On-farm evaluation of the impact of drying and storage on the carotenoid content of orange-fleshed sweet potato (Ipomea batata Lam.)

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On-farm evaluation of the impact of drying and storage on the carotenoid content of orange-fleshed sweet potato (*Ipomea batata* Lam.)

Running head: On-farm carotenoid loss in sweet potato chips

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Abstract: Drying of orange-fleshed sweet potato was evaluated under African rural conditions. Three locally-built dryers (open air-sun; tunnel and shade) were tested using Resisto and MGCL01 varieties in Mozambique. Total carotenoid losses were low in all dryers being 9.2% on average. After drying sweet potato chips were stored in a traditional way (jute bags inside a mud house). Chip size (thin, thick chip or slice) had a significant effect on drying ($p<0.05$) but not on storage; and variety had an effect on both. Total carotenoid losses during storage were much higher being 83.7% on average, after four months, with main individual carotenoids fitting a first order kinetics degradation. Globally carotenoid losses on-farm or on-research station, were of similar level.

Keywords: *Ipomea batata* (L.) Lam, carotenoids, storage, drying, on-farm, on-research.

INTRODUCTION

Mozambique is one of the poorest countries in the world, and additionally, one of the most affected by vitamin A deficiency; 71% of the children under five are deficient (Aguayo & Baker, 2005). White-fleshed sweet potato (WFSP) is traditionally part of the Mozambican diet, as a source of carbohydrate. An integrated agricultural and nutritional intervention involving households with young children in rural areas of Mozambique has demonstrated that regular consumption of orange-fleshed sweet potato (OFSP), rich in β-carotene, significantly improved the vitamin A status of the children (Low *et al.,* 2007). The marketing and consumption of OFSP in Mozambique has increased as a result of initiatives by Centro Internacional de la Papa (CIP) and Instituto de Investigação Agrária de Moçambique (IAAM), and recent promotion programmes, such as the HarvestPlus Reaching End Users Project (2006-2010). New ways of consuming OFSP in forms such as juice, bread and confectionary products are being investigated in order to extend the availability and nutritional benefits through both home consumption and trade. The availability of fresh sweet potato is seasonal and storage of the fresh root beyond 3 months is difficult (Tomlins *et al*., 2007). Hence the production of dried products could potentially extend the availability of sweet potato by up to 4-6 months. Sun-drying of sweet potato is a traditional processing practice in many developing countries including a number of African countries (Woolfe, 1992). Although sun-drying of sweet potato has been reported in Mozambique (Dove R., pers. comm.), reports have been scarce. A World Vision survey for OVATA in Zambezia district, Mozambique (van Straaten, 2006) indicated that about 35% of households who grow sweet potato also practiced drying of sweet potato. Sun-drying is a non-controlled technology and previous studies on a range of commodities have demonstrated that the level of drying technology used

has an impact on provitamin A carotenoid retention (Bechoff *et al*., 2009; Chen *et al*., 2007; Desorby *et al*., 1997; Mulokozi & Svanberg, 2003; Negi & Roy, 2000). Sun-drying could result in higher carotenoid losses than with other technologies, such as solar-drying (Mulokozi & Svanberg, 2003; Negi & Roy, 2000). However recent publications (Bengtsson *et al*., 2008; Bechoff *et al*., 2009; Bechoff *et al*., 2010a) have showed that carotenoid losses from sweet potato chips during sun-drying were low and were similar to solar-drying. In addition, it was demonstrated in an on-station study in Uganda (Bechoff *et al*., 2010a), that losses of carotenoids were much more critical during storage for four months (70.4%) than during drying (9.0%). Tomlins *et al*. (2007) argued that experimental results obtained on a research station do not necessarily transfer to the farm situation because of variations in farmer knowledge and the local environment. It was therefore important to verify the on-station results in typical rural setting.

In order to better preserve provitamin A in sweet potato drying, there was a further need to determine whether process variables influence carotenoid degradation and the rate of degradation during storage. In an on-farm study, variables that can be straightforwardly explored are sweet potato chip size and variety. In laboratory trials, chip size has been reported to influence carotenoid degradation in sweet potato during sun-drying (Bechoff *et al*., 2009) and the variety of sweet potato has also been reported to influence carotenoid degradation (Bechoff *et al*., 2010a). Determination of kinetics of carotenoid degradation in dried sweet potato during storage under laboratory conditions has been reported in literature (Haralampu & Karel, 1983; Stephanovitch & Karel, 1982) but field studies measuring carotenoid kinetics in dried food commodities such as sweet potato are scarce. The determination of carotenoid degradation rate under on-farm conditions could bring a practical

help to farmers and millers with the evaluation of dried OFSP shelf life that could potentially lead to an improvement of the product quality.

The aim of the study was to evaluate simple and low-cost drying and storage for orange-fleshed sweet potato (OFSP) on-farm. The main objective was to measure the level of carotenoid loss after solar and sun drying and over a four-month storage period taking into account the effect of variety and chipping.

MATERIALS AND METHODS

Root samples

Mature sweet potato roots (MGCL01 and Resisto varieties), about 80 kg per variety, were purchased from farmers around Lualua, Zambézia Province, Mozambique (105 km from Quelimane, the Province Capital). The exact root harvest age was not known. All roots were processed within one to three days after harvest.

Dryers

Three dryers were constructed on a farm belonging to a subsistence farmer at Lualua. Apart from the greenhouse clear plastic (Strawberry 3 seasons BPI-VISQUEEN®, UK thickness 150 µm), all building materials were obtained locally and constructed by local craftsmen. Each of the dryers was mounted on a simple wooden structure that was fitted with straw mats.

- The tunnel dryer had similar dimensions to the on-research station dryer in Uganda (Bechoff *et al*., 2010a). It had a total length of 9 m and a width of 1.5 m. The collector (absorber) occupied the first 3.5 m and was formed of an iron metal sheet. The rest of the dryer (5.5 m) was used as drying area. The floor of the drying area was made of straw mats covered with black plastic sheeting to insulate the structure. Clear greenhouse plastic covered the whole

structure apart from the inlet and outlet allowing air flow and protected by mosquito net (0.55m^2 each). The dryer had a 6° slope.

- The open air dryer (exposed to direct sun) had a length of 6 m and a width of 1.5m with a height of 0.9m and had a 6° slope.

- The shade dryer was identical to the open air dryer and with the addition of a grass lined roof. The roof was about 0.6 m larger and longer than the table in order to protect it from sun light. The shade dryer was flat (*i.e.* without a 6° slope) because of building constraints.

- Each dryer could fit 6 trays of 4 kg fresh sample each and surface area per tray was 1.03m^2.

The geographical position of the dryers was determined using GPS (GPS 60, GARMIN®). Dryers were positioned facing north; this allowed maximum sun exposure in the southern hemisphere. Temperature/humidity dataloggers (Tinytalk 2 Geminidatalogger, Chichester, UK) were placed in the tunnel dryer and under the shade for ambient temperature measurement.

Drying

Drying trials were carried out in duplicate on different days (one day and three days after harvest). Roots were washed and spread on a black plastic under the shade for draining. Five fresh roots per variety were collected for carotenoid analysis. On the drying day, unpeeled roots were chipped using either a mechanical rotary disc chipper producing either thick and thin chips, or were hand-sliced (traditional way). Size (thickness, width, length) of ten fresh chips or slices was recorded using a digital calliper. Samples (4 kg) were weighed (Hanson Electronic Chrome Effect Scale; ±1 g) after careful mixing (using a quartering technique). All preparation operations were carried out in the shade to minimize losses in carotenoids. Sweet potato samples were evenly spread on mosquito mesh trays (6 trays per dryer) at a density of 3.9 kg.m^{-2}. Loading time was recorded for each dryer. Samples were weighed and turned frequently during drying. Samples were left overnight in the dryers because rain was unlikely

at the time of the study. Under these field conditions, the end of drying was evaluated subjectively by the presence of flour and a characteristic cracking noise when crushed in the hand. The fresh samples of chips/slices per treatment with an initial weight of 4 kg (per sample) reached a final weight of 1.5 kg for MGCL01 and 1.0 kg for Resisto after drying.

Collection of dried sweet potato chips for analysis and storage

A carefully mixed portion of dried chips/slices (about 200 g) was collected in zip-polythene bags and placed in a cooler bag before they were transported (within a couple of hours) to a freezer (-20 ºC) in Quelimane. The remainder of the chips/slices were used for the storage study (at ambient temperature). Samples were stored in traditional bags made of jute and hung inside a house constructed from mud in Lualua. In order to measure losses during storage, sub-samples (200 g chips or slices per stored sample) were removed respectively after 1 month (31 days), 2 months (62 days) and 4 months (125 days) and placed in polythene bags in a cooler bag and quickly transferred and stored in the freezer. The datalogger recording the ambient temperature during storage was unfortunately lost, but it is estimated from records taken nearby in Quelimane that the temperature in the mud house was on average 25 ºC with minimum/maximum temperatures of 20/31 ºC (Weather Underground Quelimane, 2007).

Carotenoid analysis

Chip samples in zip bags were stored at -20°C for 1-6 months before analysis because of delays and the low sample throughput for this method. No significant carotenoid loss was observed on chips in freezer in this interval ($p<0.05$) (Bechoff 2010). Samples were milled into flour (particle sizes of less than 1 mm) using a Laboratory mill 3600 (Perten Instruments, Segeltorp, Sweden) and extracted in duplicate in a randomised order. Carotenoids were identified and quantified using the method described by Bechoff *et al*. (2010b). The extraction stage was adapted from Rodriguez-Amaya and Kimura (2004). A portion of the homogeneous

representative sample (0.4-2.0 g of flour) was re-hydrated for 20 min in 10 ml deionised water, homogenised with 50mL methanol:tetrahydrofuran (THF) (1:1) for 1 minute and filtered. The homogenised extract was rinsed with methanol:THF (1:1) until there was no yellow colour left in the filtrate. Partition between the aqueous phase and organic phase containing the carotenoids was achieved by addition of petroleum ether (PE -40-60° C). The PE phase was further washed with water, dried by addition of anhydrous sodium sulphate, then filtered and made up to volume (50 ml). For the determination of total carotenoid content, absorbance was measured at 450 nm using a diode array Hewlett Packard 8452A spectrophotometer. For the determination of individual carotenoids by HPLC, the carotenoid extracts in PE were dried by flushing with nitrogen in a dry block system at 35º C. The extracts were dissolved in 1 ml dichloromethane:MTBE (methyl tert-butyl ether): methanol 50:40:10. Reverse-phase high performance liquid chromatography using an Agilent 1100 system (Massy, France) was used following the method of Dhuique-Mayer *et al.* (2007). Carotenoids were separated through a C_{30} reverse phase column (250 x 4.6 mm i.d.) packed with 5µm YMC (EUROP GmbH, Germany) at a flow rate of 1 $ml.min^{-1}$, a column temperature at 25º C and an injection volume of 20 µl. Concentrations were determined by comparison to a standard curve using pure β- carotene (Extrasynthese, Genay, France).

Dry matter determination

Samples were collected for dry matter determination, before and after drying at the same time as for carotenoids analysis. Determinations were made by drying triplicate 5 g samples at 105 ºC to constant weight (minimum 24h) (AOAC, 1984).

Statistical analyses and calculation of carotenoid degradation rates

Normality of sample distribution was tested using Shapiro-Wilk and Kolmogorov Smirnov tests ($p < 0.05$). Analysis of variance (ANOVA) was carried out to determine whether there were significant differences between samples with one up to four factors. A significant difference between samples was determined by a Tukey test. Data were processed on SPSS 15.00 (SPSS UK Ltd. Woking, Surrey, UK) for Windows software.

Linear regression (on Excel) was used to determine the rate of degradation k following the formula $C = C_0 - kt$ (zero order kinetics) or $\ln C = \ln C_0 - kt$ (first order kinetics) where C_0 is the total carotenoid content after drying ($\mu g.g^{-1}$); C the total carotenoid content at storage time t ($\mu g.g^{-1}$); k the rate constant ($days^{-1}$) and t the storage time (days).

RESULTS AND DISCUSSION

Effect of dryer on total carotenoid loss

Independently of the dryer or variety, average total carotenoid loss during drying was 9.2%. In all cases, levels of loss were less than 24.6% (Table 1). Effect of different factors (new chipper and traditional slicing) and three dryers (shade; sun; tunnel) on the two varieties was evaluated on total carotenoid losses (Table 2). The type of dryer had a significant effect ($p<0.01$) on total carotenoid loss. Because control over drying was limited in these field conditions, dry matter was included as covariate in the analysis of variance from data presented in Table 2. The three dryers gave significantly different results of loss: on average there were 13.0%, 10.0% and 1.9% for the tunnel dryer; open air dryer and shade dryer respectively (Table 1). Slight but significantly lower retention of total carotenoids in the tunnel dryer compared to the open air dryer could be explained by the higher temperature

during drying (up to 55°C whilst the ambient temperature did not go above 33°C) (Table 1). There was furthermore an issue with moisture evacuation from the product in the tunnel dryer, which is illustrated by the maximum 100% relative humidity reached at night. This may have resulted from a disadvantageous wind direction at this time of the year, blowing East-West, whereas the tunnel was positioned North-South. As compared with the on-station study (Bechoff *et al*., 2010a) using a similar but optimally oriented tunnel dryer, the on-farm tunnel dryer showed some technical limitations in terms of air flow circulation. In terms of carotenoid losses, the difference in the tunnel and open-air sun dryers (using chips of the same size) was not significant (9.0% for the tunnel and open-air sun dryers in the earlier on-station study) (Bechoff *et al*., 2010a) and small (13% and 10% respectively working with thin chips in this on-farm study). The tunnel dryer however protected against insects and rain. This type of dryer was mostly designed for experimental use and, because its cost was estimated to be ten times the cost of an open air dryer and five times that of a shade dryer, mainly due to imported materials, it would not be a feasible proposition for Mozambican farmers to adopt. The open air and shade dryer would be the dryers most suited to rural situation in Mozambique because of their improved carotenoid retention, lower cost and availability of most materials locally (on the farm or in the next village).

Complete protection from sun light and lower temperatures for shade-drying compared to tunnel and open air sun dryers can explain the improved carotenoid retention from shade drying. In this study, from an overall product quality perspective, the shade dryer worked well with thin chips but was not well adapted to handcut slices (traditional way) because of longer drying times leading to off-odours. Researchers, working with different commodities, have reported conflicting results regarding carotenoid losses during shade-drying. Chavez *et al*. (2007) reported that shaded-dried yellow cassava that contained carotenoids had improved

carotenoid retention compared to sun-dried one, while Negi & Roy (2000), working on leafy vegetables, reported that higher carotenoid losses were obtained in shade and sun-drying as opposed to solar (cabinet) drying. Theses inconsistencies in the literature could be the result from different environmental conditions (temperature, humidity and wind) and different product characteristics influencing carotenoid retention during drying.

Effect of chipping on total carotenoid loss after drying

Traditional slices, thick and thin chips had an average thickness of about 5.2 mm, 2.9 mm and 0.4 mm respectively. The effect of chipping treatment using three chipping treatment is reported in open air drying for both MGCL01 and Resisto varieties (Table 1). There was no difference between the thin chips and slices but drying thick chips resulted in significantly higher loss than the other chipping methods, respectively 14.6% for thick chips and 10.7% for thin chips; 9.3% for traditional slices ($p<0.01$) (Table 3). Greater losses of total carotenoids in thick chips compared to thin chips could be explained by inadequate chip size: with a small surface area to volume ratio, thick chips may have evacuated moisture less efficiently and the core of the chips may have been less protected during drying. Longer drying times were associated with greater losses of carotenoids during drying of sweet potato (Bechoff *et al.* 2007). Bechoff *et al*. (2009) working on OFSP also reported that surface area of chip resulted in differential carotenoid loss in sun-drying. In the drying of carrots Wang & Xi (2005) reported that β-carotene degradation increased with sample thickness and was also linked to moisture content reached. In the case of slices, reasons might have been different. Greater losses of total carotenoids in thick chips compared to slices could be explained by the greater damage of tissues due to mechanical chipping as opposed to manual slicing. More investigation is still needed to understand the relationships between chip surface/volume, moisture evacuation and carotenoid loss during drying.

Effect of variety on total carotenoid loss after drying

Sweet potato variety had a significant impact on total carotenoid loss ($p<0.01$). Resisto, with a dry matter content of 27.0%, lost more carotenoids (mean loss of 13.2%) than MGCL01 with a dry matter of 35.4% (mean loss of 5.2%) (Table 1). A similar trend of higher dry matter varieties being associated with lower carotenoid losses was reported by Bechoff *et al.* (2010a) in on-station trials with six OFSP varieties. This difference between losses in Resisto and MGCL01 varieties might result from difference between dry matter contents that would influence the drying process.

Effect of chipping on total carotenoid loss during storage

Overall average losses in carotenoids from stored chips and slices after one month; two and four months of storage are presented in Figure 1. No effect of chipping was reported when analysing thin, thick chips and slices during storage (ANOVA; $p<0.01$). The lack of interaction between chipping and storage time confirmed that there was consistently no effect of chipping throughout the storage period. Working on pure β-carotene encapsulated in dextrose equivalent maltodextrin by three drying processes: spray, drum and freeze drying, Desorby *et al*. (1997) found that larger particles obtained in drum drying had improved β-carotene stability over storage when compared with the other processes. Mills & Hart (1945) working on dehydrated sweet potato also found that six month-stored flour had higher carotene loss than sliced material at ambient temperature and concluded that sweet potato should be stored in the way they are dehydrated rather than milled into flour. In the present study, the lack of difference from chipping, however, did not agree with the results by Desorby *et al*. (1997) and Mills & Hart (1945), but it is believed that the difference in retention observed in these previous studies is a result of the very different particle sizes of samples tested (*i.e.* flour and slices) that may have resulted in differential porosity to air

oxidation. This present study demonstrated that there was no effect of chip size in stored samples. Oxidation is reported as the main factor responsible for carotenoid degradation during storage of dried sweet potato (Emenhiser *et al*., 1999). Therefore the lack of differences in this study is hypothesised to result from similar air oxygen diffusion through the different chip/slice sizes (that did not differ as much in size as with flour and slices) of the samples stored in jute bags.

Effect of variety on total carotenoid loss during storage

There was a significant effect of variety during storage of dried sweet potato ($p<0.01$). Resisto with 26.8%, 47.8%, 78.6% loss after one month, two and four months of storage, had lower total carotenoid losses than the MGCL01 variety with 39.0%, 63.2%, 87.7% respectively (Figure 1). This could possibly result from differential composition in other constituents that can enhance or delay carotenoid degradation: for instance, enhancers could be unsaturated fatty acids that are mostly linoleic and linolenic acids in sweet potato (Walter & Purcell, 1974) and were related to lipid peroxidation (Arya *et al*., 1979), and inhibitors of carotenoid oxidation could be phenolic compounds. Phenolic content has been positively correlated to antioxidant activity in various sweet potato varieties (Teow *et al*., 2007). More investigation is required to understand varietal differences with regard to carotenoid retention.

Estimation of vitamin A activity in chips after drying and storage

Immediately after drying, average total carotenoid contents for Resisto and MGCL01 respectively were 355.6 $\mu g.g^{-1}$ and 218.2 $\mu g.g^{-1}$ on a dry weight basis. According to Bechoff *et al.* (2010a), these values corresponded to an estimated vitamin A activity of 24 617 and 15 107 $RE.kg^{-1}$ respectively and were largely beyond the recommended daily allowance for children (4000 $RE.kg^{-1}$). After a four month-storage, average total carotenoid contents for

Resisto and MGCL01 were 73.4 µg.g^{-1} and 25.9 µg.g^{-1} on a dry weight basis respectively. These values corresponded to an estimated vitamin A activity of 5080 and 1796 RE.kg^{-1} respectively. After four month-storage the vitamin A activity is strongly reduced and only Resisto variety meets the RDA. However because of other quality issues (*i.e.* presence of insects) the recommended storage period should not exceed 3 months for Resisto. In order to meet the RDA, the storage time for MGCL01 should not be over two months. These estimates however do not take into account losses occurring during the further processing of dried sweet potato into a form eaten by consumers. This should be the subject of another research study.

Identification of carotenoids before and after storage

The individual carotenoid compounds before drying, after drying and after 4 month-storage of dried sweet potato were tentatively identified by HPLC (Figure 2). Resisto had the same chromatographic profile as MGCL01. Therefore only the chromatograms for Resisto are shown. The main compound is trans-β-carotene (peak 7) resolved at 37 min. and representing 84% of the total carotenoid concentration, both for Resisto and MGCL01 samples on average (over dried and stored samples). Other peaks were minor compounds mostly degradation products of all-trans-β-carotene and even present in fresh root samples in very small quantities. The presence of β-carotene 5,6 epoxide has been reported by Kósambo *et al.* (1998) in fresh sweet potato roots. On average (for dried and stored sliced Resisto variety) percentages were the followings; β-carotene 5,6-epoxide (4.0%), 5,6-epoxide (3.2%) 9-cis (1.3%) and 13-cis-β-carotene (3.1%). Trans-β-carotene, β-carotene 5,6-epoxide, 9-cis and 13-cis-β-carotene were previously identified using the same HPLC system on a different sweet potato variety (Bechoff *et al.*, 2009). In spite of the degradation of β-carotene, no clear increase of degradation products was readily observed using the HPLC technique. There are minor differences between the chromatographic profiles of those samples, fresh (Figure 2A) or dried (Figure 2B) or dried and subsequently stored (Figure 2C): peaks a (possibly β-

carotene-5,6,5',6'-diepoxide); b (possibly β-carotene-5,6,5',8'-diepoxide) were found in fresh roots, peaks a, b and c (25 min.unidentified) were found in dried chips but peak c was only detected after four months of storage. Peak 2 (β-carotene 5,6 epoxide) was not affected by drying but was sharply reduced during storage. On the other hand, peaks 3 (β-carotene 5,8 epoxide) and 6 (13-cis β-carotene) decreased at a lower rate during storage. Storage affected more the chromatographic profile of carotenoids than drying did. Harsher conditions of processing may be necessary to induce more differences in the carotenoid profile. In contrast to this study, significant differences in the chromatographic profile of fresh and heated citrus juices (5h; 95ºC) have been described by Dhuique-Mayer *et al.* (2007). The present profile of carotenoids in OFSP flour showed that there were very few qualitative differences in the chromatogram of samples immediately before or after drying, or after storage for 4 months.

Kinetics of individual carotenoid degradation during storage

Kinetics of carotenoid loss per variety are presented in Table 4. For trans β-carotene and β-carotene 5,6-epoxide, the coefficients of correlation with storage time were generally higher than R=-0.95. MGCL01 variety fitted better first order kinetics whilst Resisto fitted equally zero and first order kinetics and this has not been reported previously. Instead, it has been shown that dried food fitted first order kinetics degradation during storage (Hidalgo & Brandolini, 2008; Koca *et al*., 2007). Nevertheless, working on pure β-carotene powder, Minguez-Mosquera & Jaren-Galan (1995) demonstrated that degradation followed zero-order kinetics in an organic anhydrous medium while in an aqueous medium it followed first-order kinetics. Zero order reactions are found when the substrate is in excess. Because Resisto had twice as much trans-β-carotene as MGCL01 this could possibly explain why the zero order reaction also fitted Resisto. This indicates that the oxidant had no limitation on the substrate which means that oxygen from the air could easily penetrate the product. There are a few discrepancies between the two models because in order zero Resisto degradation was faster

than MGCL01 and order one the opposite. Because coefficients of correlation were higher in first order, particularly on MGCL01, the first order was considered. First order rates of degradation were 0.0171 day^{-1} for trans-β-carotene on Resisto and 0.0251 day^{-1} on MGCL01. The rate of degradation of β-carotene 5,6 epoxide was slightly faster than that of trans-β-carotene (0.0249 and 0.0315 day^{-1} on Resisto and MGCL01 respectively) and this was in accordance with recent work by Bechoff *et al.* (2010b).

Isomers of β-carotene, 13-cis- and 9-cis-, degraded following first order kinetics however with coefficients of correlation with storage time lower than trans-β-carotene and 5,6 epoxide-β-carotene (R~0.80). Rate constants of 13-cis- and 9-cis isomers in Resisto and MGCL01 being 0.0080; 0.0102 and 0.0115; 0.0190 day^{-1} respectively were less than that of trans-β-carotene (0.0171 and 0.0251 day^{-1}). This observation is significant because, to our knowledge, the rate of degradation of cis-isomers has not been widely reported in literature when working on storage. A degradation of cis-isomers jointly with trans-β-carotene in solar-drying was however reported by Bechoff *et al*. (2009); Kidmose *et al*. (2007); Mulokozi & Svanberg (2003) working on sweet potato drying. In summary, these results showed that the concentration of all the carotenoids was proportionally reduced in storage.

CONCLUSION

Compared to the earlier study carried out on-research station in Uganda (Bechoff *et al*. 2010a), retentions of total carotenoids after on-farm drying in Mozambique were similar, when considering the same type of dryers (tunnel or sun dryers). It was shown in both studies that a higher level of technology (tunnel dryer) as compared with a lower level of technology (open air sun drying on raised trays), did not necessarily lead to a higher carotenoid retention.

The lack of difference in carotenoid retention between different chip sizes during storage is also positive for farmers, because it means that they can limit their management costs because traditional hand slicing of sweet potato was as good as the use of a mechanical chipper on the retention of carotenoids. On the other hand, the effect of variety was significant in drying and storage. These observations require investigation on more varieties as this was noted in the research station based study (Bechoff *et al*. 2010a).

Total carotenoid losses during storage were high and these considered being slightly greater than the losses determined on-station in Uganda (results after four month-storage). Higher losses in the on-farm based study in Mozambique may be explained by higher temperatures and lower relative humidity (Bechoff *et al*., 2010b) especially in the day. In order to meet a significant part of daily nutritional requirements in provitamin A (100g corresponding to 100% of RDA for children) (Bechoff *et al*., 2010a), chip samples should not be stored for more than two months for MGCL and four months for Resisto. However Resisto chips should preferably not be stored more than three months because of insect damage.

It is possible to do on-farm research and to get similar results to that obtained on-research station. These findings are important when transferring technology from a research station, which includes control over research-parameters, to the more realistic situation of the farm where farmers themselves monitor the drying and storage of their crops.

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Table 1: Total carotenoid losses after drying influenced by treatment (dryer, chipping) using MGCL01 and Resisto varieties

Variety	Chipping	Dryer	Dry matter content (%)	Drying time* (h)	Total carotenoid content (μg.g^{-1} db)**	Total carotenoid loss (%)
MGCL 01	Fresh roots		35.4		235.6 (6.5) bc	-
	Thin chips	Tunnel	93.9	25.5	210.2 (5.0) a	10.8
		Open	92.1	23.8	224.2 (6.0) abc	4.9
		Shade	89.9	26.5	238.0 (6.2) bc	-1.0***
	Thick chips	Open	89.6	23.9	224.5 (1.9) abc	4.7
	Slices	Tunnel	91.4	47.7	204.9 (2.6) a	13.0
		Open	87.7	47.6	219.4 (3.2) ab	6.9
		Shade	86.8	50.7	242.5 (6.3) c	-2.9***
Resisto	Fresh roots		27.0		434.4 (0.7) e	-
	Thin chips	Tunnel	91.9	26.1	371.1 (2.5) bc	14.6
		Open	91.5	25.4	362.8 (13.0) b	16.5
		Shade	89.9	50.7	401.0 (8.3) cd	7.7
	Thick chips	Open	91.0	62.3	327.7 (2.8) a	24.6
	Slices	Tunnel	88.8	72.4	376.2 (4.8) bc	13.4
		Open	84.0	75.4	383.6 (6.2) bc	11.7
		Shade	78.3	75.5	418.0 (1.5) de	3.8

* Drying time includes days and nights of samples spent on dryers –average of two-drying trials.

** db: dry weight basis. Each value represents the mean (standard deviation) of two extractions for two-drying trials (2^2). For each sweet potato variety, values followed by different letters are significantly different (ANOVA-Tukey test; $p<0.05$). Total carotenoid content was measured using a Hewlett Packard 8452A spectrophotometer at an absorbance of 450nm.

***Negative values are not significantly different from values in fresh sweet potatoes

Average and variation on day/night temperature and humidity respectively were 22°C (12-33°C) and 65% (25-95%) in ambient conditions; 26°C (11-55°C) and (63% (13-100%) inside the tunnel dryer.

Table 2: Effect of dryer type on carotenoid loss:

ANOVA (main effects) - Factors: variety: (Resisto, MGCL01); dryer (open, tunnel, shade); chipper (slices, thin chips); replication trial, and final dry matter (after drying) as a covariate

Source	df	Mean square
Variety	1	4.800**
Dryer	**2**	**2.000****
Chipper	1	0.100
Trial	1	0.002
Final dry matter (covariate)	1	0.600*
Error	41	0.100
Total	48	

* Significant at $p < 0.05$; ** Significant at $p < 0.01$

Table 3: Effect of chipper on carotenoid loss after open air sun drying:

ANOVA (main effects) - Factors: variety (Resisto, MGCL01); chipper (slices, thick chips, thin chips); replication trial, and final dry matter as a covariate

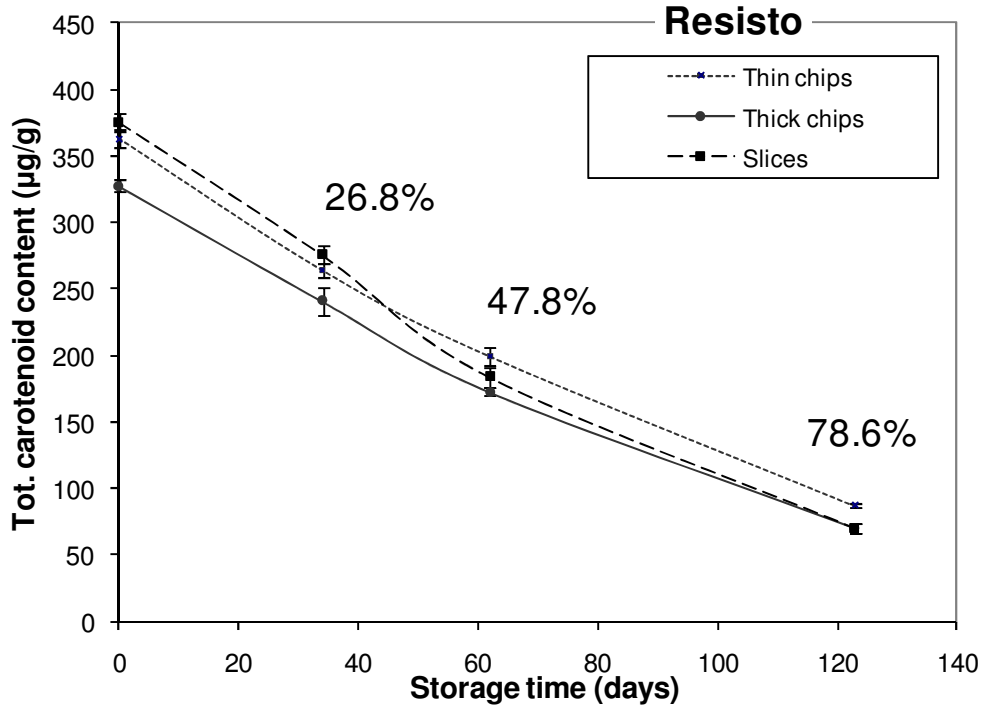
Source	df	Mean Square
Variety	1	11.000**
Chipper	**2**	**1.100****
Trial	1	<0.001
Final dry matter (covariate)	1	2.900**
Error	18	0.100
Total	23	

** Significant at $p < 0.01$

Table 4: Kinetic parameters of zero order and first order carotenoid degradation in Resisto and MGCL01 slices stored for four months

	Reaction Order	Trans-β-carotene		5,6 epoxide-β-carotene		13-cis-β-carotene		9-cis-β-carotene	
		k (day^{-1})	R	k (day^{-1})	R	k (day^{-1})	R	k (day^{-1})	R
Resisto	0	2.7643 (0.2500)	-0.976	0.1840 (0.0131)	-0.985	0.0376 (0.0054)	-0.943	0.0228 (0.0046)	-0.896
	1	0.0171 (0.0010)	-0.990	0.0249 (0.0025)	-0.971	0.0080 (0.0009)	-0.963	0.0102 (0.0012)	-0.963
MGCL 01	0	1.5436 (0.2648)	-0.922	0.0989 (0.0144)	-0.942	0.0261 (0.0081)	-0.796	0.0180 (0.0057)	-0.791
	1	0.0251 (0.0028)	-0.966	0.0315 (0.0035)	-0.965	0.0115 (0.0033)	-0.819	0.0190 (0.0039)	-0.893

Each value represents the mean (standard deviation) of two extractions



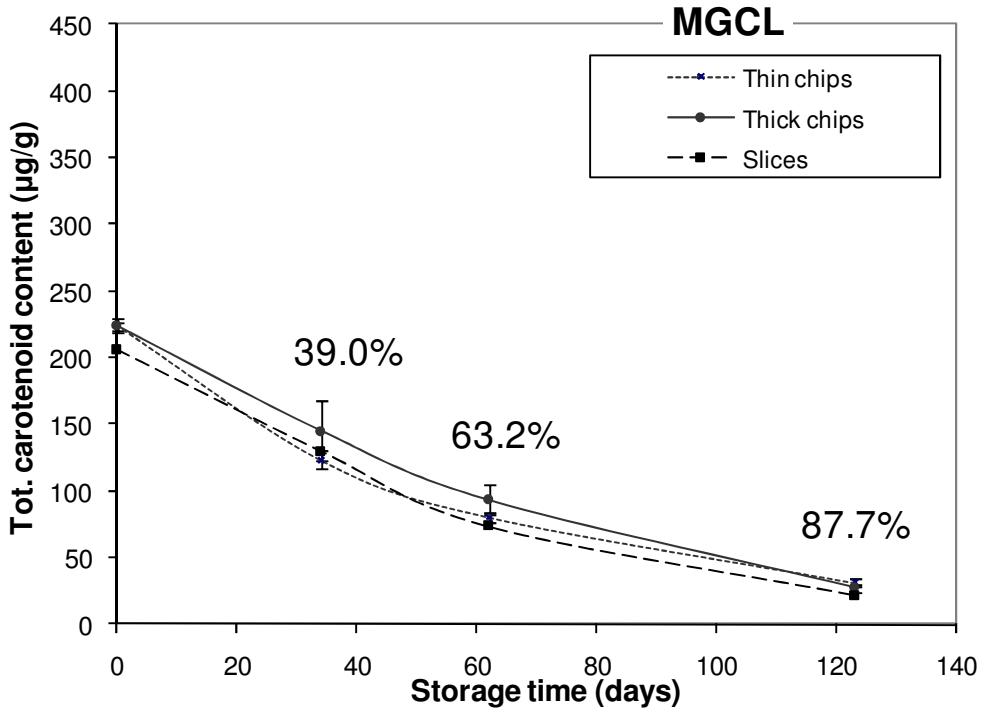


Figure 1: Kinetics of total carotenoid degradation during storage of Resisto and MGCL01 varieties chipped to three different sizes. Mean of 2^2 replicate; error bars refer to standard error.

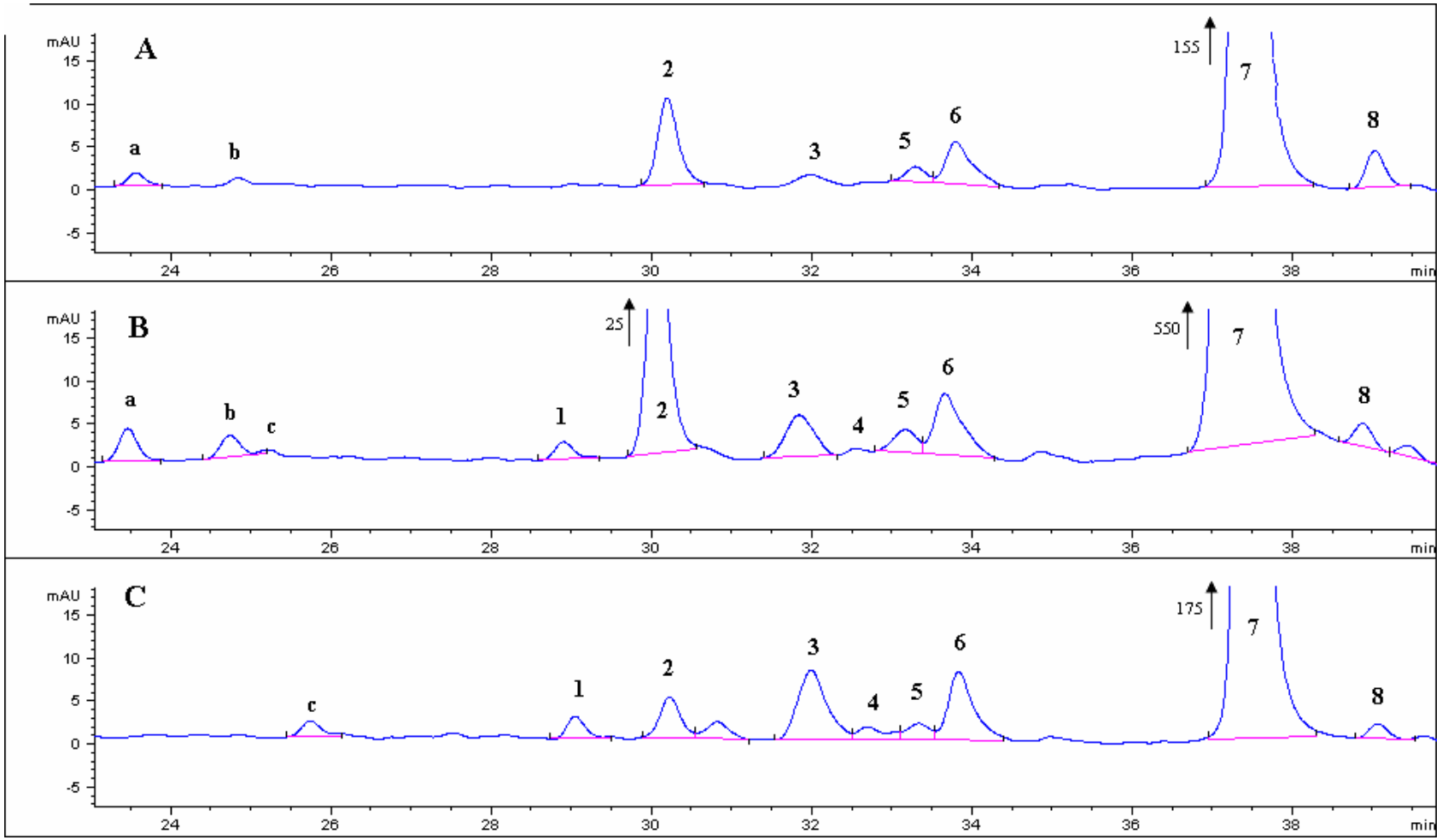


Figure 2: HPLC chromatograms at 450nm of the carotenoids of Resisto slices before drying (A), after drying (B) and after 120 days storage (C). a: Possibly β-carotene-5,6,5',6'-diepoxide (23 min.) (414; **440**; 468nm); b: Possibly β-carotene-5,6,5',8'-diepoxide (24 min.) (400; **422**; 450nm); c: unidentified (25 min.) (406; **424**; 450nm); 1: Possibly 13-cis-β-carotene-5,6 epoxide (29min.) (main wavelengths: 416; **439**; 476nm); 2: Possibly β-carotene-5,6 epoxide (30min.) (422;**446**; 472nm); 3: Possibly β-carotene-5,8 epoxide (32min.) (406;**428**; 452nm); 4&5: Unidentified; 6:13-cisβ-carotene (34min.) (338;422;**444**; 472nm); 7: All-trans-β-carotene (37min.) (**452**; 478nm); 8: Possibly 9 cis-β-carotene (39min.) (**446**; 472nm). The three graphs are not to the same scale because of differing dry matter contents (respectively 27%, 89% and 87%). The graphs have been scaled to illustrate the minor peaks and therefore the larger peaks have been truncated.

On-farm evaluation of the impact of drying and storage on the carotenoid content of orange-fleshed sweet potato (*Ipomea batata* Lam.)

Running head: On-farm carotenoid loss in sweet potato chips

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Abstract: Drying of orange-fleshed sweet potato was evaluated under African rural conditions. Three locally-built dryers (open air-sun; tunnel and shade) were tested using Resisto and MGCL01 varieties in Mozambique. Total carotenoid losses were low in all dryers being 9.2% on average. After drying sweet potato chips were stored in a traditional way (jute bags inside a mud house). Chip size (thin, thick chip or slice) had a significant effect on drying ($p<0.05$) but not on storage; and variety had an effect on both. Total carotenoid losses during storage were much higher being 83.7% on average, after four months, with main individual carotenoids fitting a first order kinetics degradation. Globally carotenoid losses on-farm or on-research station, were of similar level.

Keywords: *Ipomea batata* (L.) Lam, carotenoids, storage, drying, on-farm, on-research.

INTRODUCTION

Mozambique is one of the poorest countries in the world, and additionally, one of the most affected by vitamin A deficiency; 71% of the children under five are deficient (Aguayo & Baker, 2005). White-fleshed sweet potato (WFSP) is traditionally part of the Mozambican diet, as a source of carbohydrate. An integrated agricultural and nutritional intervention involving households with young children in rural areas of Mozambique has demonstrated that regular consumption of orange-fleshed sweet potato (OFSP), rich in β-carotene, significantly improved the vitamin A status of the children (Low *et al.,* 2007). The marketing and consumption of OFSP in Mozambique has increased as a result of initiatives by Centro Internacional de la Papa (CIP) and Instituto de Investigação Agrária de Moçambique (IAAM), and recent promotion programmes, such as the HarvestPlus Reaching End Users Project (2006-2010). New ways of consuming OFSP in forms such as juice, bread and confectionary products are being investigated in order to extend the availability and nutritional benefits through both home consumption and trade. The availability of fresh sweet potato is seasonal and storage of the fresh root beyond 3 months is difficult (Tomlins *et al*., 2007). Hence the production of dried products could potentially extend the availability of sweet potato by up to 4-6 months. Sun-drying of sweet potato is a traditional processing practice in many developing countries including a number of African countries (Woolfe, 1992). Although sun-drying of sweet potato has been reported in Mozambique (Dove R., pers. comm.), reports have been scarce. A World Vision survey for OVATA in Zambezia district, Mozambique (van Straaten, 2006) indicated that about 35% of households who grow sweet potato also practiced drying of sweet potato. Sun-drying is a non-controlled technology and previous studies on a range of commodities have demonstrated that the level of drying technology used

has an impact on provitamin A carotenoid retention (Bechoff *et al*., 2009; Chen *et al*., 2007; Desorby *et al*., 1997; Mulokozi & Svanberg, 2003; Negi & Roy, 2000). Sun-drying could result in higher carotenoid losses than with other technologies, such as solar-drying (Mulokozi & Svanberg, 2003; Negi & Roy, 2000). However recent publications (Bengtsson *et al*., 2008; Bechoff *et al*., 2009; Bechoff *et al*., 2010a) have showed that carotenoid losses from sweet potato chips during sun-drying were low and were similar to solar-drying. In addition, it was demonstrated in an on-station study in Uganda (Bechoff *et al*., 2010a), that losses of carotenoids were much more critical during storage for four months (70.4%) than during drying (9.0%). Tomlins *et al*. (2007) argued that experimental results obtained on a research station do not necessarily transfer to the farm situation because of variations in farmer knowledge and the local environment. It was therefore important to verify the on-station results in typical rural setting.

In order to better preserve provitamin A in sweet potato drying, there was a further need to determine whether process variables influence carotenoid degradation and the rate of degradation during storage. In an on-farm study, variables that can be straightforwardly explored are sweet potato chip size and variety. In laboratory trials, chip size has been reported to influence carotenoid degradation in sweet potato during sun-drying (Bechoff *et al*., 2009) and the variety of sweet potato has also been reported to influence carotenoid degradation (Bechoff *et al*., 2010a). Determination of kinetics of carotenoid degradation in dried sweet potato during storage under laboratory conditions has been reported in literature (Haralampu & Karel, 1983; Stephanovitch & Karel, 1982) but field studies measuring carotenoid kinetics in dried food commodities such as sweet potato are scarce. The determination of carotenoid degradation rate under on-farm conditions could bring a practical

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help to farmers and millers with the evaluation of dried OFSP shelf life that could potentially lead to an improvement of the product quality.

The aim of the study was to evaluate simple and low-cost drying and storage for orange-fleshed sweet potato (OFSP) on-farm. The main objective was to measure the level of carotenoid loss after solar and sun drying and over a four-month storage period taking into account the effect of variety and chipping.

MATERIALS AND METHODS

Root samples

Mature sweet potato roots (MGCL01 and Resisto varieties), about 80 kg per variety, were purchased from farmers around Lualua, Zambézia Province, Mozambique (105 km from Quelimane, the Province Capital). The exact root harvest age was not known. All roots were processed within one to three days after harvest.

Dryers

Three dryers were constructed on a farm belonging to a subsistence farmer at Lualua. Apart from the greenhouse clear plastic (Strawberry 3 seasons BPI-VISQUEEN®, UK thickness 150 μm), all building materials were obtained locally and constructed by local craftsmen. Each of the dryers was mounted on a simple wooden structure that was fitted with straw mats.

- The tunnel dryer had similar dimensions to the on-research station dryer in Uganda (Bechoff *et al*., 2010a). It had a total length of 9 m and a width of 1.5 m. The collector (absorber) occupied the first 3.5 m and was formed of an iron metal sheet. The rest of the dryer (5.5 m) was used as drying area. The floor of the drying area was made of straw mats covered with black plastic sheeting to insulate the structure. Clear greenhouse plastic covered the whole

structure apart from the inlet and outlet allowing air flow and protected by mosquito net (0.55m^2 each). The dryer had a 6° slope.

- The open air dryer (exposed to direct sun) had a length of 6 m and a width of 1.5m with a height of 0.9m and had a 6° slope.

- The shade dryer was identical to the open air dryer and with the addition of a grass lined roof. The roof was about 0.6 m larger and longer than the table in order to protect it from sun light. The shade dryer was flat (*i.e.* without a 6° slope) because of building constraints.

- Each dryer could fit 6 trays of 4 kg fresh sample each and surface area per tray was 1.03m^2.

The geographical position of the dryers was determined using GPS (GPS 60, GARMIN®). Dryers were positioned facing north; this allowed maximum sun exposure in the southern hemisphere. Temperature/humidity dataloggers (Tinytalk 2 Geminidatalogger, Chichester, UK) were placed in the tunnel dryer and under the shade for ambient temperature measurement.

Drying

Drying trials were carried out in duplicate on different days (one day and three days after harvest). Roots were washed and spread on a black plastic under the shade for draining. Five fresh roots per variety were collected for carotenoid analysis. On the drying day, unpeeled roots were chipped using either a mechanical rotary disc chipper producing either thick and thin chips, or were hand-sliced (traditional way). Size (thickness, width, length) of ten fresh chips or slices was recorded using a digital calliper. Samples (4 kg) were weighed (Hanson Electronic Chrome Effect Scale; ±1 g) after careful mixing (using a quartering technique). All preparation operations were carried out in the shade to minimize losses in carotenoids. Sweet potato samples were evenly spread on mosquito mesh trays (6 trays per dryer) at a density of 3.9 kg.m^{-2}. Loading time was recorded for each dryer. Samples were weighed and turned frequently during drying. Samples were left overnight in the dryers because rain was unlikely

at the time of the study. Under these field conditions, the end of drying was evaluated subjectively by the presence of flour and a characteristic cracking noise when crushed in the hand. The fresh samples of chips/slices per treatment with an initial weight of 4 kg (per sample) reached a final weight of 1.5 kg for MGCL01 and 1.0 kg for Resisto after drying.

Collection of dried sweet potato chips for analysis and storage

A carefully mixed portion of dried chips/slices (about 200 g) was collected in zip-polythene bags and placed in a cooler bag before they were transported (within a couple of hours) to a freezer (-20 ºC) in Quelimane. The remainder of the chips/slices were used for the storage study (at ambient temperature). Samples were stored in traditional bags made of jute and hung inside a house constructed from mud in Lualua. In order to measure losses during storage, sub-samples (200 g chips or slices per stored sample) were removed respectively after 1 month (31 days), 2 months (62 days) and 4 months (125 days) and placed in polythene bags in a cooler bag and quickly transferred and stored in the freezer. The datalogger recording the ambient temperature during storage was unfortunately lost, but it is estimated from records taken nearby in Quelimane that the temperature in the mud house was on average 25 ºC with minimum/maximum temperatures of 20/31 ºC (Weather Underground Quelimane, 2007).

Carotenoid analysis

Chip samples in zip bags were stored at -20°C for 1-6 months before analysis because of delays and the low sample throughput for this method. No significant carotenoid loss was observed on chips in freezer in this interval ($p<0.05$) (Bechoff 2010). Samples were milled into flour (particle sizes of less than 1 mm) using a Laboratory mill 3600 (Perten Instruments, Segeltorp, Sweden) and extracted in duplicate in a randomised order. Carotenoids were identified and quantified using the method described by Bechoff *et al*. (2010b). The extraction stage was adapted from Rodriguez-Amaya and Kimura (2004). A portion of the homogeneous

representative sample (0.4-2.0 g of flour) was re-hydrated for 20 min in 10 ml deionised water, homogenised with 50mL methanol:tetrahydrofuran (THF) (1:1) for 1 minute and filtered. The homogenised extract was rinsed with methanol:THF (1:1) until there was no yellow colour left in the filtrate. Partition between the aqueous phase and organic phase containing the carotenoids was achieved by addition of petroleum ether (PE -40-60° C). The PE phase was further washed with water, dried by addition of anhydrous sodium sulphate, then filtered and made up to volume (50 ml). For the determination of total carotenoid content, absorbance was measured at 450 nm using a diode array Hewlett Packard 8452A spectrophotometer. For the determination of individual carotenoids by HPLC, the carotenoid extracts in PE were dried by flushing with nitrogen in a dry block system at 35º C. The extracts were dissolved in 1 ml dichloromethane:MTBE (methyl tert-butyl ether): methanol 50:40:10. Reverse-phase high performance liquid chromatography using an Agilent 1100 system (Massy, France) was used following the method of Dhuique-Mayer *et al.* (2007). Carotenoids were separated through a C_{30} reverse phase column (250 x 4.6 mm i.d.) packed with 5µm YMC (EUROP GmbH, Germany) at a flow rate of 1 $ml.min^{-1}$, a column temperature at 25º C and an injection volume of 20 µl. Concentrations were determined by comparison to a standard curve using pure β- carotene (Extrasynthese, Genay, France).

Dry matter determination

Samples were collected for dry matter determination, before and after drying at the same time as for carotenoids analysis. Determinations were made by drying triplicate 5 g samples at 105 ºC to constant weight (minimum 24h) (AOAC, 1984).

Statistical analyses and calculation of carotenoid degradation rates

Normality of sample distribution was tested using Shapiro-Wilk and Kolmogorov Smirnov tests ($p < 0.05$). Analysis of variance (ANOVA) was carried out to determine whether there were significant differences between samples with one up to four factors. A significant difference between samples was determined by a Tukey test. Data were processed on SPSS 15.00 (SPSS UK Ltd. Woking, Surrey, UK) for Windows software.

Linear regression (on Excel) was used to determine the rate of degradation k following the formula $C = C_0 - kt$ (zero order kinetics) or $\ln C = \ln C_0 - kt$ (first order kinetics) where C_0 is the total carotenoid content after drying ($\mu g.g^{-1}$); C the total carotenoid content at storage time t ($\mu g.g^{-1}$); k the rate constant ($days^{-1}$) and t the storage time (days).

RESULTS AND DISCUSSION

Effect of dryer on total carotenoid loss

Independently of the dryer or variety, average total carotenoid loss during drying was 9.2%. In all cases, levels of loss were less than 24.6% (Table 1). Effect of different factors (new chipper and traditional slicing) and three dryers (shade; sun; tunnel) on the two varieties was evaluated on total carotenoid losses (Table 2). The type of dryer had a significant effect ($p<0.01$) on total carotenoid loss. Because control over drying was limited in these field conditions, dry matter was included as covariate in the analysis of variance from data presented in Table 2. The three dryers gave significantly different results of loss: on average there were 13.0%, 10.0% and 1.9% for the tunnel dryer; open air dryer and shade dryer respectively (Table 1). Slight but significantly lower retention of total carotenoids in the tunnel dryer compared to the open air dryer could be explained by the higher temperature

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during drying (up to 55°C whilst the ambient temperature did not go above 33°C) (Table 1). There was furthermore an issue with moisture evacuation from the product in the tunnel dryer, which is illustrated by the maximum 100% relative humidity reached at night. This may have resulted from a disadvantageous wind direction at this time of the year, blowing East-West, whereas the tunnel was positioned North-South. As compared with the on-station study (Bechoff *et al*., 2010a) using a similar but optimally oriented tunnel dryer, the on-farm tunnel dryer showed some technical limitations in terms of air flow circulation. In terms of carotenoid losses, the difference in the tunnel and open-air sun dryers (using chips of the same size) was not significant (9.0% for the tunnel and open-air sun dryers in the earlier on-station study) (Bechoff *et al*., 2010a) and small (13% and 10% respectively working with thin chips in this on-farm study). The tunnel dryer however protected against insects and rain. This type of dryer was mostly designed for experimental use and, because its cost was estimated to be ten times the cost of an open air dryer and five times that of a shade dryer, mainly due to imported materials, it would not be a feasible proposition for Mozambican farmers to adopt. The open air and shade dryer would be the dryers most suited to rural situation in Mozambique because of their improved carotenoid retention, lower cost and availability of most materials locally (on the farm or in the next village).

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Complete protection from sun light and lower temperatures for shade-drying compared to tunnel and open air sun dryers can explain the improved carotenoid retention from shade drying. In this study, from an overall product quality perspective, the shade dryer worked well with thin chips but was not well adapted to handcut slices (traditional way) because of longer drying times leading to off-odours. Researchers, working with different commodities, have reported conflicting results regarding carotenoid losses during shade-drying. Chavez *et al*. (2007) reported that shaded-dried yellow cassava that contained carotenoids had improved

carotenoid retention compared to sun-dried one, while Negi & Roy (2000), working on leafy vegetables, reported that higher carotenoid losses were obtained in shade and sun-drying as opposed to solar (cabinet) drying. Theses inconsistencies in the literature could be the result from different environmental conditions (temperature, humidity and wind) and different product characteristics influencing carotenoid retention during drying.

Effect of chipping on total carotenoid loss after drying

Traditional slices, thick and thin chips had an average thickness of about 5.2 mm, 2.9 mm and 0.4 mm respectively. The effect of chipping treatment using three chipping treatment is reported in open air drying for both MGCL01 and Resisto varieties (Table 1). There was no difference between the thin chips and slices but drying thick chips resulted in significantly higher loss than the other chipping methods, respectively 14.6% for thick chips and 10.7% for thin chips; 9.3% for traditional slices ($p<0.01$) (Table 3). Greater losses of total carotenoids in thick chips compared to thin chips could be explained by inadequate chip size: with a small surface area to volume ratio, thick chips may have evacuated moisture less efficiently and the core of the chips may have been less protected during drying. Longer drying times were associated with greater losses of carotenoids during drying of sweet potato (Bechoff *et al.* 2007). Bechoff *et al*. (2009) working on OFSP also reported that surface area of chip resulted in differential carotenoid loss in sun-drying. In the drying of carrots Wang & Xi (2005) reported that β-carotene degradation increased with sample thickness and was also linked to moisture content reached. In the case of slices, reasons might have been different. Greater losses of total carotenoids in thick chips compared to slices could be explained by the greater damage of tissues due to mechanical chipping as opposed to manual slicing. More investigation is still needed to understand the relationships between chip surface/volume, moisture evacuation and carotenoid loss during drying.

Effect of variety on total carotenoid loss after drying

Sweet potato variety had a significant impact on total carotenoid loss ($p<0.01$). Resisto, with a dry matter content of 27.0%, lost more carotenoids (mean loss of 13.2%) than MGCL01 with a dry matter of 35.4% (mean loss of 5.2%) (Table 1). A similar trend of higher dry matter varieties being associated with lower carotenoid losses was reported by Bechoff *et al.* (2010a) in on-station trials with six OFSP varieties. This difference between losses in Resisto and MGCL01 varieties might result from difference between dry matter contents that would influence the drying process.

Effect of chipping on total carotenoid loss during storage

Overall average losses in carotenoids from stored chips and slices after one month; two and four months of storage are presented in Figure 1. No effect of chipping was reported when analysing thin, thick chips and slices during storage (ANOVA; $p<0.01$). The lack of interaction between chipping and storage time confirmed that there was consistently no effect of chipping throughout the storage period. Working on pure β-carotene encapsulated in dextrose equivalent maltodextrin by three drying processes: spray, drum and freeze drying, Desorby *et al.* (1997) found that larger particles obtained in drum drying had improved β-carotene stability over storage when compared with the other processes. Mills & Hart (1945) working on dehydrated sweet potato also found that six month-stored flour had higher carotene loss than sliced material at ambient temperature and concluded that sweet potato should be stored in the way they are dehydrated rather than milled into flour. In the present study, the lack of difference from chipping, however, did not agree with the results by Desorby *et al.* (1997) and Mills & Hart (1945), but it is believed that the difference in retention observed in these previous studies is a result of the very different particle sizes of samples tested (*i.e.* flour and slices) that may have resulted in differential porosity to air

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Deleted: In this study, a new finding was that there was a major varietal effect associated to chipping ($p<0.01$). (Table 3); total carotenoid loss was on average 17.6% on Resisto and 5.5% on MGCL01. Resisto chips produced by thick chipper were sticky and took a long time to dry (62.3h). The combined effect did not exist when dry matter was included as covariate in the analysis of variance (Table 3). Therefore the higher sensitivity of Resisto to the chipping type compared to MGCL01 can be explained by its lower initial dry matter content that requires evacuating more moisture during drying and is in agreement with Bechoff *et al.* (2010a); Hagenimana *et al.* (1999). ¶ ¶

oxidation. This present study demonstrated that there was no effect of chip size in stored samples. Oxidation is reported as the main factor responsible for carotenoid degradation during storage of dried sweet potato (Emenhiser *et al*., 1999). Therefore the lack of differences in this study is hypothesised to result from similar air oxygen diffusion through the different chip/slice sizes (that did not differ as much in size as with flour and slices) of the samples stored in jute bags.

Effect of variety on total carotenoid loss during storage

There was a significant effect of variety during storage of dried sweet potato ($p<0.01$). Resisto with 26.8%, 47.8%, 78.6% loss after one month, two and four months of storage, had lower total carotenoid losses than the MGCL01 variety with 39.0%, 63.2%, 87.7% respectively (Figure 1). This could possibly result from differential composition in other constituents that can enhance or delay carotenoid degradation: for instance, enhancers could be unsaturated fatty acids that are mostly linoleic and linolenic acids in sweet potato (Walter & Purcell, 1974) and were related to lipid peroxidation (Arya *et al*., 1979), and inhibitors of carotenoid oxidation could be phenolic compounds. Phenolic content has been positively correlated to antioxidant activity in various sweet potato varieties (Teow *et al*., 2007). More investigation is required to understand varietal differences with regard to carotenoid retention.

Estimation of vitamin A activity in chips after drying and storage

Immediately after drying, average total carotenoid contents for Resisto and MGCL01 respectively were 355.6 $\mu g.g^{-1}$ and 218.2 $\mu g.g^{-1}$ on a dry weight basis. According to Bechoff *et al.* (2010a), these values corresponded to an estimated vitamin A activity of 24 617 and 15 107 $RE.kg^{-1}$ respectively and were largely beyond the recommended daily allowance for children (4000 $RE.kg^{-1}$). After a four month-storage, average total carotenoid contents for

Resisto and MGCL01 were 73.4 µg.g^{-1} and 25.9 µg.g^{-1} on a dry weight basis respectively. These values corresponded to an estimated vitamin A activity of 5080 and 1796 RE.kg^{-1} respectively. After four month-storage the vitamin A activity is strongly reduced and only Resisto variety meets the RDA. However because of other quality issues (*i.e.* presence of insects) the recommended storage period should not exceed 3 months for Resisto. In order to meet the RDA, the storage time for MGCL01 should not be over two months. These estimates however do not take into account losses occurring during the further processing of dried sweet potato into a form eaten by consumers. This should be the subject of another research study.

Identification of carotenoids before and after storage

The individual carotenoid compounds before drying, after drying and after 4 month-storage of dried sweet potato were tentatively identified by HPLC (Figure 2). Resisto had the same chromatographic profile as MGCL01. Therefore only the chromatograms for Resisto are shown. The main compound is trans-β-carotene (peak 7) resolved at 37 min. and representing 84% of the total carotenoid concentration, both for Resisto and MGCL01 samples on average (over dried and stored samples). Other peaks were minor compounds mostly degradation products of all-trans-β-carotene and even present in fresh root samples in very small quantities. The presence of β-carotene 5,6 epoxide has been reported by Kósambo *et al.* (1998) in fresh sweet potato roots. On average (for dried and stored sliced Resisto variety) percentages were the followings; β-carotene 5,6-epoxide (4.0%), 5,6-epoxide (3.2%) 9-cis (1.3%) and 13-cis-β-carotene (3.1%). Trans-β-carotene, β-carotene 5,6-epoxide, 9-cis and 13-cis-β-carotene were previously identified using the same HPLC system on a different sweet potato variety (Bechoff *et al.*, 2009). In spite of the degradation of β-carotene, no clear increase of degradation products was readily observed using the HPLC technique. There are minor differences between the chromatographic profiles of those samples, fresh (Figure 2A) or dried (Figure 2B) or dried and subsequently stored (Figure 2C): peaks a (possibly β-

carotene-5,6,5',6'-diepoxide); b (possibly β-carotene-5,6,5',8'-diepoxide) were found in fresh roots, peaks a, b and c (25 min.unidentified) were found in dried chips but peak c was only detected after four months of storage. Peak 2 (β-carotene 5,6 epoxide) was not affected by drying but was sharply reduced during storage. On the other hand, peaks 3 (β-carotene 5,8 epoxide) and 6 (13-cis β-carotene) decreased at a lower rate during storage. Storage affected more the chromatographic profile of carotenoids than drying did. Harsher conditions of processing may be necessary to induce more differences in the carotenoid profile. In contrast to this study, significant differences in the chromatographic profile of fresh and heated citrus juices (5h; 95ºC) have been described by Dhuique-Mayer *et al.* (2007). The present profile of carotenoids in OFSP flour showed that there were very few qualitative differences in the chromatogram of samples immediately before or after drying, or after storage for 4 months.

Kinetics of individual carotenoid degradation during storage

Kinetics of carotenoid loss per variety are presented in Table 4. For trans β-carotene and β-carotene 5,6-epoxide, the coefficients of correlation with storage time were generally higher than R=-0.95. MGCL01 variety fitted better first order kinetics whilst Resisto fitted equally zero and first order kinetics and this has not been reported previously. Instead, it has been shown that dried food fitted first order kinetics degradation during storage (Hidalgo & Brandolini, 2008; Koca *et al*., 2007). Nevertheless, working on pure β-carotene powder, Minguez-Mosquera & Jaren-Galan (1995) demonstrated that degradation followed zero-order kinetics in an organic anhydrous medium while in an aqueous medium it followed first-order kinetics. Zero order reactions are found when the substrate is in excess. Because Resisto had twice as much trans-β-carotene as MGCL01 this could possibly explain why the zero order reaction also fitted Resisto. This indicates that the oxidant had no limitation on the substrate which means that oxygen from the air could easily penetrate the product. There are a few discrepancies between the two models because in order zero Resisto degradation was faster

than MGCL01 and order one the opposite. Because coefficients of correlation were higher in first order, particularly on MGCL01, the first order was considered. First order rates of degradation were 0.0171 day^{-1} for trans-β-carotene on Resisto and 0.0251 day^{-1} on MGCL01. The rate of degradation of β-carotene 5,6 epoxide was slightly faster than that of trans-β-carotene (0.0249 and 0.0315 day^{-1} on Resisto and MGCL01 respectively) and this was in accordance with recent work by Bechoff *et al.* (2010b).

Isomers of β-carotene, 13-cis- and 9-cis-, degraded following first order kinetics however with coefficients of correlation with storage time lower than trans-β-carotene and 5,6 epoxide-β-carotene (R~0.80). Rate constants of 13-cis- and 9-cis isomers in Resisto and MGCL01 being 0.0080; 0.0102 and 0.0115; 0.0190 day^{-1} respectively were less than that of trans-β-carotene (0.0171 and 0.0251 day^{-1}). This observation is significant because, to our knowledge, the rate of degradation of cis-isomers has not been widely reported in literature when working on storage. A degradation of cis-isomers jointly with trans-β-carotene in solar-drying was however reported by Bechoff *et al*. (2009); Kidmose *et al*. (2007); Mulokozi & Svanberg (2003) working on sweet potato drying. In summary, these results showed that the concentration of all the carotenoids was proportionally reduced in storage.

CONCLUSION

Compared to the earlier study carried out on-research station in Uganda (Bechoff *et al.* 2010a), retentions of total carotenoids after on-farm drying in Mozambique were similar, when considering the same type of dryers (tunnel or sun dryers). It was shown in both studies that a higher level of technology (tunnel dryer) as compared with a lower level of technology (open air sun drying on raised trays), did not necessarily lead to a higher carotenoid retention.

The lack of difference in carotenoid retention between different chip sizes during storage is also positive for farmers, because it means that they can limit their management costs because traditional hand slicing of sweet potato was as good as the use of a mechanical chipper on the retention of carotenoids. On the other hand, the effect of variety was significant in drying and storage. These observations require investigation on more varieties as this was noted in the research station based study (Bechoff *et al*. 2010a).

Total carotenoid losses during storage were high and these considered being slightly greater than the losses determined on-station in Uganda (results after four month-storage). Higher losses in the on-farm based study in Mozambique may be explained by higher temperatures and lower relative humidity (Bechoff *et al*., 2010b) especially in the day. In order to meet a significant part of daily nutritional requirements in provitamin A (100g corresponding to 100% of RDA for children) (Bechoff *et al*., 2010a), chip samples should not be stored for more than two months for MGCL and four months for Resisto. However Resisto chips should preferably not be stored more than three months because of insect damage.

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It is possible to do on-farm research and to get similar results to that obtained on-research station. These findings are important when transferring technology from a research station, which includes control over research-parameters, to the more realistic situation of the farm where farmers themselves monitor the drying and storage of their crops.

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Table 1: Total carotenoid losses after drying influenced by treatment (dryer, chipping) using MGCL01 and Resisto varieties

Variety	Chipping	Dryer	Dry matter content (%)	Drying time* (h)	Total carotenoid content (µg.g^{-1} db)**	Total carotenoid loss (%)
MGCL 01	Fresh roots		35.4		235.6 (6.5) bc	-
	Thin chips	Tunnel	93.9	25.5	210.2 (5.0) a	10.8
		Open	92.1	23.8	224.2 (6.0) abc	4.9
		Shade	89.9	26.5	238.0 (6.2) bc	-1.0***
	Thick chips	Open	89.6	23.9	224.5 (1.9) abc	4.7
	Slices	Tunnel	91.4	47.7	204.9 (2.6) a	13.0
		Open	87.7	47.6	219.4 (3.2) ab	6.9
		Shade	86.8	50.7	242.5 (6.3) c	-2.9***
Resisto	Fresh roots		27.0		434.4 (0.7) e	-
	Thin chips	Tunnel	91.9	26.1	371.1 (2.5) bc	14.6
		Open	91.5	25.4	362.8 (13.0) b	16.5
		Shade	89.9	50.7	401.0 (8.3) cd	7.7
	Thick chips	Open	91.0	62.3	327.7 (2.8) a	24.6
	Slices	Tunnel	88.8	72.4	376.2 (4.8) bc	13.4
		Open	84.0	75.4	383.6 (6.2) bc	11.7
		Shade	78.3	75.5	418.0 (1.5) de	3.8

* Drying time includes days and nights of samples spent on dryers –average of two-drying trials.
** db: dry weight basis. Each value represents the mean (standard deviation) of two extractions for two-drying trials (2^2). For each sweet potato variety, values followed by different letters are significantly different (ANOVA-Tukey test; $p<0.05$). Total carotenoid content was measured using a Hewlett Packard 8452A spectrophotometer at an absorbance of 450nm.
***Negative values are not significantly different from values in fresh sweet potatoes
Average and variation on day/night temperature and humidity respectively were 22°C (12-33°C) and 65% (25-95%) in ambient conditions; 26°C (11-55°C) and (63% (13-100%) inside the tunnel dryer.

Table 2: Effect of dryer type on carotenoid loss:

ANOVA (main effects) - Factors: variety: (Resisto, MGCL01); dryer (open, tunnel, shade); chipper (slices, thin chips); replication trial, and final dry matter (after drying) as a covariate

Source	df	Mean square
Variety	1	4.800**
Dryer	**2**	**2.000****
Chipper	1	0.100
Trial	1	0.002
Final dry matter (covariate)	1	0.600*
Error	41	0.100
Total	48	

* Significant at $p < 0.05$; ** Significant at $p < 0.01$

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Table 3: Effect of chipper on carotenoid loss after open air sun drying: ANOVA (main effects) - Factors: variety (Resisto, MGCL01); chipper (slices, thick chips, thin chips); replication trial, and final dry matter as a covariate

Source	df	Mean Square
Variety	1	11.000**
Chipper	2	1.100**
Trial	1	<0.001
Final dry matter (covariate)	1	2.900**
Error	18	0.100
Total	23	

** Significant at p < 0.01

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Table 4: Kinetic parameters of zero order and first order carotenoid degradation in Resisto and MGCL01 slices stored for four months

	Reaction Order	Trans-β-carotene		5,6 epoxide-β-carotene		13-cis-β-carotene		9-cis-β-carotene	
		k (day^{-1})	R	k (day^{-1})	R	k (day^{-1})	R	k (day^{-1})	R
Resisto	0	2.7643 (0.2500)	-0.976	0.1840 (0.0131)	-0.985	0.0376 (0.0054)	-0.943	0.0228 (0.0046)	-0.896
	1	0.0171 (0.0010)	-0.990	0.0249 (0.0025)	-0.971	0.0080 (0.0009)	-0.963	0.0102 (0.0012)	-0.963
MGCL 01	0	1.5436 (0.2648)	-0.922	0.0989 (0.0144)	-0.942	0.0261 (0.0081)	-0.796	0.0180 (0.0057)	-0.791
	1	0.0251 (0.0028)	-0.966	0.0315 (0.0035)	-0.965	0.0115 (0.0033)	-0.819	0.0190 (0.0039)	-0.893

Each value represents the mean (standard deviation) of two extractions

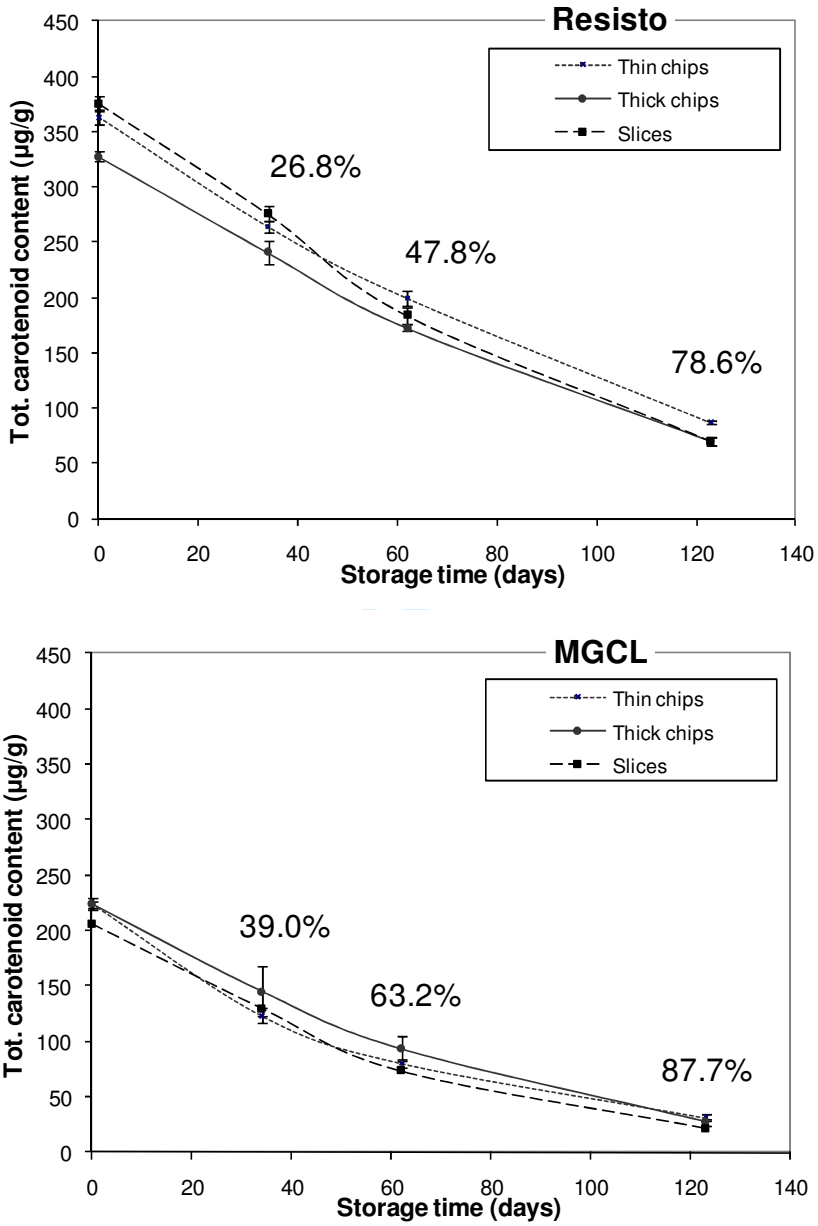

Figure 1: Kinetics of total carotenoid degradation during storage of Resisto and MGCL01 varieties chipped to three different sizes. Mean of 2^2 replicate; error bars refer to standard error.

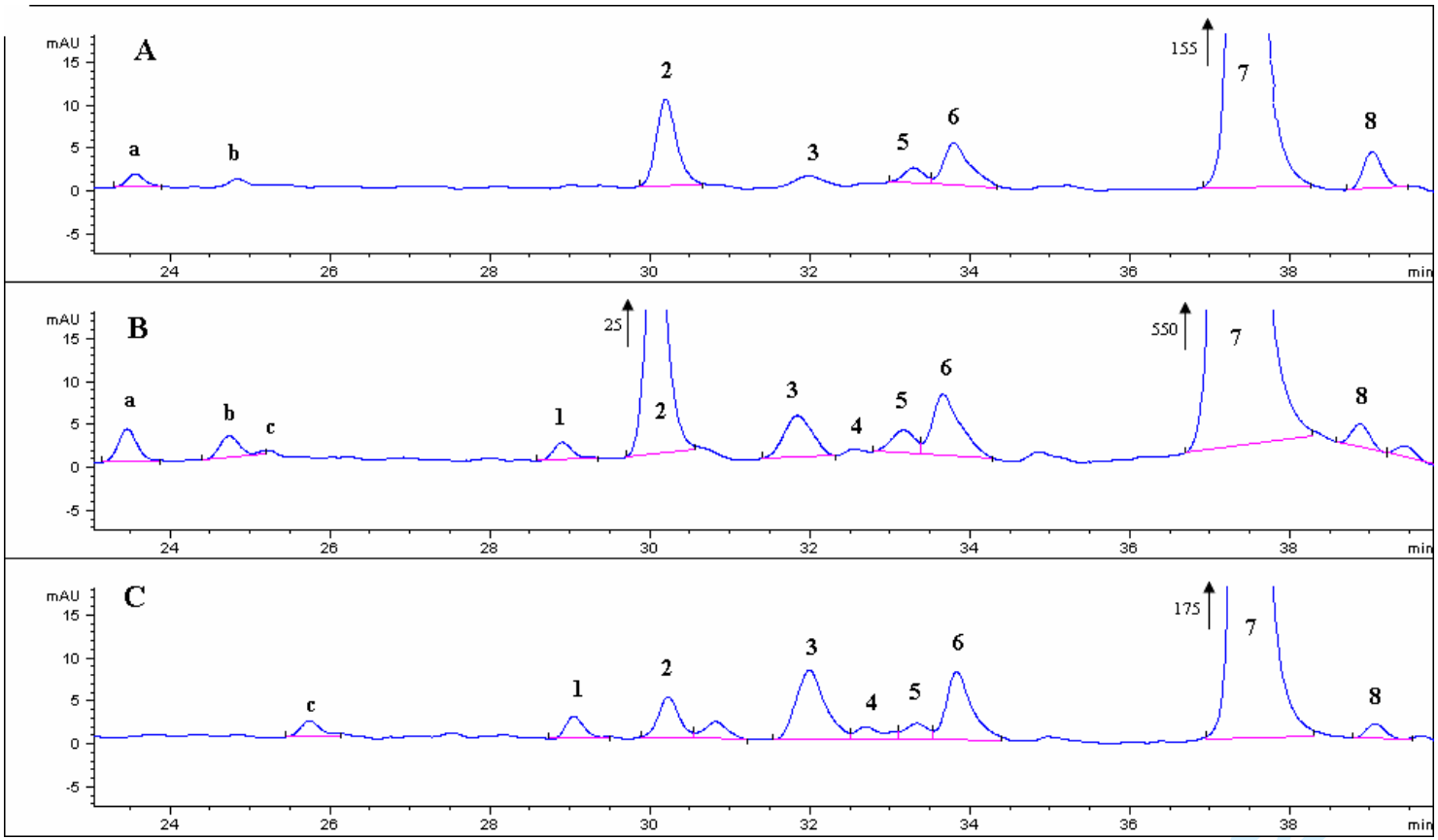

Figure 2: HPLC chromatograms at 450nm of the carotenoids of Resisto slices before drying (A), after drying (B) and after 120 days storage (C). a: Possibly β-carotene-5,6,5',6'-diepoxide (23 min.) (414; **440**; 468nm); b: Possibly β-carotene-5,6,5',8'-diepoxide (24 min.) (400; **422**; 450nm); c: unidentified (25 min.) (406; **424**; 450nm); 1: Possibly 13-cis-β-carotene-5,6 epoxide (29min.) (main wavelengths: 416; **439**; 476nm); 2: Possibly β-carotene-5,6 epoxide (30min.) (422;**446**; 472nm); 3: Possibly β-carotene-5,8 epoxide (32min.) (406;**428**; 452nm); 4&5: Unidentified; 6:13-cisβ-carotene (34min.) (338;422;**444**; 472nm); 7: All-trans-β-carotene (37min.) (**452**; 478nm); 8: Possibly 9 cis-β-carotene (39min.) (**446**; 472nm). The three graphs are not to the same scale because of differing dry matter contents (respectively 27%, 89% and 87%). The graphs have been scaled to illustrate the minor peaks and therefore the larger peaks have been truncated.

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Dry matter (covariate):	no		yes	
Source	df	Mean Square	df	Mean Square
Variety (V)	1	109904.20**	1	78458.84**
Chipper (C)	2	1352.88**	2	1629.99**
Trial (T)	1	514.30**	1	149.53
V x C	2	1872.34**	2	84.51
V x T	1	396.09*	1	1.51
C x T	2	394.72**	2	87.09
V x C x T	2	68.59	1	40.77
Error	12	53.43	12	53.43
Total	24		24	

* Significant at $p < 0.05$;