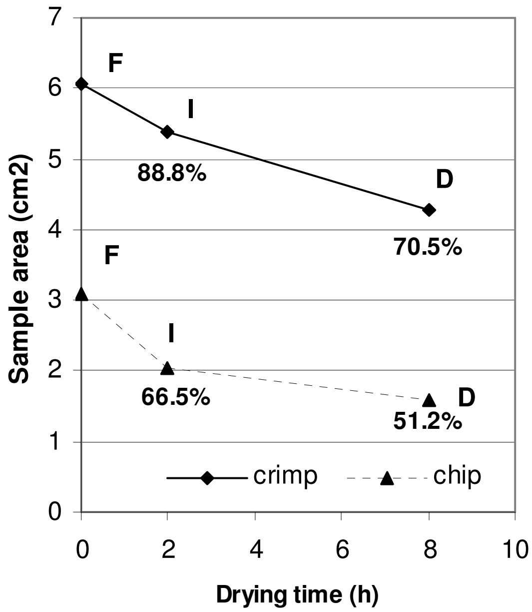

Figure 4: Reduction of sample visible surface area during open air-sun drying. F=fresh; I=after two hours of drying; D=dried. Each value is a mean of 30 samples.

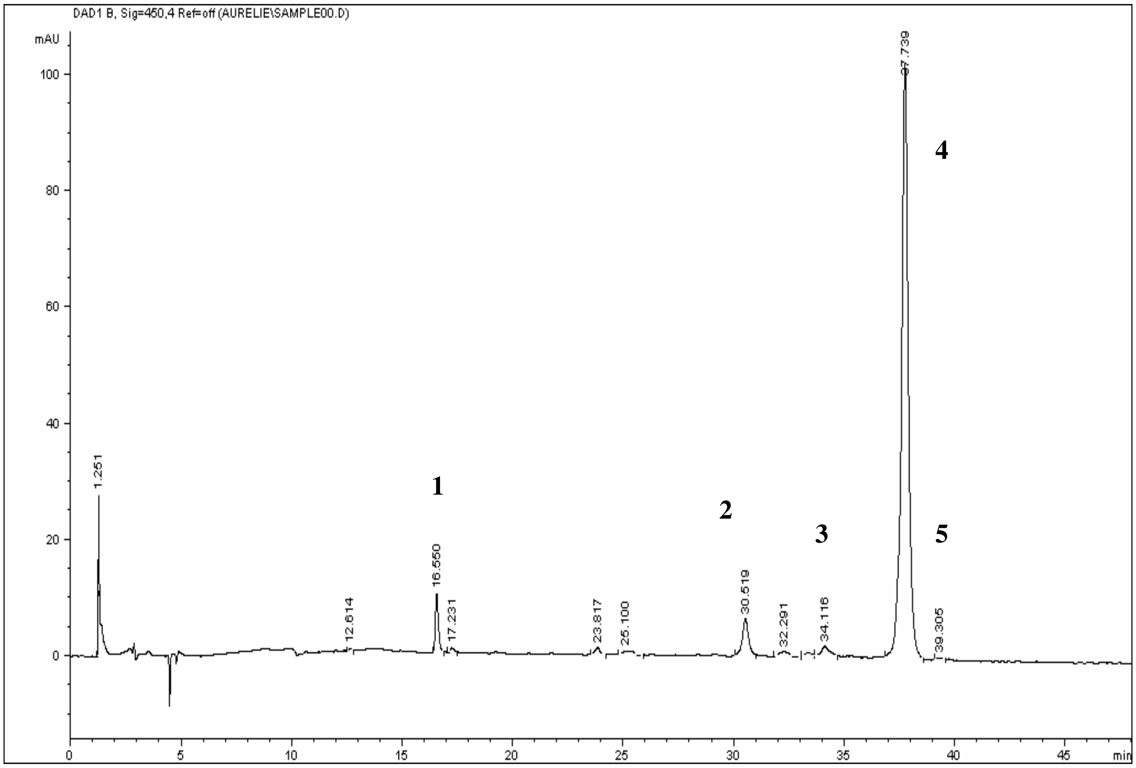

Figure 5: Reverse phase HPLC separation of carotenoids in raw sweetpotatoes

1. non-identified polar carotenoid; 2. β-carotene 5,6 epoxide; 3. 13-cis- β-carotene, 4. all trans-β-carotene; 5. probably 9-cis - β-carotene

Table

Table 1: Tray loading, drying time, moisture content and water activity of flours made from dried chips and crimped slices

Dryer	Slicing	Tray loading (kg/m^2)	Drying time (h)	Moisture content (%)*	Water activity (Aw)**
Hot air cross flow	Chips	8	2.0	11.0	0.442
	Slices	15	7.5	9.8	0.378
Solar	Chips	3.5	8.5	10.0	0.413
	Slices	3.5	8.5	9.9	0.397
Sun	Chips	3.5	8.0	9.9	0.443
	Slices	3.5	8.0	11.2	0.449

**Mean of three replicates with a standard deviation lower than 1%*
***Mean of two replicates*

Table 2: Influence of drying treatment on losses of total carotenoid content and *trans-β*-carotene content in chips.

Dryer	**Loss in total carotenoids (%)**	**Loss in *trans-β* carotene (%)**
Hot air	13a	16a
Solar	21ab	23ab
Sun	33b	34b

Values in the same column followed with different letters are significantly different; ANOVA Tukey ($p \leq 0.05$).

Table 3: Influence of size reduction and drying treatment on total carotenoid content of dried sweetpotato (µg/g db)

	Solar	Sun
Chip	294(17)a	250(8)b
Crimped slice	307(20)a	319(18)a

Each value corresponds to an average of three extractions made on 100g flour from milled dried slices. Values followed with different letters are significantly different; ANOVA Tukey ($p \leq 0.05$).

Table 4: *Trans-β*-carotene and minor carotenoids as percentage of total carotenoids content in fresh and dried sweetpotato

Average retention time (min.)	37	34	30	39
Identified compound	*Trans-β*-carotene	*13-cis-β*-carotene	*β*-carotene 5,6 epoxide	*9-cis-β* carotene
Fresh (%)	86.0±3.8a	2.3±0.7a	5.6±1.5a	1.3±0.9a
Dried (%)	88.2±3.6a	2.7±1.0a	4.5±0.7b	1.1±0.6a

Each value corresponds to an average of 20 extractions made on a puree from five fresh roots or on a 100g-flour from milled dried chips/slices. Values in the same column followed with different letters are significantly different; Independent T-test

Table 5: Estimated vitamin A activity of samples of fresh and dried sweetpotato under different conditions based on their carotenoids content and contribution to daily vitamin A requirement

Treatment	*Trans*-*β*-carotene (µg/g db)	*13- cis-β*-carotene (µg/g db)	*β*-carotene 5,6 epoxide (µg/g db)	*9-cis-β*-carotene (µg/g db)	Estimated vitamin A activity (RE/100g db)*	Contribution to daily vitamin A requirement (% fb)**
Fresh	293.0 (13.3)a	9.1 (0.4)ab	18.4 (1.4)a	6.0 (1.1)a	2,382 (111) a	-
Chipped& cross flow dried	246.9 (22.8)abc	10.2 (0.9)a	14.6 (1.0)ab	4.6 (0.1)abc	2,012 (182) abc	448
Crimped sliced& cross flow dried	232.0 (23.4)bc	10.2 (0.7)a	13.2 (0.5)ab	4.9 (1.5)ab	1,893 (189)bc	427
Chipped& sun dried	198.6 (18.5)c	6.3 (2.7)ab	9.3 (4.9)b	2.4 (1.1)bcd	1,596 (174)c	360
Chipped& greenhouse solar dried	226.0 (16.9)bc	10.4 (1.4)a	12.4 (0.7)ab	5.4 (0.2)a	1,847 (128)bc	416

Each value corresponds to an average of three extractions made on a puree from five fresh roots or on 100g-flour from milled dried chips/slices. Values in the same column followed with different letters are significantly different

**µg retinol equivalent (RE) = 1/ 13µg trans-β-carotene (Haskell et al. 2004) and half of the provitamin A activity for other pro-vitamin A compounds µg retinol equivalent (RE) = 1/ 26µg cis-β-carotene and β-carotene 5,6 epoxide. Calculated on a dry weight basis (db)*

*** According to FAO/WHO (2002) recommendations are 400 RE per 100 g per day for children (2-6 years old); calculated per 100g of flour on a fresh weight basis (fb).*