EFFECT OF PRETREATMENTS FOR RETAINING TOTAL CAROTENOIDs IN DRIED AND STORED ORANGE-FLESHED-SWEET POTATO CHIPS

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ABSTRACT

Various dipping pretreatments have been investigated for orange-fleshed sweet potato (OFSP) to retain carotenoids after drying and subsequent storage. Effects of blanching, sodium metabisulfite (0.5 or 1%), acids (ascorbic acid [1%] or citric acid [0.5%]) or salt (1%), either singly or as mixtures, were tested on dried OFSP chips that were stored for up to 6 months in ambient conditions. Overall, there was a positive effect of dipping on total carotenoid content after drying compared with control (P < 0.05). A slight improvement in carotenoid content was observed during the first month of storage with ascorbic acid, sodium metabisulfite, and mixtures of sodium metabisulfite and citric acid, or ascorbic acid and salt pretreatments, but these higher levels were not maintained over longer storage periods (4–6 months). The general lack of improvement was believed to result from the leaching and degradation of the chemicals during storage.

PRACTICAL APPLICATIONS

Vitamin A deficiency (VAD) is a major cause of blindness among children in developing countries and some crops such as orange-fleshed sweet potato (OFSP) rich in provitamin A could help tackle VAD. Drying is a traditional preservation process of sweet potato in some developing countries where it is consumed, but the problem is that losses of carotenoids occur during drying and subsequent storage of OFSP chips. Some practical and affordable ways for processors of OFSP in developing countries to reduce these losses are needed. This manuscript provides practical information on the effect of dipping pretreatments on carotenoid losses, in particular, during storage. This information can be relevant for farmers and millers working with OFSP or other root crops. More generally, this work can inform users of the above chemical pretreatments on the effect of these on carotenoid preservation in similar dried food commodities.

INTRODUCTION

Dietary intervention with the use of locally grown crops could help tackle public health problem of vitamin A deficiency. Sweet potato (Ipomoea batatas Lam.) is a staple food in many parts of Africa, and some newly promoted varieties contain high quantities of provitamin A (Low et al. 2001). In East Africa, steaming, boiling and drying are the most common methods of processing (Hall et al. 1998). Of these processes, drying is a means of producing a tradable product for local use, use in commercially available composite flours or as a replacement of wheat flour in bakery products. It is a convenient way of preserving sweet potato, and it is usually stored during the off season for between 4 and 6 months (Hall et al. 1998). However, it has been demonstrated that high losses of provitamin A occur during storage in ambient conditions (Bechoff et al. 2010). After 4 months of storage at ambient temperature, an average loss of 70.4% of total carotenoids was observed.
carotenoids was reported working with Ejumula and Kakamega orange-fleshed sweet potato (OFSP) varieties in Uganda. These results were subsequently confirmed when more varieties were dried and stored together (Ejumula; Kakamega [SPK004]; SPK004/1; SPK004/6; Kabode [SPK004/6]). The retention of carotenoids in OFSP was also studied with different reduction sizes. No improvement in retention during drying and subsequent storage was reported when using slices instead of thin chips (Bechoff et al. 2011). High losses of carotenoids during storage of dried OFSP were considered a critical issue in all cases. To reduce carotenoid losses, techniques, which could potentially be applied, include storage at lower temperature (Cinar 2004), in a vacuum by the use of oxygen-free packaging (Emenhiser et al. 1999), coating with cyclodextrin (Desorby et al. 1997), blanching or chemical pretreatment (Arya et al. 1979; Van Hal 2000).

The low level of resources by farmers in Uganda is a major constraint to finding cost-effectiveness and practical solutions for improving storage. Consequently, it was decided to explore the effect of low-cost chemical pretreatments and blanching. Pretreatments of vegetables, fruits or roots have been reported to significantly reduce carotenoid degradation during storage (Dutta et al. 2005). Sulfite is widely used as a food preservative to inhibit oxidation either by oxygen (in air) or enzymes (Isaac et al. 2006). Baloch et al. (1987) reported that sulfiting using sodium metabisulfite had a significant effect in improving the carotenoid content in diced dried carrots stored at 37°C for 4 months. Retention of carotenoids in diced carrot samples treated with sodium metabisulfite compared with untreated samples was 76.6 and 51.1%, respectively. Moreover, blanching of food using various processes (water, vacuum steam, in-can, microwave) with temperatures varying between 75 and 98°C and times between 1 to 10 min have been reported to efficiently inactivate enzymes (such as peroxidases and lipoxygenases) that can degrade carotenoids (Baloch et al. 1977). A combination of sodium metabisulfite (0.2%) plus sodium chloride (NaCl) (3%) was also shown to significantly reduce carotenoid destruction in pretreated and dried carrots (Arya et al. 1982). Salting is still widely practiced in Africa and other parts of the world. Salting reduces the osmotic tension of cells and increases the stress on bacteria and enzymes that can degrade food and its constituents such as carotenoids (Wijnker et al. 2006). In bread making, NaCl has a positive effect on the preservation of carotenoids because it delays dough oxidation (King Arthur Flour Company 2009). It has been shown in the case of carrots, carotenoids were more stable if they were soaked (10% solution for 30 min at 20°C), blanched (2.25 min at 96°C) and air-dried (Speck et al. 1977). Another pretreatment is acidification. Acidifying by addition of lemon or tamarind juice is used as a traditional preservation process in Eastern parts of Uganda (Okwadi, 2008). Acidity can help reduce enzymatic activity by lowering the pH value and, in addition, some acids have an antioxidant property (e.g., ascorbic acid) and can reduce oxidation. Addition of ascorbic acid has a positive effect on the antioxidative activity of dried carrots during storage (Yen et al. 2008). Moreover, a combination of sodium metabisulfite (0.5%) and citric acid indicated an increased efficiency. At a low pH value (2.5), high-quality sweet potato flour was obtained due to improved efficiency of sulfite or a decrease in activity of enzymatic activity (Van Hal 2000).

The effect of low-cost pretreatments on the carotenoid content during drying and storage of sweet potato has been reported by few authors (Singh et al. 2006) in comparison with other roots or vegetables, such as carrot. Therefore, there was a need to evaluate these pretreatments (single or combined) for the preservation of carotenoids in OFSP, in particular, under the conditions applicable to developing countries. This study explored the impact of various pretreatments to retain carotenoids after drying and after storage over 6 months at ambient temperature.

**MATERIALS AND METHODS**

**Sweet Potato Root Samples**

Roots were collected from Wobulenzi, Luwero district, Uganda. Roots were of Ejumula (deep orange fleshed) and Kakamega (light orange fleshed) varieties. Ejumula had a typical total carotenoid content of 200–300 μg/g and Kakamega of 80–120 μg/g on a dry weight basis. Mature roots (80 kg per variety for two trials) were harvested after a growing season of 6 months. Within a day after harvest, the roots were washed and drained.

All drying trials were carried out using the same batch of sweet potatoes in replicate and were undertaken during the same week with a 3-day interval. Unpeeled roots were chipped using a rotary disk chipper (mean ± standard deviation chip thickness [n = 20]: 1.6 ± 0.6 mm). The samples of chips were subsequently carefully mixed using a quartering technique to divide it into subsamples (4 kg each). The quartering technique consists in dividing the whole of the sample into four equal divisions and, then, removing two opposite quarters. The remaining two quarters are combined into one pile, and the process is repeated until the desired sample size (4 kg) is obtained.

Thin chips were used because they took less time to dry than sliced or diced sweet potato (slices took an extra day to dry than chips). Chips are also easier to sample and to mill into flour.

**Pretreatments**

The study was conducted in two stages: the preliminary experiment was a “screening” experiment to test the effect of
single chemical pretreatment on two different OFSP varieties (Ejumula and Kakamega). Subsequently to the preliminary experiment, it was decided to conduct a more detailed experiment on the effect of pretreatment (main experiment) working with only the variety that contained the highest carotenoid content (Ejumula) and testing the effect of single chemical was as well as combined chemical pretreatments. The outcomes of the main experiment should indicate which pretreatment (single; combined) and which chemical worked best to limit carotenoid degradation, in particular, during storage of dried chips.

Freshly chipped sweet potato (4 kg) (wrapped in a stiff mesh cotton net) was immersed either in 5 L deionized water mixed with chemical at ambient temperature for 30 min or blanched in boiling deionized water. Deionized water was used as a control for the experiment. It was considered that tap water may contain other dissolved substances that might have interfered with the results.

For the preliminary experiment, the treatment solutions were sodium metabisulfite (1% w/v) (pH = 4.5), ascorbic acid (1% w/v) (pH = 2.5) and salt (1% w/v) (pH = 6.7). The pH value of the solution was recorded at 25°C (Thermo Orion pH/conductivity meter, Thermo Scientific, Two Rivers, WI).

For the main experiment, the solutions used were sodium metabisulfite (0.5% w/v) (pH = 4.9); the concentration of sodium metabisulfite in solution was reduced from 1 to 0.5% because of the risk of allergy [Russell and Gould 2003]; citric acid (0.5% w/v) (pH = 2.0); ascorbic acid (1% w/v) (pH = 2.5); NaCl (1% w/v) (pH = 6.7); citric acid: NaCl (0.5%:1%); ascorbic acid: NaCl (1%:1%); sodium metabisulfite: citric acid (0.5%:0.5%) (pH = 2.2) and deionized water (pH = 6.7).

Samples were blanched in boiling deionized water at a temperature of 96°C (TEL-TRU Thermometer, Rochester, NY) at NARL, Kawanda, Uganda (altitude: 1,193 m). Temperature at the core of the samples varied between 60 and 82°C during the blanching process. To determine the optimal blanching time, the peroxidase test was used. The peroxidase test procedure followed an adaptation of Food Agriculture Organisation (FAO) peroxidase test for vegetables (Enachescu Dauthy 1995). Deionized water (20 mL), 1 mL of guaiacol (1% in 96% ethanol) and hydrogen peroxide (0.3%) were successively added on 10 g of crushed, blanched sample. A rapid and intensive brown-reddish tissue and liquid coloring indicated a high-peroxidase activity (positive reaction). A gradual appearance of a pink color indicates an incomplete peroxidase inactivation. However, peroxidase was considered inactivated if no color appeared in the first minute because later appearance of brownish color could be a bias due to the air oxidation of guaiacol.

During the soaking of sweet potato in the deionized water for chemical pretreatment or blanching, some of the soluble solids were noted to leach from the sweet potato into the surrounding liquid. In order to accurately calculate the losses in carotenoids, the losses of soluble solid needed to be estimated. The loss in soluble solid (LS) was defined as the percentage of mass lost after pretreatment and drying. It was calculated as a ratio between the dry solid mass before drying and the dry solid mass after drying of pretreated samples. The following Eq. (1) was used:

\[
LS = 1 - \frac{DM_m}{DM_i} \cdot m_i
\]

where \( DM \) is the dry matter (%) after drying, \( DM_i \) is the initial dry matter of fresh chips, \( m \) is the mass of sweet potato chips after drying and \( m_i \) is the initial mass of chips before drying (4 kg per treatment). Total carotenoid content on a fresh basis was the content directly measured from the sample. Total carotenoid content on a dry weight basis was determined by dividing total carotenoid content on a fresh basis by DM. It took into account the moisture contained in the product. Total carotenoid content on a nonsoluble solid basis took into account LS and was determined by multiplying total carotenoid content on a fresh basis by 1-LS.

**Drying**

Sun drying was carried out on black polythene sheets laid upon a raised platform (about 1 m above the ground). Chips were evenly spread on drying trays with a density of 3.9 kg/m² (based on the sample weight before pretreatment). Samples were weighed every 2 h in the first stage and three times a day in the last stages of drying. Ambient temperature, humidity, wind speed and irradiance were recorded every 30 min when samples were on the dryers using a Vantage Pro-meteorological station (Davis Instruments, Hayward, CA) and mean drying time was recorded (Table 1). All samples were removed from dryers and placed under a shelter at night and when it rained. The end of drying was evaluated by the presence of flour and a characteristic cracking noise when crushed in the hand. Dry matter content of dried chips ranged between 85.2 and 93.3%.

**Storage**

From an initial quantity of fresh chips of 4 kg per treatment, the final quantity of dried chips obtained was about 1.4 kg for Ejumula and 1.5 kg for Kakamega. Immediately after drying and after careful mixing using a quartering technique, about 1/3 of the chips were placed in the freezer for carotenoid analysis. The rest of the chips (2/3) were stored at ambient temperature in double layer woven white opaque polypropylene bags. These were stored in a room with small windows (allowing daylight through). Duplicates of drying trials were stored in different bags. Stored samples were collected at
Intervals of 1 month (31 days), 2 months (62 days), 4 months (125 days) and 6 months (187 days). Data for temperature and humidity over an 8.5-month period are found in Bechoff et al. (2010).

**Total Carotenoid Analysis**

Total carotenoid analysis was undertaken both in the U.K. (for dried samples from the preliminary and main experiments) and in Uganda (for dried samples from the main experiment that have been stored). Extractions were carried out in duplicate on the duplicate trials (four replicates per treatment). In all cases, collected samples were stored in a freezer (−20°C). Some of the samples could not be analyzed in Uganda because frequent power shortages delayed the work. Therefore, these analyses were completed in the U.K. For the samples analyzed in the U.K., dried sweet potato chips were transported in a cooler bag to the U.K. (maximum 24 h outside the freezer) and stored in a freezer immediately upon arrival. The effect of such a transport was proven to be negligible on the carotenoid degradation (Bechoff et al. 2010). Samples analyzed in the U.K. were milled either by a Laboratory mill 3,600 (position 3) (in the U.K.) or a model C/11/1 (Glen Mills, Clifton, NJ) (position 17) (in Uganda).

A portion of the homogeneous representative sample (0.5–1.0 g of flour) was homogenized with 50 mL of methanol : tetrahydrofuran (THF) (1:1) using a Polytron PT1200E (Kinematica, Littau/Lucerne, Switzerland) homogenizer (in Uganda) or an Ultra-turax (IKA Janke and Kunkel Labortechnik, Staufen, Germany) homogenizer (in the U.K.) for 1 min. In all cases, before homogenizing the flour, it was rehydrated for 20 min in 10 mL of deionized water. The homogenized extract was filtered through a porosity 2-sintered glass funnel by vacuum and rinsed with methanol : THF (1:1) until there was no yellow color left in the filtrate. The extracts were combined and poured into a 500-mL separating funnel filled with 40 mL of petroleum ether (PE). After washing once with 50 mL of 10% NaCl and thrice with 200 mL of deionized water, the upper PE phase containing the carotenoid extract was collected in a 100-mL flask. The PE phase was dried by addition of anhydrous sodium sulfate until some crystals remained loose. This was then filtered into a 50-mL volumetric flask through glass wool and made up to volume with PE. Absorbance at 450 nm was read on Genesys 10 UV (Thermo Scientific, Two Rivers, WI), a UV-visible spectrophotometer (in Uganda), or a Diode Array detector spectrophotometer (Hewlett Packard HP8452A, Agilent Technologies U.K. Ltd., Cheshire, U.K.) (in the U.K.) at 450 nm. Concentrations were determined by comparison with an external standard curve using pure β-carotene (95% UV-synthetic powder, type 1, SIGMA, Dorset, U.K.) and an absorption coefficient of β-carotene in PE of 2,592 (Rodriguez-Amaya and Kimura 2004). β-carotene standard curve was determined by plotting eight concentration levels. Coefficients of correlation ($r^2$) between 0.997 and 0.999 indicated excellent linearity.

**Statistical Analysis**

Normality was assessed for all the samples ($P < 0.05$). Analysis of variance (ANOVA) was carried out to determine whether there were significant differences between samples. A significant difference between samples was determined using the Tukey test ($P < 0.05$). Correlations between samples analyzed in two different laboratories were determined using Pearson test ($P < 0.01$). All data were processed on SPSS 15.00 (SPSS UK Ltd. Woking, Surrey, U.K.) using Windows software.

**RESULTS**

**Effect of Pretreatments on Drying**

**Preliminary Experiment.** There was a good correlation between samples analyzed in the U.K. and Uganda (Pearson test—$r^2 = 0.92$ for $n = 25$ samples from the initial experiment), which showed that the results obtained in both laboratories (Uganda and U.K.) were coherent.

The effects of preliminary experimenting with pretreatments on the total carotenoid content after drying are presented in Tables 2 and 3. Pretreatment had a significant impact on carotenoid content using both dry basis (Table 2) and nonsoluble solid basis (Table 3) (two-way ANOVA; $P < 0.05$). The determination of total carotenoid content of

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**TABLE 1. ENVIRONMENTAL CONDITIONS DURING OPEN-SUN DRYING OF ORANGE-FLESHED SWEET POTATO CHIPS AND DRYING TIME**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Trial</th>
<th>Ambient temperature (°C)</th>
<th>Ambient relative humidity (%)</th>
<th>Wind speed (m/s)</th>
<th>Irradiance (W/m²)</th>
<th>Time on dryers (h)</th>
<th>Time under shelter* (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary</td>
<td>1st</td>
<td>26 (18–33)</td>
<td>66 (30–100)</td>
<td>2 (0–6)</td>
<td>392 (64–887)</td>
<td>17</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>31 (28–34)</td>
<td>33 (22–49)</td>
<td>4 (0–6)</td>
<td>504 (148–863)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Main</td>
<td>1st</td>
<td>28 (22–30)</td>
<td>57 (46–77)</td>
<td>9 (6–13)</td>
<td>636 (19–888)</td>
<td>8</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>2nd</td>
<td>28 (18–34)</td>
<td>49 (28–100)</td>
<td>5 (2–11)</td>
<td>615 (110–958)</td>
<td>13</td>
<td>16</td>
</tr>
</tbody>
</table>

* Does not include time on dryers. Mean (minimum–maximum).

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Mean (minimum–maximum).
Ejumula variety on a dry basis showed that the pretreatments of unsoaked, salt, sodium metabisulfite and ascorbic acid-treated samples did not differ significantly. The blanched samples had the highest carotenoid level after drying (Table 2). Using the peroxidase test, the adequate blanching time for peroxidase inactivation was 11 min for Ejumula (4 kg) and 8 min for Kakamega (4 kg) varieties, respectively. Determination of total carotenoid content of Kakamega variety on a dry basis showed that salt-treated samples had the lowest carotenoid level followed by sodium metabisulfite, unsoaked and ascorbic acid-treated samples. Blanched samples had the highest carotenoid content after drying (Table 2).

On the other hand, when the total carotenoid content was determined on nonsoluble solid basis (Table 3), the blanched samples had the lowest value together with salt-treated samples for both varieties. Sodium metabisulfite-treated samples had similar carotenoid level to salt-treated samples for Ejumula but significantly higher for Kakamega. Sodium metabisulfite-treated samples were not significantly different from ascorbic acid-treated and unsoaked samples for Ejumula variety. Unsoaked samples had significantly higher carotenoid level than the soaked samples for Kakamega variety. Overall, the carotenoid content of both varieties was affected by chemicals in the same way.

For all of the samples from the single pretreatment experiment, very significant correlations were obtained between LS and carotenoid content on a dry weight basis with correlations coefficient of 0.619 and 0.832 on Ejumula and Kakamega, respectively (n = 10; P < 0.01) (Table 2). A relationship between carotenoid content and soluble solid loss was similarly reported by Baloch et al. (1977) for LSs and increases in carotenoid content (basis on leached material) of carrots. This proved that leaching of soluble solids is a major factor responsible for the apparent increase in carotenoid content (Baloch et al. 1977). Hence, in order to obtain a more accurate value of carotenoid degradation on soaked or blanched samples working on a nonsoluble solid basis has been recommended. Thus, leaching of solids occurring during blanching can artificially increase the level of retention. Furthermore it was observed, in our trials, that drying of blanched chips was difficult because starch gelatinization rendered the chips sticky. A similar observation was made by Van Hal (2000) who raised the issue that blanching could "act as a form of incomplete cooking." Gelatinization could also be a problem at milling because gelatinized samples become too hard (Van Hal 2000). Consequently, blanching was not carried out in the main experiment.

Main Experiment. Results of the main experiment on the effect of pretreatments on the total carotenoid content of the Ejumula variety are presented in Table 4 on a nonsoluble basis. Consistent with the preliminary experiment, the unsoaked (untreated) samples had the highest carotenoid content after drying (269.4 µg/g) (P < 0.05). Within the soaked samples, samples dipped in deionized water had the lowest carotenoid content (237.7 µg/g) together with the citric acid-treated samples (232.2 µg/g) (P < 0.05). Compared with samples dipped in deionized water, all

### Table 2. Total Carotenoid Content (µg/g) Dry Basis for Ejumula and Kakamega Varieties of Orange-Fleshed Sweet Potato after Single Chemical Pretreatment and Drying

<table>
<thead>
<tr>
<th>Pretreatment</th>
<th>Ejumula</th>
<th>Kakamega</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unsoaked</td>
<td>123.2 (2.9)</td>
<td>123.2 (2.9)</td>
</tr>
<tr>
<td>1% salt</td>
<td>115.1 (1.4)</td>
<td>115.1 (1.4)</td>
</tr>
<tr>
<td>1% sodium metabisulfite</td>
<td>121.2 (9.0)</td>
<td>121.2 (9.0)</td>
</tr>
<tr>
<td>1% ascorbic acid</td>
<td>125.1 (4.3)</td>
<td>125.1 (4.3)</td>
</tr>
<tr>
<td>Blanched</td>
<td>164.9 (19.7)</td>
<td>164.9 (19.7)</td>
</tr>
</tbody>
</table>

Each value represents the mean (standard deviation) of 22 analyses (two drying trials, two extractions per trial). Two-way analysis of variance (factors: pretreatment [five levels]; trial [two levels]); different letters a, b, c in columns represent significant differences between treatments. Tukey test, P < 0.05.

### Table 3. Total Carotenoid Content (µg/g) Nonsoluble Solid Basis for Ejumula and Kakamega Varieties of Orange-Fleshed Sweet Potato after Single Chemical Pretreatment and Drying

<table>
<thead>
<tr>
<th>Pretreatment</th>
<th>Total carotenoid content (µg/g) insb</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ejumula</td>
</tr>
<tr>
<td>Blanched</td>
<td>206.9 (25.1)</td>
</tr>
<tr>
<td>1% salt</td>
<td>210.7 (31.2)</td>
</tr>
<tr>
<td>1% sodium metabisulfite</td>
<td>226.9 (27.2)</td>
</tr>
<tr>
<td>1% ascorbic acid</td>
<td>230.7 (36.5)</td>
</tr>
<tr>
<td>Unsoaked</td>
<td>233.5 (25.8)</td>
</tr>
</tbody>
</table>

Each value represents the mean (standard deviation) of 2² analyses (two drying trials, two extractions per trial). Two-way analysis of variance (factors: pretreatment [five levels]; trial [two levels]); different letters a, b, c in columns represent significant differences between treatments. Tukey test, P < 0.05.

TABLE 2. TOTAL CAROTENOID CONTENT (µg/g) DRY BASIS FOR EJUMULA AND KAKAMEGA VARIETIES OF ORANGE-FLESHED SWEET POTATO AFTER SINGLE CHEMICAL PRETREATMENT AND DRYING

TABLE 3. TOTAL CAROTENOID CONTENT (µg/g) NONSOLUBLE SOLID BASIS FOR EJUMULA AND KAKAMEGA VARIETIES OF ORANGE-FLESHED SWEET POTATO AFTER SINGLE CHEMICAL PRETREATMENT AND DRYING
pretreatments except for citric acid had a positive impact on carotenoid content. Compared with the deionized water-treated sample as a control proved that pretreatment had an impact on carotenoid content. Nevertheless, this also means that the soaking process had a disadvantageous effect on carotenoid content after drying compared with nonsoaking. The addition of NaCl improved the carotenoid content of citric acid-treated samples (232.2 μg/g versus 254.7 μg/g, respectively); however, the response was not consistent for the two trials (standard deviation of 34.6). NaCl did not significantly improve the carotenoid content of those samples treated with ascorbic acid (260.4 μg/g versus 260.8 μg/g, respectively). Citric acid slightly improved the content of sodium metabisulfite-treated samples (259.6 μg/g versus 250.0 μg/g, respectively). In summary, the combination of the three pretreatments (citric acid–salt, ascorbic acid–salt and metabisulfite–citric acid) did not make a major difference on carotenoid content after drying.

**Effect of Pretreatment on Storage**

The total carotenoid loss was determined at different intervals over the 6 months storage of dried samples (Ejumula variety) for the main experiment (Table 5). Dried samples prepared using the pretreatments of deionized water, citric acid and citric acid salt had significantly lower total carotenoid content after storage than the other treatments (two-way ANOVA; \( P < 0.05 \)). Salt-treated samples had higher content than deionized water, citric acid and citric acid–salt-pretreated samples but lower content than unsoaked samples. Salt–ascorbic-treated samples had similar content to unsoaked samples. Ascorbic acid– and sodium metabisulfite-treated samples also had similar content to unsoaked samples. The combination of sodium metabisulfite–citric acid resulted in a slight improvement in carotenoid content. The data in Table 5 shows the total carotenoid content for each pretreatment at different storage intervals.

### Table 4. Total Carotenoid Content (μg/g) Nonsoluble Solid Basis for Ejumula Variety of Orange-Fleshed Sweet Potato After Combined Chemical Pretreatment and Drying

<table>
<thead>
<tr>
<th>Pretreatment</th>
<th>Total Carotenoid Content (μg/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deionized water (control)</td>
<td>237.7 (24.0)</td>
</tr>
<tr>
<td>0.5% citric acid</td>
<td>232.2 (17.6)</td>
</tr>
<tr>
<td>0.5% sodium metabisulfite</td>
<td>250.0 (12.8)</td>
</tr>
<tr>
<td>1% salt</td>
<td>251.4 (18.8)</td>
</tr>
<tr>
<td>0.5% citric acid, 1% salt</td>
<td>254.7 (34.6)</td>
</tr>
<tr>
<td>0.5% citric acid, 0.5% sodium metabisulfite</td>
<td>259.6 (13.8)</td>
</tr>
<tr>
<td>1% ascorbic acid, 1% salt</td>
<td>260.4 (12.6)</td>
</tr>
<tr>
<td>1% ascorbic acid</td>
<td>260.8 (11.5)</td>
</tr>
<tr>
<td>Unsoaked</td>
<td>269.4 (14.9)</td>
</tr>
</tbody>
</table>

Each value represents the mean (standard deviation) of 22 analyses (two drying trials, two extractions per trial). Two-way analysis of variance (factors: pretreatment [nine levels]; storage month [six levels]; different letters a, b, c, d, e in columns represent significant differences between treatments. Tukey test, \( P < 0.05 \).

### Table 5. Total Carotenoid Content (μg/g) of Ejumula Variety of Orange-Fleshed Sweet Potato After 1-, 2-, 4- and 6-Month Storage Influenced Under Combined Pretreatments on Nonsoluble Solid Basis

<table>
<thead>
<tr>
<th>Storage (months)</th>
<th>Deionized water</th>
<th>0.5% citric acid</th>
<th>0.5% sodium metabisulfite</th>
<th>0.5% citric acid, 1% sodium metabisulfite</th>
<th>1% ascorbic acid, 1% salt</th>
<th>1% ascorbic acid</th>
<th>Unsoaked</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>123.4 (9.9)</td>
<td>132.3 (16.6)</td>
<td>126.4 (20.8)</td>
<td>134.9 (15.6)</td>
<td>137.0 (15.6)</td>
<td>134.1 (12.8)</td>
<td>130.5 (12.8)</td>
</tr>
<tr>
<td>2</td>
<td>91.2 (14.4)</td>
<td>93.4 (12.7)</td>
<td>98.3 (15.6)</td>
<td>109.3 (25.4)</td>
<td>119.3 (25.4)</td>
<td>123.5 (12.3)</td>
<td>126.1 (16.9)</td>
</tr>
<tr>
<td>4</td>
<td>74.5 (12.4)</td>
<td>54.0 (17.6)</td>
<td>63.4 (20.3)</td>
<td>84.6 (11.1)</td>
<td>76.2 (20.2)</td>
<td>82.1 (12.1)</td>
<td>104.8 (12.1)</td>
</tr>
<tr>
<td>6</td>
<td>41.3 (13.1)</td>
<td>37.1 (8.9)</td>
<td>42.1 (12.9)</td>
<td>43.0 (29.2)</td>
<td>47.4 (14.4)</td>
<td>47.7 (16.3)</td>
<td>47.4 (14.4)</td>
</tr>
</tbody>
</table>

Each value represents the mean (standard deviation) of 22 analyses (two drying trials, two extractions per trial). Two-way analysis of variance (factors: pretreatment [nine levels]; storage month [six levels]; different letters a, b, c, d, e in lines represent significant differences between treatments. Tukey test, \( P < 0.05 \).
significantly higher content than unsoaked samples only after 1 month of storage. Hence, pretreatments by ascorbic acid and sodium metabisulfite and combined treatments (ascorbic acid–salt and sodium metabisulfite–citric acid) had a significant impact on carotenoid content during storage compared with control in deionized water in a global analysis of storage.

Two-way ANOVA conducted for each storage time individually revealed that after 1 month of storage, sodium metabisulfite–citric acid, ascorbic acid, sodium metabisulfite, unsoaked samples had higher carotenoid contents than the control (deionized water) \( P < 0.05 \) (163.0, 155.1, 138.5, 144.1 and 123.4 \( \mu \text{g/g} \), respectively) (two-way ANOVA per storage time; \( P < 0.05 \)). Sodium metabisulfite–citric acid-treated samples also had a significantly higher content than unsoaked samples. On the other hand, citric acid, citric acid–salt, salt and ascorbic acid–salt had similar contents to the control after 1 month of storage (132.3, 126.4, 134.9, 137.0 and 123.4 \( \mu \text{g/g} \), respectively). Therefore, there was initially a significant effect of adding sodium metabisulfite or ascorbic acid to the soaking water for samples, but there was no effect of adding citric acid or salt. After a 2-month storage period, however, there was no difference between untreated and sodium metabisulfite–citric acid-treated samples (123.8 and 126.0 \( \mu \text{g/g} \), respectively). After 6 months of storage, no difference was found between the control and the unsoaked samples (41.3 and 47.4 \( \mu \text{g/g} \), respectively) and between most pretreated samples though sodium metabisulfite, ascorbic acid and citric–sodium metabisulfite treatment still gave the highest carotenoid values (51.2, 51.6 and 53.3 \( \mu \text{g/g} \)). Citric acid-treated samples had the lowest total carotenoid content \( P < 0.05 \) (37.1 \( \mu \text{g/g} \)).

**DISCUSSION**

Researchers have investigated the role of a range of pretreatments, such as NaCl, sulfur additives and other antioxidants, on the stability of carotenoids in food vegetables, fruits and roots after drying and storage but with mixed conclusions (Arya et al. 1979). Our work showed that the use of dipping pretreatments has little effect on carotenoid preservation in OFSP.

Samples treated with sodium metabisulfite or ascorbic acid did not have higher carotenoid content than unsoaked samples (Table 4). In accordance with our results, Karabulut et al. (2007) demonstrated that there was no difference in \( \beta \)-carotene content between sulfurated (by burning elemental sulfur in an enclosed place) and untreated (nonsulfurated) apricots after drying in hot air or in the sun. However, Yen et al. (2008) showed that hot air-dried or freeze-dried diced carrots treated with a solution of ascorbic acid (0.1%) + glucose (1%) had significantly better \( \beta \)-carotene content than unsoaked ones, which is in contrast to our results. After drying, however, samples treated with sodium metabisulfite or ascorbic acid had higher contents than samples soaked in deionized water (Table 4). Working on pineapple and papaya, Sian and Ishak (1991) also reported an improvement of total carotenoid content using sodium metabisulfite (0.2, 0.4 and 0.6%) after drying with deionized water as a control. These divergences in results after drying between these studies could be the result of the differences in food product composition, slice thickness, type of chemical added and incorporation of the chemical in the food matrix.

This work only considers total carotenoid content. However, it could be possible for cis-isomerization to occur. Doering et al. (1995) reported that cis-isomers of trans-\( \beta \)-carotene could significantly increase during processing at temperatures greater than 35°C. A significant increase of 13-cis-isomer was demonstrated in drum-dried OFSP and in blanched ones (Chandler and Schwartz 1988). Working with sun drying of OFSP, Bechoff et al. (2009), however, showed that there was no increase of cis-isomers in OFSP during drying. Harsher conditions would probably be required for cis-isomerization to occur. In this study, an increase of cis-isomers seems unlikely with samples soaked in different pretreatment at ambient temperature (around 23°C). However, it is plausible that blanching (at temperatures above 60°C) could have caused some minor cis-isomerization in accordance with Chandler and Schwartz (1988).

After a typical storage period for dried sweet potato (4–6 months), there was no significant effect of sodium metabisulfite (0.5%) compared with untreated or deionized water-dipped samples (Table 5). Working with diced OFSP pretreated with 0.2% sodium bisulfite for 5 min at room temperature, Cinar (2005) also did not show an improvement in the half life of metabisulfite-treated samples after 120 days at 4 or 25°C. Losses of \( \beta \)-carotene from dried carrots stored 12 months at room temperature (22–26°C) were 60 (deionized water: control), 56 (0.05% sulfite) and 59% (0.2% sulfite) (Zhao and Chang 1995). This was in accordance with our results that showed that there were few differences between untreated and sodium metabisulfite-treated samples after 6 months. In contrast, Baloch et al. (1987) showed that soaking carrots in sodium metabisulfite before dehydration had a significant effect on carotenoid content after drying and after storage at 37°C for 440 days (14 months). Carotenoid content was further improved when, in addition to sulfiting, carrots were also blanched. The differences of results with sodium metabisulfite might be explained by the incorporation of sulfite into the product, which may further influence the degradation of sulfite in storage (Baloch et al. 1987). Zhao and Chang (1995) described a sharp decrease in residual sulfite content in sulfite-treated carrots during storage (92% loss in 12 months). Sulfite may be lost by reaction with disulfide groups or thiols in proteins and low molecular weight

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intermediates (e.g., glutathione). Other reactions such as the formation of complexes between sulfate and aldehydes or other carbonyl compounds (i.e., some sugars) can remove its antioxidant activity (Russell and Gould 2003).

The lack of the effect of pretreatments on reducing carotenoid losses during drying can be explained by the following. Ascorbic acid is easily oxidized because it is water soluble and temperature sensitive (Labuza 1973) (Table 5). NaCl is known for its impact on osmoregulation and can denaturize enzymes, such as peroxidases, that could degrade carotenoids in sweet potato. The use of NaCl (1%), however, did not reduce carotenoid degradation during storage (Table 5). Latapi and Barrett (2006), working on tomato, also reported that carotenoid degradation rate was reduced by the use of sodium metabisulfite but not by addition of NaCl (10%). Likewise, Baloch et al. (1997) showed that salt (2%) did not have an influence on carotenoid content in dried tomato powder stored at 40°C for 90 days. In contrast, Arya et al. (1979) reported that NaCl (5%) significantly reduced the degradation of carotenoids in sun-dried carrots stored at room temperature (16–32°C) for 3 months.

Furthermore, soaking samples (30 min) at ambient temperature (water temperature ~15°C) resulted in lower carotenoid contents after drying compared with untreated samples (Table 4). This was believed to result from leaching of carotenoids in the water, which had an orange color after the sweet potato chips had been removed. A similar observation was made by Sian and Ishak (1991) after water blanching (70–100°C; 1–12 min) papaya and pineapple. In most studies, the control sample was soaked in deionized water (Baloch et al. 1987; Sian and Ishak 1991; Jaramillo-Flores et al. 2005). It was shown, however, in this study that untreated samples should also be used as an additional control because they gave a different result than deionized water-soaked samples. Moreover, the use of untreated samples is a way to compare the benefit of using no treatment at all (i.e., samples simply dried such as farmers would traditionally do) with the benefit of using pretreatment. Hence, in this study, a reduced soaking time may have led to improvements in carotenoid content because this might limit carotenoid loss into the solution (Sian and Ishak 1991). Shorter soaking times of 5 min were used by Baloch et al. (1987) on carrots. However, in this study, there were no differences in total carotenoid content of soaked or unsoaked samples after 6 months of storage (Table 5). In conclusion, the use of soaking as pretreatment may have had an effect on the carotenoid content during drying but had a limited impact on the carotenoid content during storage.

CONCLUSIONS

The tested pretreatments (chemicals or blanching) were selected because they were affordable and locally available in Uganda. After drying, unsoaked samples had a higher carotenoid content than the soaked samples. However, most pretreated and soaked samples (salt treated; ascorbic acid and sodium metabisulfite treated) had higher content than the control that had been dipped in deionized water. Only samples soaked in citric acid did not have an improved carotenoid level after drying. It can be concluded that applying chemical pretreatment was effective, but the soaking itself had a negative impact on carotenoid content after drying. In fact, the loss of carotenoids from soaking was greater than the benefit gained by the application of chemical additives.

A slight improvement in the carotenoid content in the first month of storage compared with control (deionized water) was not considered to be sufficient for these pretreatments to be more widely promoted. The lack of improvement in the carotenoid content loss was believed to result from the degradation of the chemicals in storage as reported by Zhao and Chang (1995). Alternative approaches (e.g., coating, improved packaging or reduced temperature) to preserving the carotenoid content of dried OFSP chips are therefore suggested.

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