POLISH JOURNAL OF FOOD AND NUTRITION SCIENCES
Pol. J. Food Nutr. Sci. 2004, Vol. 13/54, No 3, pp. 237–241

RETENTION OF ASCORBIC ACID DURING APPLE CHIPS PRODUCTION AND STORAGE*

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Key words: functional food, convective drying, apple chips, ascorbic acid

The retention of ascorbic acid (AA) in apple chips determined during the production of experimental batches was on average 83%. During chips preparation for drying, AA losses accounted for 5% and during drying – for 12%. Ascorbic acid stability during product storage in retail packages was quite high. After 9 months of storage at favourable conditions (7°C, 45% relative humidity (RH)), AA retention was 80.4%, whereas during storage at room temperature – only 63.1%. It was proved that there is an unlimited possibility of enriching apple chips in ascorbic acid (even up to 1200 mg/100 g of ready-to-eat product).

INTRODUCTION

It is commonly known that vitamin C is indispensable for proper growth and functioning of the human organism. Despite numerous activities which propagate healthy nutrition and articles disseminating knowledge on the role of vitamin C in prevention of many diseases, among them tumour diseases, the consumption of this vitamin in Poland is still insufficient [Borek-Wojciechowska, 2000]. Research results indicate that 31–45% of children and 62–66% of adults consume less vitamin C than provided for in nutritional guidelines. Taking into consideration health protection and prophylaxis, it seems necessary to look for new, attractive products, constituting a valuable source of nutrients and complying with consumers' expectations and taste. Such a novel and valuable product are dried, ready-to-eat crispy fruit chips which, due to a high concentration of dry matter, theoretically should be rich in vitamin C.

Vitamin C losses during fruit drying depend on raw material type and drying method, as well as additional factors, *e.g.* blanching or sulfitation. Its losses may vary from 10% at careful selection of technological parameters to almost total destruction in the case of drastic hydrothermal treatment and long drying with intensive airflow [Hulme, 1971; Sikorski *et al.*, 1988]. Taking into consideration the fact that the vitamin C content of apples of cultivable varieties stored for 8–13 weeks at a temperature of 3–5°C may be *e.g.* from 11 to 17 mg/100 g [Samotus, 1988], 100 g of dried apple chips produced from such raw material should contain about 100 mg of vitamin C, which corresponds to 130% of daily vitamin C requirements of adults. A product so rich in vitamin C might be advertised as both a functional food and a crispy snack.

The aim of the research was to estimate the actual ascorbic acid (AA) losses in the process of crispy dried fruit production (taking dried apple chips as an example), and to assess AA stability during storage of the finished product. In addition, an experiment was carried out to estimate the efficiency of apple chips enrichment in AA.

MATERIAL AND METHODS

Raw material. The raw material for apple chips production were apples of 'Idared' cv. picked at the harvest maturity and stored in normal atmosphere for about 6 months at a temperature of 0°C. The day before apple chips production, the fruits were removed from the storage chamber, heated to room temperature, washed and prepared for processing.

Apple chips production. Apple chips production was carried out according to the technology elaborated at the Research Institute of Pomology and Floriculture [Płocharski & Konopacka, 1999]. The apples were cut with skin and core perpendicularly to the vertical axis into slices 2.2±0.1 mm thick. As soon as possible the slices were immersed in 25.0±0.2% Brix pre-treatment syrup, containing 20% saccharose, 5% apple juice concentrate, 0.25% citric acid, and 0.12% SO_2. Treatment of slices was carried out for 2 min at 20°C. During each technological replication simulating industrial production, 1.6 kg of slices were saturated in 1 kg of solution in four successive batches, 400 g each (marked as A, B, C, D) so that the solution to slices ratio was higher than 2:1. During the dipping step, apple slices were gently agitated in order to assure good contact of apple flesh with syrup components. Changes in the weight and soluble solids content of syrup and slices were deter-

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mined for each batch after successive pre-treatment stages. The slice samples were taken and quickly frozen to -25°C prior to AA analysis. The residues of the treated slices were put in a single layer on sieves made of acid-resistant steel and convectively dried for 2 h at a temperature of 88±1°C and velocity of 4.0±0.2 m/s. The AA content was determined separately for each batch of chips from successive treatments. The dry matter content of the raw material, slices, and apple chips was determined by vacuum drying. The experiment was performed in three technological replications.

Apart from producing apple chips with a natural AA content, an additional experiment was carried out, in which the efficiency of dried apple chips enrichment in AA was estimated. The experiment was performed in an analogous way as the one described above, except that 1% of AA (maximum dose indicated in the patent) was added to the pre-treatment syrup [Płocharski & Konopacka, 1999].

Apple chips storage. After removing from the dryer, the apple chips were tightly closed in glass jars to equilibrate the moisture content of the product. After a few days of storage, the chips were packed in small packages (about 30 g) made of aluminium foil under nitrogen atmosphere. Corresponding batches of retail packages were placed in conditions simulating warehouse rooms (7±2°C, 45% RH), and under increased humidity and at room temperature (18±2°C, 90% RH). The AA content was determined after 0, 1, 2, 3, 6 and 9 months of storage on chips sampled from three randomly selected packages.

Determination of ascorbic acid (vitamin C). Ascorbic acid content was determined by HPLC using a HP 1100 Hewlett-Packard chromatograph equipped with a DAD detector and an autosampler.

Sample preparation: the apple slices were preliminary comminuted with a plastic knife. The chips were ground in a mortar. Then a cold (0–4°C) 6% solution of HPO_3 was added to 3 g of disintegrated slices or 5 g of chips. The mixture was homogenized for 3 min by means of a Silverstone Machine Ltd homogenizer, which was followed by quantitative transfer of the homogenate to a 100 mL flask filled up with a 6% solution of HPO_3. The material prepared in this way was preliminary filtered (Filtrak 389).

The saturating solution or the extract of slices and chips were diluted 10-fold in a cold HPO_3 solution, and passed through an activated SPE column Sep-Pak C-18 (Waters). Before analysis, the samples were filtrated through a 14 mm syringe filter 0.45 μm, Nylon, and placed in autosampler vials. Analyses were made in two replications. The chromatographic system consisted of two Supelco LC-18 (25 cm x 4 mm, 5 m) columns connected in series. The determination was carried out at 30°C using 1% phosphate buffer (pH 2.5, flow rate 0.8 mL/min) as a mobile phase. The retention time of AA was on average 12.2 min. The detection was carried out at a wavelength of 244 nm with a bandwidth of 6 nm, and reference at 360 nm with a bandwidth of 60 nm.

The results were expressed in mg/100 g of the product, and then – in order to compare AA retention at particular production stages – they were converted into mg/100 g dry matter.

The obtained results were statistically analysed by the method of variance analysis by R. A. Fisher. The significance of differences in the AA content of particular batches of solutions, slices, and chips was evaluated by the Duncan's test at a significance level of 5%.

RESULTS AND DISCUSSION

AA retention in dried apple chips

The AA content of the raw material used for chips production was on average 10.7 mg/100 g of fresh matter, which corresponds to 81.7 mg/100 g of dry matter (Figure 1). After the first stage of production, which included apple slices cutting and dipping in a pre-treatment solution, it was found that AA losses were *ca.* 5%. Although the losses were on average very small, there was a wide variation in the experimental values as regards individual batches and technological replications (Figure 1), which is in agreement with other reports [Kropp, 1958]. This is connected with a high variation between apples originating from the same tree [Kropp, 1958; Rutkowski, 2002].

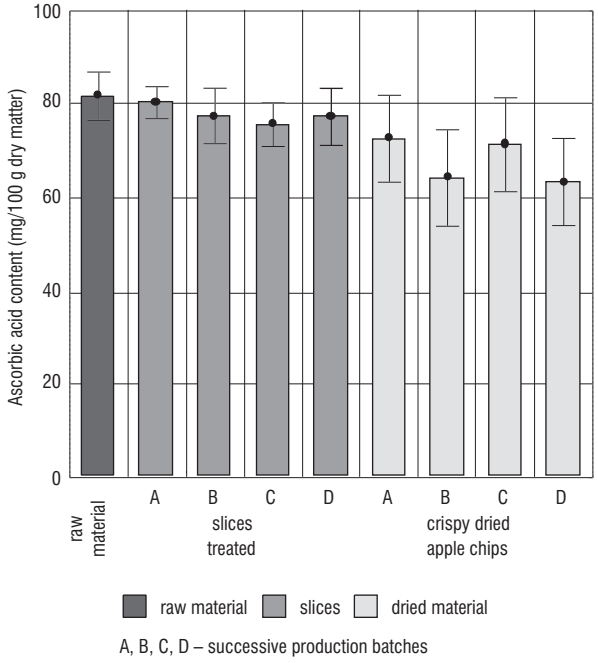

FIGURE 1. The ascorbic acid content of the raw material, treated slices, and dried product, taking into account the effect of variability for successive batches treated in a partially-used syrup solution.

It was found that about 50% of losses observed during the preliminary treatment were caused by AA leaching from the sliced apple flesh into the pre-treatment solution. This was confirmed by a quantitative analysis of changes in the AA content of the samples taken out from the solution after pre-treatment of particular raw material batches. AA leaching depends on slice thickness (2.2±0.1 mm).

The final AA content of apple chips dried to a moisture content of 2% was on average 66.5 mg/100 g of the final product (67.9 mg/100g dry matter), which corresponds to 87.4% retention of AA in relation to its content of slices after pre-treatment, and 83.1% in relation to its content of the raw material.

Because AA is very susceptible to different environmental factors, the degree of its retention in processed products is often used to express the degree of other natural food compounds degradation. Lin *et al.* [1998] applied AA retention as an indicator of dried material quality. The fact that the amount of AA retained in particular batches of the product (A, B, C, D) did not differ significantly ($p \leq 0.05$) confirms that slow depletion of basic saturating solution compounds did not affect the retention of AA and other valuable nutrients.

The average AA retention in crispy dried apples (83%) is a high value, showing that the parameters of pre-treatment were adequate and proving high nutritional quality of the product obtained. To compare, apple slices dried under similar conditions but without preliminary treatment retained 6% less AA than the product examined, despite a shorter drying time (1.5 h at 88°C). Lower AA retention in dried apple slices was also found by Markowski *et al.* [1996; unpublished data] in earlier experiments, in the case of both convective and freeze drying (retention was about 70% compared with raw material).

It seems that good AA retention was a result of a very short time between slicing and slices dipping in the pre--treatment syrup. Also the short dipping time (2 min), low preliminary treatment temperature (20°C), and the addition of SO_2 and citric acid (despite low concentrations) affected positively AA retention. Sugar solution could also have a positive effect.

AA losses during storage

Changes in AA content of apple chips observed during 9-month storage of the product in retail packages are presented in Figure 2. Irrespective of storage conditions, the highest AA losses were noted after the first month of storage. The amount of losses in relation to the average initial content was 9.7% (for 18°C, 90% RH) and 10.6% (for 7°C, 45% RH). In the case of chips stored under warehouse conditions, this range of losses was observed during all 9 months of the experiment. For the first three months, chips from packages stored at room temperature and high humidity showed the same value of losses as those stored under favourable conditions. In a longer time, as expected, higher AA losses were detected for products stored at a higher temperature. Probably temperature was not the only factor generating AA losses. Although the packaging material was aluminium foil showing high resistance to water permeability, a significant increase in chips moisture was observed after 6 and 9 months of storage under unfavourable conditions, probably due to inadequate leakage tightness.

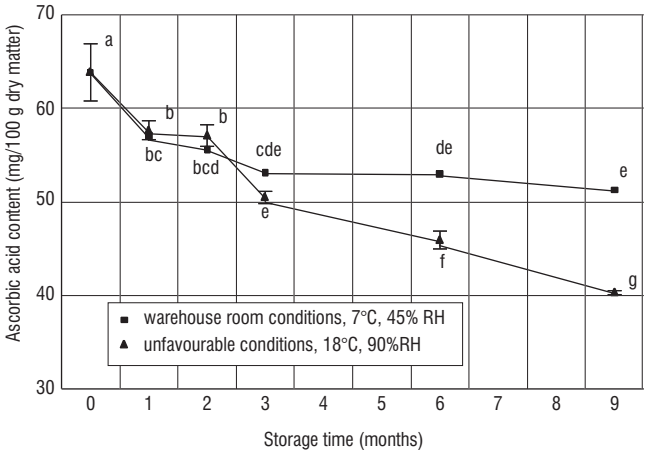

FIGURE 2. The AA losses during apple chips storage in retail packages under different humidity and temperature conditions. The means followed by the same letter do not differ significantly at $\alpha = 0.05$

Finally, after 9 months AA retention was 80.4% for packages stored at 7°C, 45% RH, and 63.1% for packages stored at room temperature and high humidity.

The results obtained show high AA stability in the product examined, on condition that retail packages are characterized by high resistance to moisture and stored under conditions of a low temperature and low humidity.

Estimation of the possibilities of apple chips enrichment in AA

The chips were vitaminized by adding AA to pre-treatment syrup, in the amount of 1% in relation to the solution weight. During 2 min of the treatment, apple slices absorbed about 190 mg AA/100 g of slices, which indicates that they absorbed approximately 30% of AA present in the saturating solution.

Despite significant AA losses after the treatment of particular batches (before treatment – 1093 mg/100 mL, after treatment: A – 1061 mg/100 mL, B – 1032 mg/100 mL, C – 1003 mg/100 mL, D – 951 mg/100 mL), the amount of AA absorbed in the successive batches of chips did not differ considerably (Figure 3).

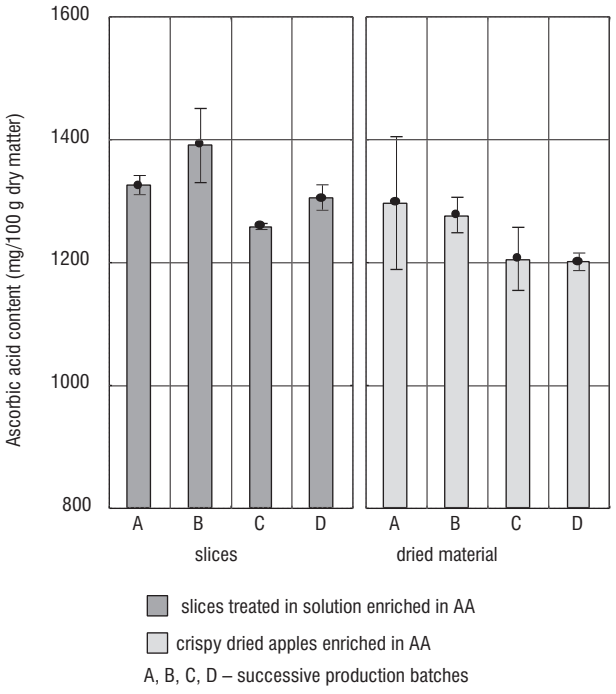

FIGURE 3. The AA content of slices and dried chips treated in a solution with a 1% addition of AA.

The retention of AA in dried enriched chips was very high, it constituted 95% of the initial AA content. After drying, the AA content of batches did not differ significantly, either. The enriched chips contained on average 1218 mg AA/100 g (1245 mg AA/100 g of dry matter, Figure 3). The results obtained indicate that crispy dried food, such as

chips, may satisfy daily recommended level of vitamin C for adults when consumed in the amount of 30 g. Chips were treated in a solution containing 1% of AA and therefore they were very sour; in practice it would be reasonable to lower the concentration of AA in pre-treatment syrup to obtain the AA content of a 30 g retail package equal to 50% of daily vitamin C requirement.

Higher (95%) AA retention during the drying of chips enriched in AA, compared with AA retention in the not enriched product (87.4%), is probably connected with higher acidity of the saturating solution observed after supplementation with artificial AA; higher acidity inhibits polyphenoloxidase reactions [Zemel *et al.*, 1990; Tronc *et al.*, 1997], which was conducive to AA stability during further technological processes.

CONCLUSIONS

Dried apple chips may be a rich source of vitamin C. A properly conducted technological process ensures high retention of AA, both naturally present in apples and absorbed from the pre-treatment solution. AA retention in dried apple chips estimated during the production of experimental batches was on average 83%. During chips preparation for drying, AA losses accounted for 5% and during drying – for 12%. The stability of ascorbic acid during product storage in retail packages was quite high. The AA stability after 9 months of storage was 80.4% and 63.1%, for favourable (7°C, 45% RH) and unfavourable (18°C, 90% RH) storage conditions, respectively. It was also found that there is an unlimited possibility of enriching dried apple chips in ascorbic acid (even up to 1200 mg/100 g of the product).

* Paper presented at the Xth Polish Drying Symposium, 17-19 September 2003, Łódź, Poland.

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Received November 2003. Revision received December 2003 and accepted May 2004.

RETENCJA KWASU ASKORBINOWEGO W PROCESIE PRODUKCJI I PRZECHOWYWANIA SUSZONYCH CHRUPEK JABŁKOWYCH

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Beztłuszczowe chrupki jabłkowe będące formą kruchego suszu przeznaczonego do bezpośredniej konsumpcji mogą stanowić bogate źródło witaminy C. Celem pracy było oszacowanie (na przykładzie chrupek jabłkowych) realnych strat kwasu askorbinowego w procesie wytwarzania kruchego suszu owocowego, zbadanie jego stabilności w czasie przechowywania gotowego produktu oraz ocena możliwości dodatkowego wzbogacania produktu w kwas askorbinowy.

Retencja kwasu askorbinowego w suszonych chrupkach jabłkowych określona w czasie produkcji doświadczalnych partii produktu wyniosła średnio 83%, z czego 5% KA było tracone w czasie obróbki wstępnej a 12% w procesie suszenia (rys. 1). Stabilność kwasu askorbinowego w czasie przechowywania produktu w opakowaniach jednostkowych była stosunkowo wysoka, po 9 miesiącach przechowywania retencja składnika wyniosła 80,4% i 63,1%; odpowiednio dla korzystnych i niekorzystnych warunków przechowywania (rys. 2). Ponadto stwierdzono możliwość efektywnego wzbogacania chrupek w bardzo znaczące ilości kwasu askorbinowego (nawet do 1200 mg/100 g produktu).