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

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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 100 g including in sun-dried samples. Flour from orange-fleshed sweetpotato therefore has potential as a significant source of provitamin A.

1. 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 60 °C for 12 h 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 58 °C for 4 h 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 by 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.

2. Materials and methods

2.1. Raw material

Sweetpotato roots having red skin and deep orange flesh imported from the United States of America were purchased locally

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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 (14 °C) during the analysis time of 1 month.

2.2. 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.

2.3. 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%.

2.3.1. 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 (ϕ200 cm) underneath the drying trays with an air temperature between 24 and 45 °C (average 42 °C). Low temperature (mean temperature 42 °C) cross flow drying was used for a comparison to be made with solar drying (mean temperature 38 °C).

Temperature, humidity, and air velocity through the sample are presented in Fig. 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 × 0.6 m = 0.564 m^2 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% (Fig. 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).

2.3.2. 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 × 2.5 m wide. A fan was used to force air into the dryer. Five wire mesh trays (2 × 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 24–36 °C/24 to 52% (Fig. 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 Fig. 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 (0.43 × 0.45 m) were placed in the sun on a stand 10 cm above ground level.

2.4. Dimensions of chip and slice samples

Three photographs of samples (chips and slices together) in open air drying at the start of drying; after 2 h and at the end of drying were analysed using Image J 1.40 g 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.

2.5. Moisture and water activity determination

Dry matter contents were determined by drying triplicate 5 g samples at 105 °C to constant mass (AOAC, 1984). Water activity (Aw) was determined in duplicate on finely blended flour samples

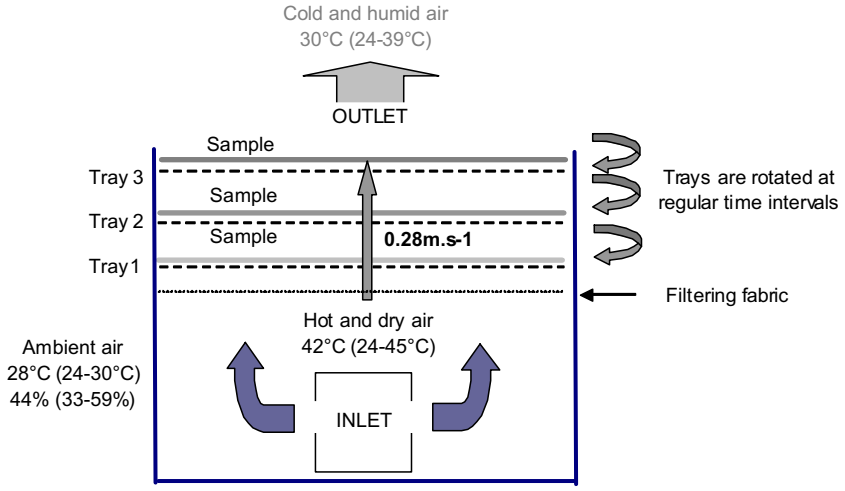

Fig. 1. SCec-T® cross flow dryer (temperature/humidity: mean (min–max)).

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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.

using an Aqualab (Decagon, Pullman, WA, USA) controlled with a sodium chloride standard solution (Aw = 0.75).

2.6. 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 −20 °C 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 −20 °C. Samples were further milled into a fine flour (<250 μm) on the Laboratory Mill 3100 (Perten Instruments, Roissy, France) before analysis.

2.7. 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. Subsamples 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 × 4.6 mm i.d. 5 μm YMC (EUROP GmbH) with a flow rate of 1 ml min^{-1}, a column temperature at 25 °C 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/10 ml for fresh samples and 50 μl/10 ml for dried samples. Concentrations were determined by comparison to a standard curve using pure β-carotene from Extrasynthese, Genay, France.

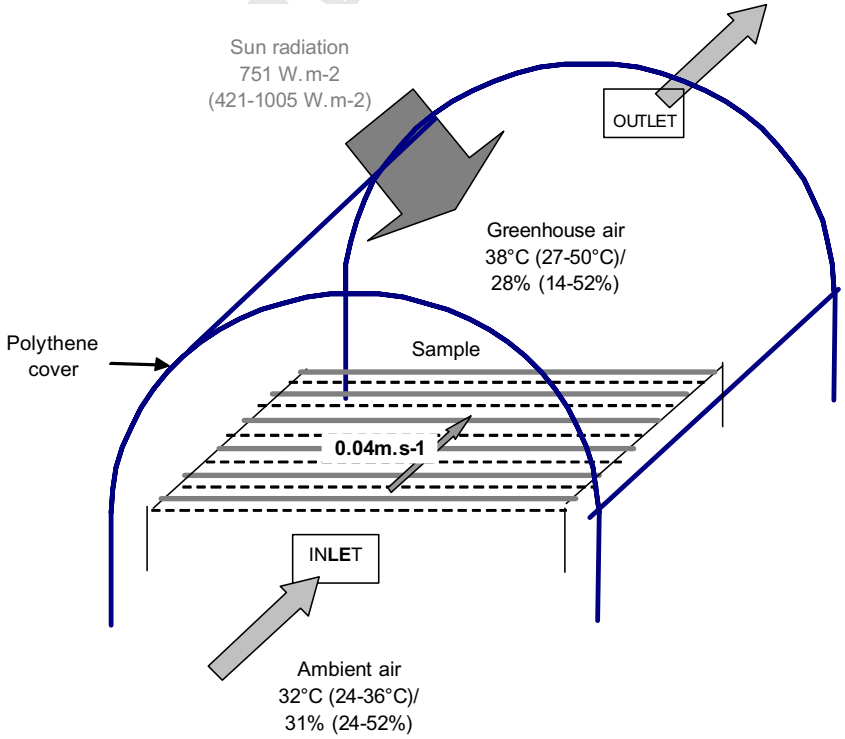

Fig. 2. SCec-Serre® greenhouse solar dryer (temperature/humidity: mean (min–max)).

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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	23 ab
Sun	33b	34b

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

Table 3
Influence of size reduction and drying treatment on total carotenoid content of dried sweetpotato (μg/g db). Q3

	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 100 g flour from milled dried slices. Values followed with different letters are significantly different; ANOVA Tukey ($p < 0.05$).

Concentration was calculated by Lambert Beer law from the absorbance (Britton et al., 1995).

2.8. 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.

3. Results and discussion

3.1. 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 Q2 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 and 0.4 (Rahman and Labuza, 1999). The water activities of the dried sweetpotato flours were therefore considered suitable for storage.

3.2. 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 from 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 (72–83%) 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 (42 °C). 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 level 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 (8 h); 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 57 °C in oven drying; and between 6–10 h in sun (30–52 °C) and solar drying (45–63 °C). 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.

3.3. 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 (Fig. 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) (Fig. 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

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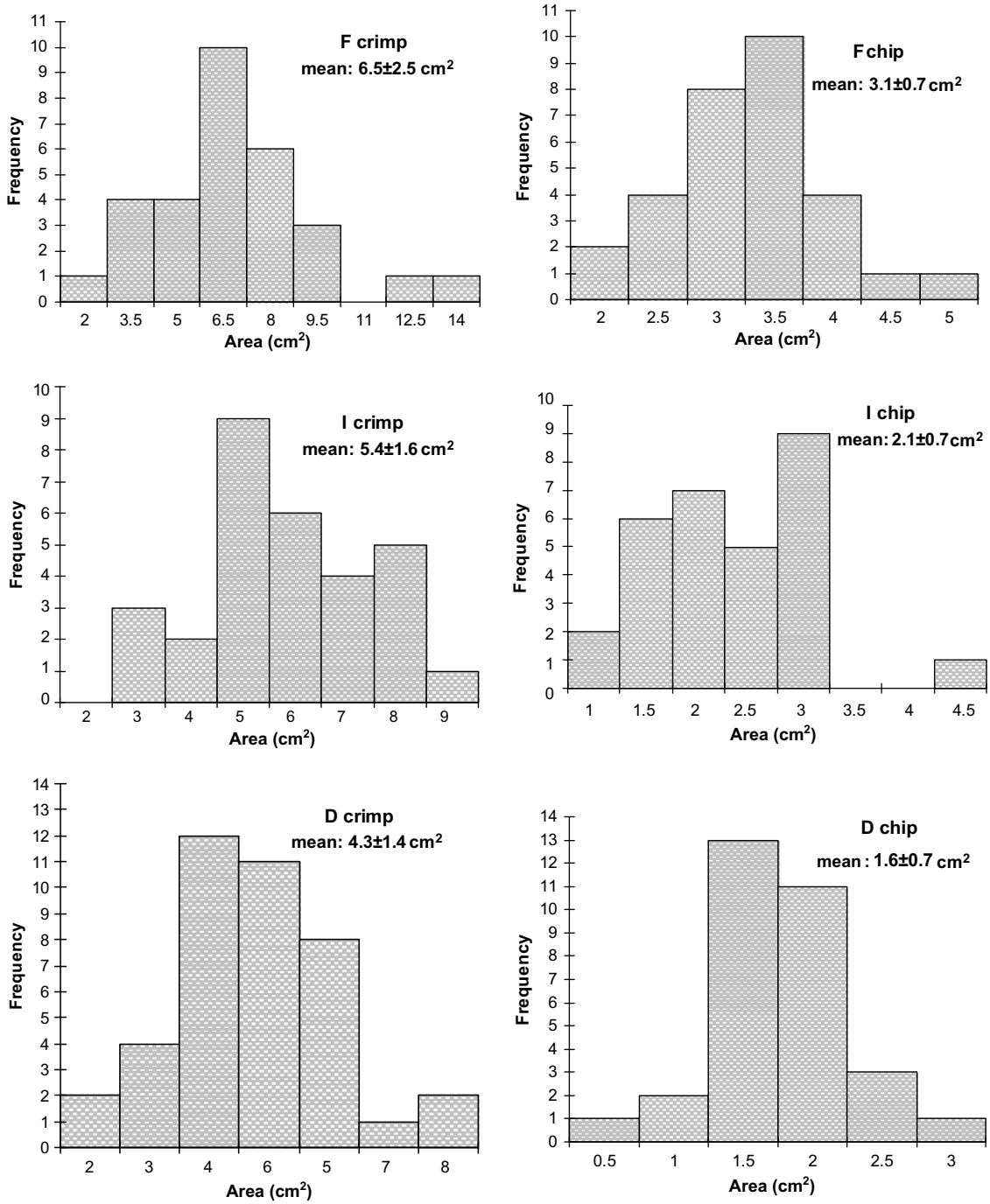

Fig. 3. Distribution of grated chip and crimp slice visible surface areas during open air-sun drying. F, fresh; I, after 2 h of drying and D, dried. Each histogram represents the area of 30 samples (mean ± standard deviation).

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.

3.4. 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 min retention times) (Fig. 5). Carotenoids were identified by diode array by their three-peak spectrum at three wavelengths.

Trans-β-carotene peak appeared at 37 min (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 min). 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

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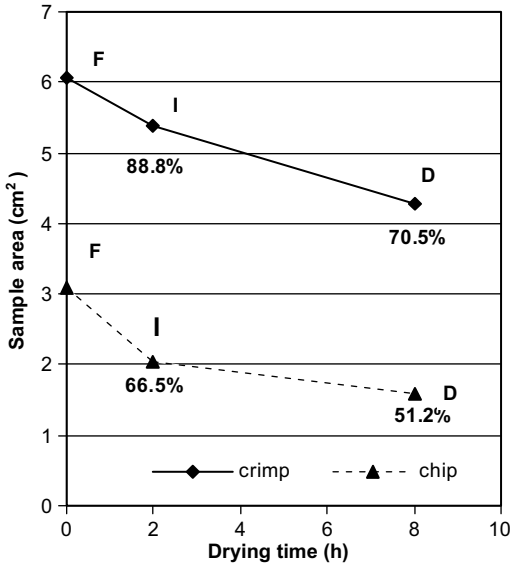

Fig. 4. Reduction of sample visible surface area during open air-sun drying. F, fresh; I, after 2 h of drying and D, dried. Each value is a mean of 30 samples.

co-injected (retention time 30 min). 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 (552 g 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 min) 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 min) was likely to be *9-cis*-β-carotene (Lessin et al., 1997; Rodriguez Amaya & Kimura, 2004; Kimura et al., 2007). No α-carotene was identified from raw sweetpotato.

3.5. 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

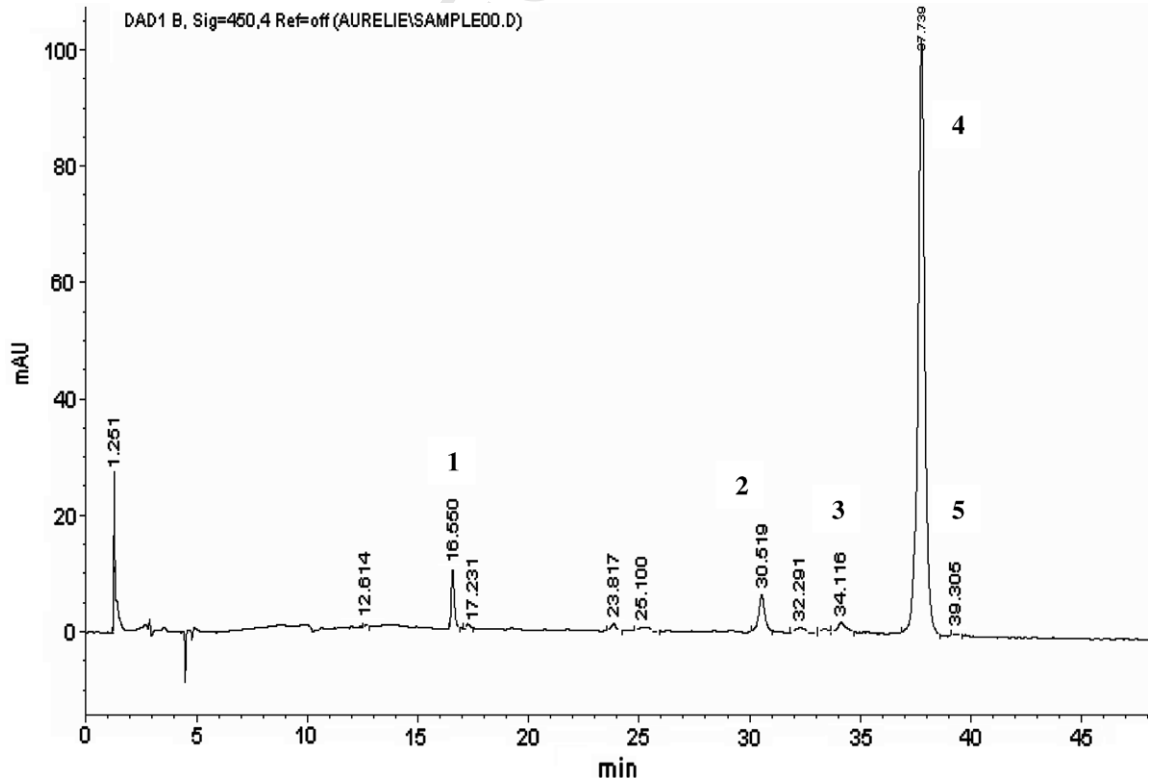

Fig. 5. Reverse phase HPLC separation of carotenoids in raw sweetpotatoes. 1, non-identified polar carotenoid; 2, β-carotene 5,6 epoxide; 3, *13-cis*-β-carotene; 4, all *trans*-β-carotene and 5, probably *9-cis*-β-carotene.

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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 100 g-flour from milled dried chips/slices. Values in the same column followed with different letters are significantly different; Independent T-test.

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 Hiranvarachat et al., (2008) showed that a minimum of 5 h at constant temperature of 60 °C 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 40 °C and never went beyond 50 °C. 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.

3.6. 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 100 g flour and was 2,382 RE per 100 g 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 100 g (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%). Kósambo (2004) reported that dried chips of Jonathan sweetpotato variety with a vitamin A activity of 853 RE per 100 g (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.

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/100 g db)*	Contribution to daily viatmin 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 and 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 and 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 and 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 and 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 100 g-flour from milled dried chips/slices. Values in the same column followed with different letters are significantly different.
* μg retinol equivalent (RE) = 1/13 μg *trans*-β-carotene (Haskell et al., 2004) and half of the provitamin A activity for other provitamin A compounds μg retinol equivalent (RE) = 1/26 μg *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/100 g per day for children (2–6 years old); calculated by 100 g of flour on a fresh weight basis (fb).

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4. 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 (8 h) 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 Mulokozi 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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