Effect of storage on quality of industrially dehydrated onion, garlic, potato and carrot

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Summary
A comprehensive study on physical and chemical quality parameters has been carried out on several highly consumed vegetables that were industrially dehydrated (carrot, onion, garlic and potato). The quality parameters determined were: dry matter, water activity, rehydration ratio, protein pattern, total polyphenols, saccharides and 2-furoylmethyl amino acid (2-FM-AA) content. After dehydration process, the main observed chemical change was the formation of 2-FM-AA, indicating the participation of amino acids (mainly lysine) in Maillard reaction evolution. With respect to the effect of 12-month storage under conditions usually used by consumers (in the dark, 19–27 °C, 15–41% relative humidity), with the exception of carrots, no remarkable amounts of 2-FM-AA were generated, in agreement with the slight variation in proteins pattern and saccharide composition. Particularly interesting is the case of onion and garlic, whose content of fructooligosaccharides (recognized prebiotic saccharides) was preserved during storage. Samples were also stable with regard to their polyphenol content and rehydration ability, showing the importance of sample pre-treatment, processing and storage conditions for preservation of bioactivity and overall quality of dehydrated vegetables. These results underline the usefulness of the indicators here determined for quality evaluation and the value of data reported for technologists, nutritionists and consumers.

Keywords
dehydrated vegetables; quality markers; storage; Maillard reaction; 2-furoylmethyl-amino acids; saccharides; proteins

Nowadays, consumers are highly interested in processed foods, which fulfill not only the nutritional requirements but also provide health benefits. Preservation of quality and easy handling and storage, particularly under non-refrigerated conditions, are also a consumer demand. Thus, and with a view to obtain processed foods of premium quality with preserved functionality, food processing industries are making a considerable effort in the improvement of existing technologies through optimization of process design.

Drying, which decreases the water content of the raw product to the level that minimizes its biochemical, chemical and microbiological deterioration, is one of the oldest methods of food preservation and represents a very important process in the food industry [1]. Forced convection by hot air is the most common industrial technique to perform food drying. Drying temperature and time, air velocity and relative humidity as well as the initial moisture content of the product are the most relevant process factors [2, 3]. Convective drying can be carried out at high temperatures for short times or at lower temperatures for longer times; the former option being usually preferred since it produces less thermal damage and consumes less energy [4]. Simplicity of operation and affordable technology are other additional advantages of convective drying for industrial food processing.

Among the different foods that can become dehydrated, vegetables hold a predominant position as they can be consumed either on their own or as ingredients for the elaboration of other food products such as soups, sauces, etc. Thus, the demand of dehydrated vegetables has considerably increased over the last few years in many countries

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and it is expected to increase even further during the next decade [5].

Dehydration by hot air may cause a series of chemical, physico-chemical, physical and biological alterations that can affect the final quality of the dehydrated vegetable. One of such chemical modifications that can take place if dehydrated vegetables are subjected to intensive treatment and/or inappropriate storage is Maillard reaction. Maillard reaction takes place between the carbonyl group from reducing saccharides and the free amino group of amino acids, peptides or proteins. In advanced stages of Maillard reaction, a loss in the nutritional value of the food may occur and the development of undesirable coloured and fluorescent compounds, together with the formation of new volatile compounds, can alter the organoleptic properties of the product [6]. Therefore, the evaluation of the initial stages of this reaction provides very valuable information for optimization of food processing, since it allows controlling this reaction before important nutritional and/or organoleptic changes take place in the dehydrated food. In this respect, quality indicators derived from the initial stages of Maillard reaction (2-furoylmethyl-amino acids, 2-FM-AA) have been previously investigated in dehydrated samples of garlic, onion and carrot [7–9]. These quality markers proved highly valuable in the study of other processed foods of vegetable origin, such as dehydrated fruits, jams and fruit-based infant foods and processed tomato products [10–13].

Other saccharides, reducing and non-reducing, may also be affected during dehydration and storage of dried vegetables. Thus, according to CARDELLE-COBAS et al. [14], accelerated storage conditions of commercial dried onion and garlic can give rise to important modifications of fructooligosaccharides (FOS), recognized as prebiotic saccharides [15].

In addition, dehydration produces shrinkage and may negatively affect the rehydration ability of dehydrated vegetables [3, 16]. This is due to a series of factors related to physical and physico-chemical changes occurring in the tissues [17], and also to chemical changes that might affect saccharides and proteins [18].

In this paper, a comprehensive study on quality parameters including major and minor saccharides, 2-FM-AA, proteins, polyphenols and rehydration capacity was carried out with highly consumed industrially dehydrated vegetables, namely, potato, carrot, onion and garlic. The changes in these parameters with storage under conditions normally used by consumers have also been assessed.

MATERIALS AND METHODS

Samples

Six industrially dehydrated samples of carrot (*Daucus carota*), onion (*Allium cepa)*, garlic (*Allium sativum)* and potato (*Solanum tuberosum*) kindly provided by a Spanish vegetable products company (Vegenat, Badajoz, Spain) were studied. Carrot samples included two carrot geometries: cubes (carrot I, 5–6 mm length, 2–3 mm width, 1.9–4.5 mg weight, and flakes (carrot II, 5–7 mm length, 1.0–1.5 mm width, 1.9–4.2 mg weight). Two sizes of onion flakes, small (onion I, 3–5 mm length, 1.0–1.5 mm width, 1.5–3.2 mg weight), and large (onion II, 6–10 mm length, 1.0–1.5 width, 2.5–4.4 mg weight), were also analysed together with garlic (10–21 mm length, 1.0–1.5 mm width, 3.2–5.5 mg weight) and potato flakes (6–12 mm length, 0.7–1.1 mm width, 1.2–2.8 mg weight). Industrial processing conditions, summarized in Tab. 1, mainly consisted of a blanching step with hot water spray (microdroplets), except for garlic sample, followed by one or two dehydration stages.

Storage assays

Dehydrated samples, packed in polypropylene individual bags (30 mm thick sample layer) and sealed, were stored in the dark for a period of 12 months under the following ambient conditions: temperature between 19.3 °C and 27.1 °C; relative humidity between 15.0% and 40.7%. After 6 and 12 months of storage, samples were taken and stored frozen at –20 °C until analysis.

Characterization of samples

The dry matter content was determined gravimetrically by drying the samples until constant weight according to the AOAC method 950.01 [19]. Water activity (a_w) measurement was carried out in a AW Sprint TH-500 instrument (Novasina,

Tab. 1. Industrial processing conditions of dehydrated vegetables under study.

Sample	Blanching		Dehydration			
			1st Stage		2nd Stage	
	t [min]	*T* [°C]	*t* [h]	*T* [°C]	*t* [h]	*T* [°C]
Carrot I	20.0	98	3.0	65–135	2.0	58
Carrot II	20.0	98	5.0	55–135	–	–
Onion I	3.0	98	6.5	50–125	–	–
Onion II	3.0	98	6.5	50–125	–	–
Garlic	–	–	5.5	58–120	–	–
Potato	30.0	98	4.5	50–125	–	–

Pfäffikon, Switzerland). Saturated aqueous solutions of LiCl, $MgCl_2$, $Mg(NO_3)_2$, NaCl, $BaCl_2$ and $K_2Cr_2O_7$ were used to calibrate the sensor unit. The Kjeldahl method was used to determine total nitrogen (TN) using 6.25 as conversion factor (TN × 6.25) (AOAC method 920.165) [20]. All determinations were carried out in duplicate.

Rehydration ratio

Rehydration of industrially processed samples was performed according to Soria et al. [18]. Dried samples were rehydrated by immersion in distilled water (solid-to-liquid ratio 1:50) at 20 °C for 24 h. Vegetables were placed onto paper towels to remove the surface water and further weighed. Each rehydration experiment was performed in duplicate and rehydration ratio was calculated as:

$$RR = m_r/m_d \quad (1)$$

where RR is rehydration ratio, and m_r and m_d are the weights of the rehydrated and the dehydrated vegetable, respectively.

Analytical determinations

HPLC analysis of 2-furoylmethyl-amino acids

Analysis of 2-FM-AA was carried out by ion-pair RP-HPLC [21]. A C_8 column (250 mm × 4.6 mm i.d.) (Alltech, Lexington, Kentucky, USA) thermostated at 37 °C was used, with a linear binary gradient (A, 4 ml·l^{-1} acetic acid; B, 3 g·l^{-1} KCl in A) and a variable-wavelength detector operating at 280 nm (LCD Analytical SM 4000, LCD, Riviera Beach, Florida, USA). The elution programme was as follows: 100% A from 0 min to 12 min, 50% A from 20 min to 22.5 min, and 100% A from 24.5 min to 30 min.

Samples (0.25 g) were hydrolysed under inert conditions (helium) with 4 ml of 8 mol·l^{-1} HCl at 110 °C for 23 h in a screw-capped Pyrex vial provided with a polytetrafluoroethylene-faced septum. A medium-grade paper filter (Whatman No. 40, General Electric Company, Fairfield, Connecticut, USA) was used to filter the sample hydrolysate and then, 0.5 ml of the filtrate was applied to a Sep-Pak C_{18} cartridge (Millipore, Billerica, Massachusetts, USA) previously activated with 5 ml of methanol and 10 ml of distilled water. A volume of 3 ml of 3 mol·l^{-1} HCl was used to elute the retained compounds from the Sep-Pak cartridge and 50 µl from the eluate were directly injected into the HPLC system.

Data obtained for standards previously synthesized in our laboratory and analysed under identical experimental conditions were used to identify 2-FM-AA other than furosine (2-FM-lysine) [13]. Quantitation was performed by the external standard method, using a commercial standard of 2-FM-lysine (Neosystem Laboratoire, Strasbourg, France). Data shown in this paper (expressed as milligrams per kilogram of protein) are the mean values of two replicates.

GC analysis of saccharides

Soluble saccharides were extracted in duplicate according to the method described by Soria et al. [18]. Dehydrated vegetables were frozen prior to grinding to powders using a laboratory mill IKA A-10 (IKA Labortechnik, Staufen, Germany). Samples (30 mg each) were weighed into a polyethylene tube and extracted at room temperature with 2 ml of Milli-Q water (Millipore) under constant stirring (50 Hz) for 20 min. Then, 8 ml of absolute ethanol were added followed by 0.2 ml of an ethanolic solution 10 mg·ml^{-1} of phenyl-β-D-glucoside (Sigma-Aldrich Chemical, St. Louis, Missouri, USA) used as internal standard. After stirring for 10 min, samples were centrifuged at 10 °C and 9600 ×g for 10 min and the supernatant was collected. Precipitates were subjected to a second extraction with 10 ml of 80% ethanol under the same conditions to obtain recovery values close to 100%. Finally, an aliquot (2 ml) of supernatant was evaporated under vacuum at 40 °C.

GC analyses were performed with an Agilent Technologies 7890A gas chromatograph (Agilent Technologies, Santa Clara, California, USA) equipped with a flame ionization detector (FID), using nitrogen as carrier gas at a flow rate of 1 ml·min^{-1}. The trimethylsilyl oxime (TMSO) derivatives, prepared as described by Soria et al. [18], were separated using two different methods according to the sample composition. For carrot and potato samples, the analysis was performed as described by Soria et al. [18] using an HP-5MS fused silica capillary column (30 m long × 0.25 mm i.d. x 0.25 µm film thickness) coated with 5% phenylmethylsilicone (J&W Scientific, Folsom, California, USA). The oven temperature was held at 200 °C for 11 min, raised to 270 °C at a heating rate of 15 °C·min^{-1}, raised again to 300 °C at 3 °C·min^{-1}, and finally raised to 315 °C at 15 °C·min^{-1}, remaining at this temperature for 3 min. The injector (split ratio 1:40) and detector temperatures were 280 °C and 315 °C, respectively.

For onion and garlic samples, analyses were carried out as described by Montilla et al. [22], using a WCOT fused silica capillary column (Chrompack, Middelburg, The Netherlands). The column (8 m long × 0.25 mm i.d. × 0.25 µm film thickness) was coated with 5% diphenyl 95% di-

methylsilicone (HT-5, Supelco, Sigma-Aldrich). Injector (split ratio 1:10) and detector temperatures were 280 °C and 360 °C, respectively. The initial oven temperature was 100 °C, raised to 250 °C at a heating rate of 10 °C·min^{-1}, and raised again to 360 °C at 5 °C·min^{-1} and holding at this temperature for 5 min.

Data acquisition and integration were performed using Agilent ChemStation Rev. B.03.01 software (Wilmington, Delaware, USA). The identification of TMSO derivatives of saccharides was carried out by comparing the experimental retention indices with those of derivatized standards. Quantitative data (in grams per kilogram of dry matter) were calculated from FID peak areas. Standard solutions of glucose, fructose, saccharose, *myo*-inositol, *scyllo*-inositol, kestose and nystose (all from Sigma-Aldrich) over the expected concentration range in vegetable extracts (0.01–5 mg·ml^{-1}) were prepared to calculate the response factor relative to phenyl-β-D-glucoside. Response factors of kestose and nystose were applied for quantitation of trisaccharides and oligosaccharides with degree of polymerisation greater or equal to 4, respectively.

Total polyphenol content

To obtain methanolic extracts, 2.5 ml of HPLC grade methanol were added to 0.1 g of sample powder and the mixture was then homogenized for 1 min at 60 Hz with an Ultra-Turrax T-25 homogenizer (IKA Labortechnik). After stirring with a Thermomixer (Eppendorf, Hamburg, Germany) for 20 min at 50 Hz, samples were centrifuged for 15 min at 2000 ×*g*. The supernatants were then filtered through 0.45 μm PVDF Acrodisc syringe filters (Sigma-Aldrich) for subsequent analysis.

Total polyphenol content was determined according to SINGLETON et al. [23] and PATRAS et al. [24], with slight modifications. Volumes of 100 μl of filtered methanolic extract, 100 μl of methanol and 100 μl of Folin-Ciocalteu reagent (2 mol·l^{-1}, Sigma-Aldrich) were mixed in a 2.0 ml microtube. Five minutes later, 700 μl of 75 g·l^{-1} Na_2CO_3 were added and the samples were vortexed briefly. After 20 min in the dark at room temperature, the samples were centrifuged at 10000 ×*g* for 3 min. The absorbance of the samples was read at 735 nm, using gallic acid solutions (10–400 mg·l^{-1}, Sigma-Aldrich) as standards. Results were expressed as grams of gallic acid equivalent (GAE) per kilogram of dry matter.

SDS-PAGE analysis of protein isolates

A weight of 100 mg of dehydrated sample powder was mixed with 2 ml of 1% sodium metabisulfite (Merck, Darmstadt, Germany) aqueous solution. Next, samples were stirred thoroughly for 2 h and centrifuged at 3000 ×*g* for 15 min. The supernatants were finally analysed by SDS-PAGE.

Protein analysis was carried out by adding 32.5 μl of sample supernant to 12.5 μl of 4X NuPAGE LSD sample buffer (Invitrogen, Carlsbad, California, USA) with 5 μl of 0.5 mol·l^{-1} dithiothreitol (DTT, Sigma-Aldrich). Samples were heated at 70 °C for 10 min and 20 μl were loaded on a 12% polyacrylamide Novex NuPAGE Bis-Tris precast gel (Invitrogen). Gels were run for 41 min at 120 mA per gel and 200 V with a continuous MES SDS running buffer (Invitrogen) and were stained using the Colloidal Blue Staining Kit (Invitrogen). A mixture of standard proteins with relative molecular weight ranging from 2.5 kDa to 200 kDa (Invitrogen) was used to estimate the molecular weight of proteins. Myosin, 200 kDa; β-galactosidase, 116.3 kDa; phosphorylase B, 97.4 kDa; bovine serum albumin, 66 kDa; glutamic dehydrogenase, 55.4 kDa; lactate dehydrogenase, 36.5 kDa; carbonic anhydrase, 31 kDa; trypsin inhibitor, 21.5 kDa; lysozyme, 14.4 kDa; aprotinin, 6 kDa; insulin B chain, 3.5 kDa and insulin A chain, 2.5 kDa were used as standards.

RESULTS AND DISCUSSION

Protein, moisture, water activity and rehydration ratio of dehydrated samples

Tab. 2 shows the initial percentage of protein and evolution of moisture, a_w and rehydration ratio with 12-month storage of industrially dehydrated carrot, onion, garlic and potato samples.

The protein values here determined were similar to data reported in the literature [7, 25]. The highest protein content corresponded to the dehydrated garlic sample. The initial moisture of the studied samples ranged from 6.4% to 9.2%, which are values that are close to those previously reported for different dehydrated vegetables [26]. Although after 12 months of storage, a slight increase in moisture was observed (8.1–10.4%), these levels were within the permissible limit to assure the microbiological stability of dehydrated vegetables (12–15%) [27]. RAHMAN et al. [28], in a study on solar-dried carrots, found a higher increase (from 7.05% to 16.22%) in the moisture content of these samples after 8 months of storage. These differences could be probably attributed to the different sample geometry and ambient humidity conditions used in the respective assays.

At the beginning of the storage, a_w values of all dehydrated vegetables analysed were within

Tab. 2. Protein content and moisture, a_w and rehydration ratio before and after 12 months of storage.

Sample	Protein [%]	Moisture [%]		a_w		Rehydration ratio	
		0 months	12 months	0 months	12 months	0 months	12 months
Carrot I	11.14	9.25	10.41	0.320	0.337	5.1	5.1
Carrot II	6.40	7.22	9.24	0.303	0.333	7.5	7.6
Onion I	8.62	7.39	8.80	0.295	0.341	3.2	3.2
Onion II	8.41	6.40	8.21	0.275	0.345	3.5	3.4
Garlic	19.13	7.77	8.09	0.312	0.372	2.6	2.6
Potato	6.82	7.84	8.10	0.277	0.351	3.8	3.9

the range 0.275–0.320. The different samples presented slight differences in the initial values of a_w, probably due to the different processing conditions, and during their storage they only underwent a slight increase in the a_w values (0.333–0.372), according to our results on dry matter. As it is well known, dried foods with a_w values close to 0.3 are stable against non-enzymatic browning, enzymatic activities and proliferation of microorganisms [29–30]. In green onion dried at 50–70 °C, GARCÍA et al. [31] found a_w values in the range 0.29–0.40, which increased up to 0.62–0.65 after a period of storage of 126 days at room temperature. The higher relative humidity in those assays (50–75%) must be considered at interpretation of these a_w data.

Regarding the rehydration ability, as presented in Tab. 2, rehydration ratio data in the range 2.6–7.5 were found for all the dehydrated samples, the highest value being that of carrot II and the lowest corresponding to garlic. Whereas no noticeable differences were observed in rehydration ratio of onions with different sample size subjected to identical dehydration process, very different results were observed in rehydration of carrots I and II. These differences could be mainly attributed to the different sample geometry (cubes and flakes) and/or processing conditions employed in dehydration, among other factors. For carrot, SORIA et al. [18] reported rehydration ratio values within the range 4.7–8.0 in dehydrated samples subjected to different processing conditions. In agreement with the scarce change in the moisture content during storage, hardly any variation in the rehydration ratio was observed, indicating the stability during 12 months of the physical structure of the dehydrated carrot, onion, potato and garlic samples. According to this, instability of solar-dried carrots after 8 months of storage at ambient temperature, conditions giving rise to moisture values near 16%, could be responsible for the decrease in the rehydration ratio observed for this dehydrated vegetable by RAHMAN et al. [28].

Total polyphenol content

Vegetables are well known to possess antioxidant activity which is, in great part, attributed to the polyphenol content. In fact, a linear correlation was observed between polyphenolic compounds and (hydrophilic) antioxidant activity of several fruits and vegetables [32–33].

As an indicator of antioxidant activity, total polyphenol content determined in industrially dehydrated carrot, onion, garlic and potato samples is shown in Fig. 1. As expected, total polyphenol content was variable according to the vegetable composition; the highest phenolic content being found in carrots and the lowest in potato. Regarding carrots I and II, different total polyphenol content was found for both types of sample. The different fresh carrot variety and/or maturity stage, probably associated with a different polyphenol

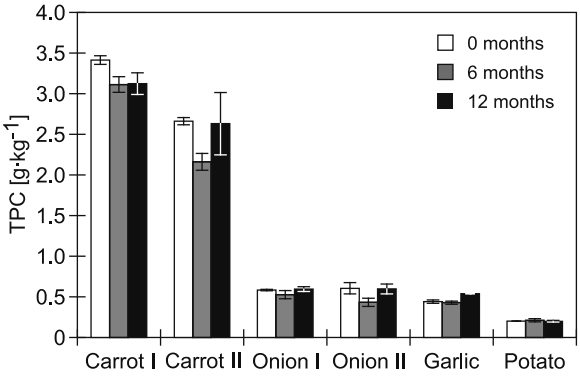

Fig. 1. Effect of storage on total polyphenol content (TPC) of industrially dehydrated carrot, onion, garlic and potato samples.

TPC is expressed as gallic acid equivalents (GAE) in grams per kilogram of dry matter.

content, together with the differences in sample processing (Tab. 1), could explain these results. As it is known, total polyphenol content in vegetables is influenced by a number of factors, including genetic variety or cultivar, soil condition, water availability, season, degree of maturity, processing, etc. [18, 32, 34–38].

In order to investigate the stability of total polyphenol content, its evolution was assessed during the storage. In general, hardly any change was observed in total polyphenol content values of vegetable samples assayed after 12 months. Similarly, PÉREZ-GREGORIO et al. [37] studied the evolution of flavonols and anthocyanins in freeze-dried onions stored at room temperature in absence of light, and no changes were observed during the 6 months of storage. In agreement with this, no change if any in total polyphenol content and antioxidant activity was also found by BENNETT et al. [32] in dried fruits during their storage at 21 °C for 5 months. In the present paper, the blanching pretreatment (98 °C for 3–30 min, Tab. 1) of fresh vegetables prior to drying seems to be efficient to control polyphenol oxidation by polyphenol oxidases and peroxidases, the main enzymes responsible for quality loss during storage of vegetables [39–40].

Maillard reaction evolution

Tab. 3 lists the results of the initial values of 2-FM-AA and their evolution with storage of dried vegetables under study. In agreement with the amino acids present in these vegetables [26], 2-FM-alanine (2-FM-Ala), 2-FM-γ-amino butyric acid (2-FM-GABA), 2-FM-lysine (2-FM-Lys) and 2-FM-arginine (2-FM-Arg) were detected depending on the studied vegetable. Regardless of the processing conditions and the protein content of the sample, the highest initial 2-FM-AA values were observed in carrot, whereas the lowest were found in garlic and potato samples, probably due to the lower content in reducing saccharides, as compared to that of the other vegetables. In the case of carrot, similar values were reported by SORIA et al. [9] for commercial dehydrated samples. However, WELLNER et al. [41] found higher concentrations of 2-FM-AA in commercial dried carrot. These dissimilar results can probably be due to the different conditions applied during drying. For onion samples, less 2-FM-derivatives were detected in this study in comparison to data reported by CARDELLE-COBAS et al. [7], probably due to differences in the dehydration process and saccharide content, among other factors.

With the exception of dehydrated carrots, under the conditions used during storage period,

Tab. 3. Evolution of 2-FM-AA content in dehydrated vegetables during 12 month-storage.

Samples	2-FM-AA [mg·kg^{-1}]									
	2-FM-Ala			2-FM-GABA			2-FM-Lys + 2-FM-Arg			
	0 months	6 months	12 months	0 months	6 months	12 months	0 months	6 months	12 months
Carrot I	2162 ± 340^{a}	3464 ± 1360^{a}	6435 ± 590^{b}	2787 ± 160^{a}	3744 ± 900^{a}	5860 ± 220^{b}	4475 ± 110^{a}	4352 ± 390^{a}	5564 ± 370^{b}
Carrot II	1180 ± 90^{a}	5422 ± 1220^{b}	6721 ± 770^{b}	2260 ± 160^{a}	3360 ± 880^{a}	7089 ± 240^{b}	4228 ± 220^{a}	5788 ± 820^{a}	9316 ± 870^{b}
Onion I	–	–	–	–	–	–	744 ± 170^{a}	728 ± 130^{a}	962 ± 60^{a}
Onion II	–	–	–	–	–	–	1124 ± 110^{a}	1325 ± 130^{ab}	1468 ± 70^{b}
Garlic	–	–	–	–	–	–	81 ± 6^{a}	79 ± 8^{a}	80 ± 5^{a}
Potato	–	–	–	–	–	–	839 ± 90^{a}	504 ± 70^{b}	663 ± 90^{ab}

Content of 2-FM-AA is expressed per kilogram of protein. Values represent mean ± standard deviation, $n = 2$.
a-b – samples with the same superscript letter within the corresponding row (0–12 months) showed no statistically significant differences for their mean values at the 95.0% confidence level.

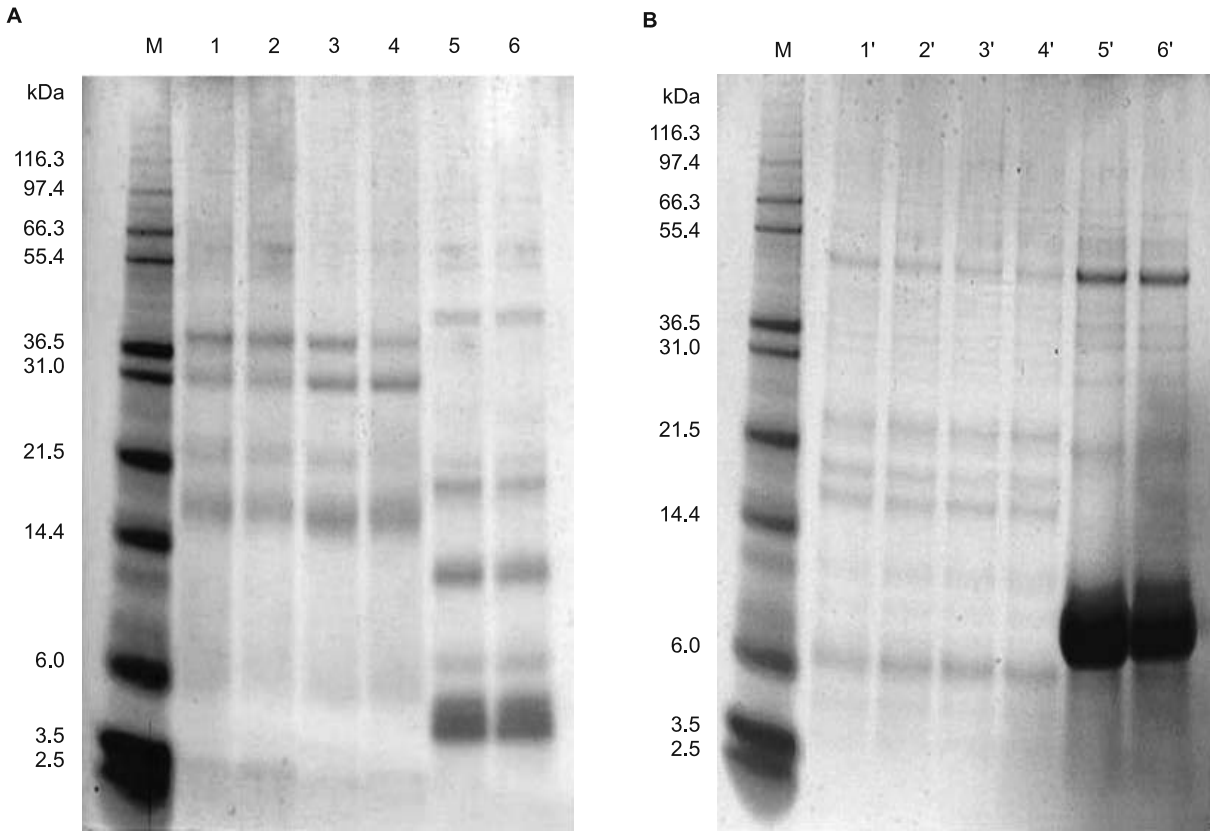

Fig. 2. SDS-PAGE analysis of dehydrated carrot, potato, onion and garlic samples before and after 12-month storage.

A – dehydrated carrot and potato samples, B – dehydrated onion and garlic samples.
M – markers of molecular weight; 1 – carrot I 0 months; 2 – carrot I 12 months; 3 – carrot II 0 months; 4 – carrot II 12 months; 5 – potato 0 months; 6 – potato 12 months; 1' – onion II 0 months; 2' – onion II 12 months; 3' – onion I 0 months; 4' – onion I 12 months; 5' – garlic 0 months; 6' – garlic 12 months.

hardly any effect on 2-FM-AA formation was observed, since Maillard reaction proceeds slowly at ambient temperature and low a_w and generally requires months before substantial browning is observed. CARDELLE-COBAS et al. [7] reported a considerable increase of 2-FM-AA content when a sample of onion was stored under inappropriate conditions during two days (50 °C, a_w 0.44). In spite of the evolution of Maillard reaction in carrot samples analysed in the present study, the levels of 2-FM-Ala, 2-FM-GABA and 2-FM-Lys + 2-FM-Arg were within the range previously reported by SORIA et al. [9] for commercial samples.

In addition to this, it is well known that Maillard reaction might potentially enhance the antioxidant activity of foods [42]. MORENO et al. [43], in a study on the storage of dehydrated onion and garlic, demonstrated that whereas the Amadori compounds originated in the first steps of Maillard reaction might exert a moderate effect on the antioxidant activity, the advanced Maillard products were the major contributors to this property. In this respect, the slight evolution of Maillard reaction during the storage of dehydrated vegetables analysed in the present study did not contribute to changes in their antioxidant activity.

SDS-PAGE analysis of proteins

Fig. 2 depicts the SDS-PAGE profiles of vegetable proteins analysed before and after 12 months of storage. Each vegetable presented a different pattern of electrophoretic bands, corresponding to the different fractions of proteins found in each species.

All carrot samples (Fig. 2A, lanes 1–4) showed a profile consisting mainly of four bands with molecular weight (*Mw*) of ~ 18 kDa, 22 kDa, 31 kDa and 41.2 kDa, very similar to that found by SORIA et al. [18] for commercial dehydrated carrots. However, this was slightly different from that of freeze-dried carrots, reported by the same authors. The differences could be attributed to structural modifications in protein taking place during hot air-drying. Potato samples

(Fig. 2A, lanes 5 and 6) showed a band with *Mw* of ~ 42 kDa, probably corresponding to patatin, and two bands with *Mw* of ~ 10 kDa and 20 kDa, presumably being serine protease inhibitors PI-1 and PI-2 and potato Kunitz-type protease inhibitor, respectively. Moreover, potato profiles also showed an intense band (as a doublet) with *Mw* < 6 kDa, which could correspond to derivatives from age-associated proteolysis due to cysteine-proteases activity. This electrophoretic profile was consistent with that recently found by WEEDA et al. [44] for fresh samples stored at 4 °C during 4–22 months. Onion samples (Fig. 2B, lanes 1'–4') showed mainly five bands with *Mw* of ~ 6 kDa, 17.9 kDa, 19.5 kDa, 23 kDa and 50 kDa, similar to those found by HERRERA-CORREDOR and CARRILLO-CASTAÑEDA [45] for fresh seed onion samples. Finally, profiles of garlic samples (Fig. 2B, lanes 5' and 6') were characterized by one intense band of *Mw* of ~ 7–13 kDa presumably corresponding to allivin, similar to that detected by WANG and NG [46] in fresh bulb samples. In addition, in dehydrated garlic, other band with a molecular weight over 30 kDa could also be clearly seen. This might correspond to a chitinase similar to those isolated from leek (*Allium porrum*) [47]. GORINSTEIN et al. [48] obtained electrophoretic patterns of raw red onion and garlic samples with specific bands in the 50 kDa to 112 kDa range of molecular mass that disappeared after boiling for more than 20 min, indicating that the least stable proteins (superoxide dismutase, among others) of these vegetables can be affected during processing.

With the exception of carrot samples, to the best of our knowledge, no works on the protein profiles of dehydrated vegetables have been previously reported. With respect to the stored samples, similar electrophoretic profiles as compared to the initial samples, were found and no protein aggregates of high molecular weight were observed. This is indicative of the scarce degree of protein degradation during storage as a result of Maillard reaction, in agreement with the low levels of 2-FM-AA listed in Tab. 3.

Saccharide analysis

As far as saccharide composition of dehydrated vegetables is concerned, different GC profiles were found depending on the studied vegetable species. As an example, Fig. 3 shows that corresponding to onion I. A similar profile with lower total saccharide amount was obtained for garlic sample. In both onion and garlic, together with mono- and disaccharides, other saccharides with higher molecular weight were also detected. However, only a very small peak in the elution region of trisaccharides was found in carrot samples and most of saccharides present in these samples were mono- and disaccharides. Dehydrated potato was the sample with the simplest saccharide chromatographic profile.

Quantitative results of saccharide analysis of dehydrated carrot, potato, onion and garlic samples after storage for 12 months are listed in Tab. 4 and Tab. 5. In carrot samples, fructose, glucose and saccharose were the major saccharides. Other minor saccharides such as the polyalcohols *scyllo*- and *myo*-inositol and the higher-carbon monosaccharide sedoheptulose were also present in both carrot I and II. The slight differences observed

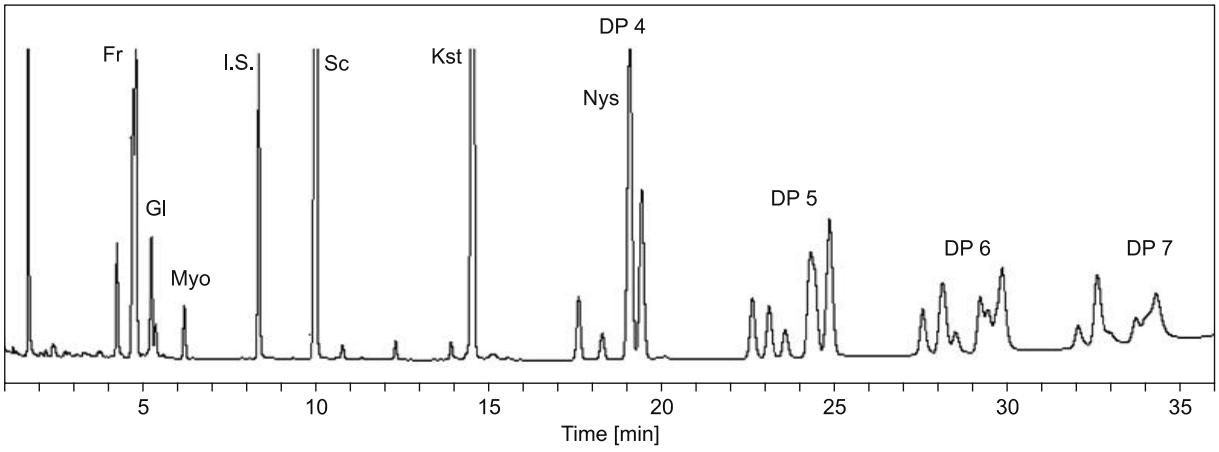

Fig. 3. Gas chromatographic profile of TMSO derivatives of saccharides in onion I.

Peaks are labelled as follows: Fr – fructose; Gl – glucose; Myo – *myo*-inositol; I. S. – phenyl-β-D-glucoside (internal standard); Sc – saccharose; Kst – kestose; Nys – nystose; DP 4 – tetrafructooligosaccharides; DP 5 – pentafructooligosaccharides, DP 6 – hexafructooligosaccharides; DP 7 – heptafructooligosaccharides. DP – degree of polymerization.

Tab. 4. Effect of storage on major and minor saccharides content of dehydrated carrot and potato samples.

Sample		Saccharides [g·kg^{-1}]							
		Fructose	Glucose	Saccharose	*Scyllo*-inositol	*Myo*-inositol	Sedoheptulose	Trisaccharides	Total saccharides
Carrot I	0 months	41.9 ± 0.2^{e}	22.3 ± 0.2^{d}	352.9 ± 0.3^{e}	2.4 ± 0.3^{ac}	4.1 ± 0.0^{e}	7.5 ± 0.1^{c}	5.4 ± 0.4^{de}	436.6 ± 0.0^{d}
	6 months	46.1 ± 0.1^{c}	23.1 ± 0.3^{d}	371.7 ± 3.4^{b}	2.0 ± 0.2^{b}	3.9 ± 0.0^{f}	8.2 ± 0.3^{c}	5.0 ± 0.0^{d}	459.9 ± 3.1^{e}
	12 months	46.6 ± 1.5^{bc}	23.5 ± 0.1^{d}	411.4 ± 0.4^{d}	2.5 ± 0.1^{a}	4.6 ± 0.1^{c}	7.8 ± 0.1^{c}	5.8 ± 0.1^{e}	502.2 ± 2.6^{b}
Carrot II	0 months	48.1 ± 2.0^{b}	36.0 ± 2.5^{b}	381.3 ± 12.1^{bc}	2.5 ± 0.0^{a}	4.9 ± 0.2^{b}	10.1 ± 0.7^{a}	7.9 ± 0.3^{b}	490.8 ± 17.1^{b}
	6 months	46.8 ± 0.3^{bc}	36.2 ± 0.3^{b}	383.7 ± 4.6^{c}	2.1 ± 0.2^{bc}	4.5 ± 0.1^{c}	12.3 ± 0.2^{b}	8.8 ± 0.2^{c}	494.5 ± 5.8^{b}
	12 months	53.2 ± 0.3^{d}	43.4 ± 0.3^{c}	404.6 ± 1.9^{d}	3.8 ± 0.1^{d}	5.7 ± 0.0^{d}	11.7 ± 0.1^{b}	9.3 ± 0.2^{c}	531.7 ± 1.8^{c}
Potato	0 months	1.2 ± 0.0^{a}	0.9 ± 0.1^{a}	4.4 ± 0.0^{a}		0.3 ± 0.0^{a}		0.3 ± 0.0^{a}	7.1 ± 0.0^{a}
	6 months	1.4 ± 0.1^{a}	1.1 ± 0.1^{a}	3.8 ± 0.0^{a}		0.3 ± 0.0^{a}		0.3 ± 0.0^{a}	6.9 ± 0.0^{a}
	12 months	2.9 ± 0.2^{a}	1.9 ± 0.1^{a}	4.0 ± 0.0^{a}		0.4 ± 0.0^{a}		0.2 ± 0.0^{a}	9.3 ± 0.3^{a}

Content of saccharides is expressed per kilogram of dry matter. Values represent mean ± standard deviation, $n = 2$.
a–f – samples with the same superscript letter within the corresponding column (0–12 months) showed no statistically significant differences for their mean values at the 95.0% confidence level.

Tab. 5. Effect of storage on major and minor saccharides content of dehydrated onion and garlic samples.

Sample		Saccharides [g·kg^{-1}]										
		Fructose	Glucose	*Myo*-inositol	Saccharose	Kestose	Nystose	Tetra-saccharides	Penta-saccharides	Hexa-saccharides	Hepta-saccharides	Total saccharides
Onion I	0 months	35.2 ± 0.9^{d}	6.2 ± 0.3^{ac}	2.2 ± 0.3^{b}	68.1 ± 5.3^{c}	75.0 ± 1.9^{d}	54.5 ± 1.5^{cd}	103.6 ± 7.7^{b}	96.5 ± 5.6^{bc}	90.7 ± 4.6^{b}	120.9 ± 10.1^{ab}	602.0 ± 35.0^{c}
	6 months	25.0 ± 0.2^{e}	5.3 ± 0.2^{b}	2.0 ± 0.0^{b}	59.1 ± 1.4^{d}	63.5 ± 0.0^{e}	50.8 ± 0.2^{c}	103.0 ± 7.3^{b}	92.7 ± 2.1^{c}	90.9 ± 9.4^{b}	108.1 ± 2.4^{b}	552.7 ± 4.2^{bc}
	12 months	29.9 ± 0.2^{f}	6.4 ± 0.3^{a}	2.4 ± 0.4^{ab}	66.7 ± 5.9^{cd}	68.4 ± 5.6^{e}	58.3 ± 1.9^{d}	100.5 ± 10.0^{b}	97.8 ± 8.8^{bc}	88.6 ± 7.9^{b}	109.7 ± 9.6^{b}	573.4 ± 36.0^{bc}
Onion II	0 months	18.5 ± 1.7^{b}	6.4 ± 0.4^{a}	1.5 ± 0.1^{c}	50.2 ± 5.3^{b}	49.2 ± 4.4^{b}	46.0 ± 3.5^{b}	100.9 ± 10.0^{b}	110.5 ± 11.8^{b}	102.3 ± 10.6^{b}	124.2 ± 11.6^{a}	565.9 ± 52.3^{bc}
	6 months	20.0 ± 0.1^{b}	5.7 ± 0.5^{bc}	2.0 ± 0.0^{b}	39.1 ± 0.9^{c}	55.8 ± 2.5^{c}	51.6 ± 3.7^{c}	95.4 ± 9.2^{b}	101.1 ± 9.2^{bc}	100.2 ± 9.0^{b}	110.4 ± 5.3^{ab}	532.6 ± 0.7^{b}
	12 months	23.1 ± 1.1^{c}	6.1 ± 0.3^{ac}	2.1 ± 0.2^{b}	49.5 ± 4.8^{b}	55.1 ± 2.8^{bc}	57.3 ± 1.7^{d}	97.1 ± 8.8^{b}	99.9 ± 3.3^{bc}	95.2 ± 4.1^{b}	121.8 ± 3.1^{ab}	552.4 ± 9.8^{bc}
Garlic	0 months	2.0 ± 0.0^{a}		2.7 ± 0.1^{a}	19.5 ± 0.6^{a}	7.0 ± 0.7^{a}	6.0 ± 0.5^{a}	7.6 ± 0.2^{a}	4.5 ± 0.4^{a}	5.4 ± 0.5^{a}		48.5 ± 2.3^{a}
	6 months	1.5 ± 0.1^{a}		2.2 ± 0.0^{b}	21.1 ± 0.1^{a}	7.4 ± 0.2^{a}	7.1 ± 0.6^{a}	7.6 ± 0.7^{a}	5.4 ± 0.5^{a}	5.0 ± 0.6^{a}		50.1 ± 0.4^{a}
	12 months	1.8 ± 0.2^{a}		2.3 ± 0.0^{ab}	22.0 ± 0.1^{a}	7.1 ± 0.6^{a}	6.6 ± 0.4^{a}	6.8 ± 0.1^{a}	5.8 ± 0.6^{a}	5.2 ± 0.4^{a}		51.0 ± 1.4^{a}

Content of saccharides is expressed per kilogram of dry matter. Values represent mean ± standard deviation, $n = 2$.
a–f – samples with the same superscript letter within the corresponding column (0–12 months) showed no statistically significant differences for their mean values at the 95.0% confidence level.

within the two carrots analysed could be mainly due to the different variety and/or maturity stage of raw samples. The obtained results are in agreement with quantitative ranges reported by SORIA et al. [49] for commercial hot air-dried carrots. In the case of potato sample (Tab. 4), as can be observed, fructose, glucose and saccharose were found in very low amounts (0.9–4.4 g·kg^{-1} dry matter), in concordance with data previously reported by MCDONALD and NEWSON [50] and LI et al. [51].

As presented in Tab. 5, a great difference in the saccharide content was detected among onion and garlic dehydrated samples here analysed. In onion samples, mono- and disaccharides were present, together with high levels of kestose, nystose and other unidentified fructooligosaccharides with a degree of polymerization of 4–7. As compared with data previously reported by other authors [7, 52], the amount of fructose and glucose in both onion samples was significantly lower. DARBYSHIRE and HENRY [53], in a study on different onion cultivars, found a large variability in the content of fructose, glucose, saccharose and fructooligosaccharides, ranging from 21–164 g·kg^{-1} dry matter, 7–200 g·kg^{-1} dry matter, 57–157 g·kg^{-1} dry matter, and 200–800 g·kg^{-1} dry matter, respectively. In agreement with this, KAHANE et al. [54] detected different content of fructose (2–45%), glucose (1–40%), saccharose (12–22%), and fructooligosaccharides (0–70%) respect to the amount of total saccharides, in different onion varieties. In addition to the variety, MUIR et al. [52] also reported a great variability in saccharide composition of vegetables, according to their degree of ripeness.

With respect to the storage at room temperature for 1 year of dehydrated vegetables, hardly any modification took place in any of the saccharides analysed after 6 or 12 months of storage. This is in good agreement with the scarce evolution of Maillard reaction in these samples, evidenced by the limited formation of 2-FM-AA (Tab. 3).

Regarding carrot samples, the evolution of Maillard reaction was not enough to greatly affect the high reducing saccharide content of these samples. Similarly, RAHMAN et al. [28] described no significant differences in total saccharide content of dehydrated carrots stored during 8 months at ambient temperature. In commercial powder onion and garlic samples stored under accelerated conditions (50 °C and 0.44 a_w), CARDELLE-COBAS et al. [14] reported important changes due to Maillard reaction and hydrolysis in the saccharide fraction, including fructooligosaccharides. However, in the present study, the milder storage conditions selected to simulate those generally employed in the market and by consumers, contributed to maintain the stability of these dehydrated products. Furthermore, the onion here analysed seems to be adequate as raw material for drying purposes, not only for its low content of monosaccharides, which contributes to a limited advance of Maillard reaction, but also for its high content of fructooligosaccharides, recognized prebiotic saccharides [15]. This fact highlights the importance of selection of the most suitable cultivar, degree of maturity of raw product for the intended industrial processing.

With regard to *myo*-inositol, it can be observed that all samples contained this compound, carrot samples having the highest content (4–6 g·kg^{-1} dry matter) and potato samples the lowest (0.3 g·kg^{-1} dry matter). Similar results were found in dehydrated carrots, onions and potatoes by other authors [49, 55–57]. However, no data have been found in the literature for garlic. The presence of *myo*-inositol in foods is important because it might help to protect against cancer and other pathologies such as diabetes mellitus and chronic renal failure [55, 58].

CONCLUSIONS

According to the results obtained, it can be said that storage conditions studied in the present paper, which are similar to those of the market and those used by consumers, have no apparent effect on the quality parameters studied (dry matter, rehydration ability, total polyphenols, Maillard reaction indicators, proteins and saccharides), probably due to the fact that the vegetables were properly treated and dehydrated in the industry. Therefore, from this point of view, these dehydrated carrot, potato, onion and garlic are sufficiently stable for at least 12 months. These results are of particular relevance in the case of constituents with certain bioactivity. Moreover, the scarce Maillard reaction advance also guarantees the preservation of nutritive value due to lysine. As nowadays there is an increasing interest in the use of dehydrated vegetables as food ingredients in the production of a number of foodstuffs, the data here reported may be valuable for technologists, nutritionists and consumers.

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