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COLOR, TEXTURE, REHYDRATION ABILITY AND PHENOLIC COMPOUNDS OF PLUMS PARTIALLY OSMODEHYDRATED AND FINISH-DRIED BY HOT AIR

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ABSTRACT

The aim of this study was to analyze the influence of the drying process by combined methods. Osmotic dehydration was performed using glucose or sorbitol solutions at different concentrations (40 or 60 °Brix), temperatures (25 or 40C) and two fruit-to-syrup ratios (1:4 or 1:10). Hot air drying was performed at different temperatures (60, 70 or 80C). Dried plums were evaluated in terms of color, texture, rehydration ability, phenolic compounds (total phenols, flavonoids) and water activity. The color was analyzed through two methods: colorimeter and image analysis. The evaluations showed a decrease in luminosity and an increase of reddening due to browning originated during the drying process. The image analysis was the most appropriate to evaluate the changes in color. Firmness of plums increased in relation to fresh fruit and was more evident at higher drying temperature. High drying temperatures provoked a collapse of the plum structure, which hindered water absorption in the rehydration process. The phenolic compounds in plums were conditioned by the drying temperature; the content of phenols and flavonoids was higher when they were dried at 70C. Plums osmodehydrated in sorbitol 60% w/w, with a fruit/syrup ratio of 1/10, at 25C and air dried at 70C obtained a high degree of dehydration and best maintained quality attributes.

PRACTICAL APPLICATIONS

Plums, natural or processed, can be considered as a functional food, since it provides nutrients and contains additional features that benefit the health of consumers. Hence, the importance to keep them with minimal changes to their nutritional value. The combined process by means of the osmotic dehydration and the hot air drying helps to preserve the desirable quality attributes of the fruit, as well as reduce the water content to obtain products stable against microbiological agents and reaction chemical. This information may help any industry of drying fruit to optimize the process conditions and reduce costs of processing and packaging.

INTRODUCTION

In the last decades, the rising demand of nutritious and natural foods such as fruits and vegetables has been remarkable, either as fresh product or processed product as ingredient to other products (Forsido *et al.* 2013; Romojaro *et al.* 2013). Owing to their high moisture content and water activity, they become highly perishable, and thus fresh fruits and vegetables have a short shelf life (Badwaik *et al.* 2014). In industrial terms, they require conservation techniques that minimize the changes in the characteristics of the original food. The dehydration process includes various methods such as the traditional ones, i.e., sun drying, to the other modern methods such as osmotic dehydration (OD), hot air drying (HAD), vacuum drying, fluidized bed drying, drum drying, etc. Apart from these, combined dehydration methods are also used such as microwave vacuum drying, microwave-assisted air drying, etc. (Badwaik *et al.* 2014). Among these processes, OD has gained an increasing interest, mainly as pretreatment, combined with other conservation techniques such as HAD (Badwaik *et al.* 2012; Djendoubimrad *et al.* 2013).

OD consists of the immersion of fruits or vegetables (whole or in pieces) in solutions of sugars or alcohols (sucrose, fructose, glucose, sorbitol) (Khoyi and Hesari 2007) or biopolymers (pectin, starch, maltodextrins) (Mudahar *et al.* 1991) or salts (Ozen *et al.* 2002; Quintero Chávez *et al.* 2012) or combinations of these solutes (Badwaik *et al.* 2012). It is characterized by flux exchange of water and solutes permitting the fruit to lose water and gain solids, depending on the process conditions (the nature and size of the product to dehydrate, the type and concentration of osmotic agent, the fruit-to-syrup ratio, temperature and process time) (Alakali *et al.* 2006; Kaleta and Górnicki 2010; Nagai *et al.* 2015). In general, during the first 2–3 h of contact between the fruit and the syrup a high rate of water loss is achieved. After this period, the rate begins to decrease due to a lower difference in the osmotic pressure and a greater resistance to mass transfer (Barbosa-Cánovas and Vega Mercado 2000). Dehydration of fruits in concentrated solutions followed by a final stage of HAD allows reaching moisture values that guarantee the stability of the final product, maintaining the sensory characteristics of the fruit. The increase of the soluble solid content allows decreasing the enzymatic activity, thus reducing the susceptibility of the fruit to browning (Monnerat *et al.* 2010; Djendoubimrad *et al.* 2013; Nagai *et al.* 2015).

HAD is a method widely used in fruit and vegetable conservation, which increases shelf life apart from having other advantages such as weight and volume reduction that derive in lower food transport and storage costs (Togrul 2010; Sledz *et al.* 2013; Aiquan *et al.* 2014).

In literature, there are numerous research on food preservation in general, as well as on the particular case of high-water content foods such as plums (Franklin *et al.* 2006; Tarhan 2007). Plums are an excellent source of vitamin A, calcium, magnesium, iron, potassium and fiber. Like other fruits, they have high content of vitamin C, they are rich in carbohydrates and they have low content of fats and calories (Doymaz 2004). Many studies have shown that plums have high antioxidant activity, given by their polyphenolic components (coumaric, chlorogenic and neochlorogenic acids, flavonoids and anthocyanins) (Chun and Kim 2004; Romojaro *et al.* 2013). These compounds, besides contributing towards the colour and sensory characteristics as (color and taste), exhibit a wide range of physiological properties, such as antioxidant, anticancer, antimicrobial, antiallergenic, antimutagenic, anti-inflammatory and antithrombotic properties and its use has proven effective in the prevention of cancer and cardiovascular disease; hence, the importance of their study (Balasundram *et al.* 2006; Orak 2007; Forsido *et al.* 2013; Rubio-Perez *et al.* 2014). Many authors such as Franklin *et al.* (2006), Piirainen *et al.* (2007) and Gallaher and Gallaher (2008) highlighted plums, natural or processed, as a functional food that provides nutrients and contains additional features that benefit the health of consumers of the product – hence, the importance to keep them with minimal changes to their nutritional value.

The objective of this work is to preserve plums by combined dehydration techniques – OD followed by HAD – with minimal changes in product quality (texture, color, rehydration capability, phenolic compounds).

MATERIALS AND METHODS

Samples

For the development of experimental design, portions of plums of the variety D'ente (*Prunus doméstica* L.) were used. Plums had been harvested from the Chacra Experimental at the Facultad de Agronomía of UNICEN located in the city of Azul, Buenos Aires (Argentina). Initial moisture of the fresh fruit was 4.205 ± 1.218 g water g/dry solid (AOAC 1980a) and the initial content of soluble solids was 18.75 ± 1.48%, determined by Abbe refractometer (accuracy ±0.01) (AOAC 1980b). Initial water activity was 0.966 ± 0.002. The fruits were kept refrigerated at 5C before the tests. Samples selected by size and quality were washed and dried with absorbent paper, then the stones were removed and they were manually cut into pieces of one-eighth (average weight 2.4 g) (Fig. 1).

Drying by Combined Methods

OD was carried out for 2 h – period of high speed of water removal (Barbosa Cánovas and Vega Mercado 2000) – by immersing of samples in solutions of glucose ($C_6H_{12}O_6$) or sorbitol ($C_6H_{14}O_6$). These solutions were prepared at 40 or 60% (w/w) in distilled water from glucose syrup (82% [w/w]) or sorbitol (67% [w/w]) using an Erlenmeyer flask

FIG. 1. PIECE OF FRUIT ANALYZED

of 2 L and fruit : syrup ratios of 1:4 or 1:10. Samples were kept immersed in the solutions using a stainless steel mesh to prevent flotation. Two temperatures were tested: 25 and 40C (Rodríguez *et al.* 2010). Osmodehydrated plums were dried in a forced convection oven at laboratory level during 5 h, at an air speed of 0.92 ± 0.03/ms, at different temperatures (60, 70 or 80 ± 0.5C). All experiments were conducted in duplicate.

Determination of Water Activity

Water activity was determined through the equipment Aqualab (model 3TE, Pullman, WA). For equipment calibration, saturated solutions of NaCl ($a_w = 0.753 \pm 0.003$ at 25C) and KCl ($a_w = 0.843 \pm 0.003$ at 25C) were used. The reading of the water activity was taken when the difference in temperature between the chamber and the dried sample was ±0.5C. All measurements were performed at 25C and in duplicate (Zotarelli *et al.* 2012).

Color Determination through the Minolta Colorimeter

The surface color (parameters *L*, *a* and *b*) of dried plums was determined using a Minolta colorimeter (model CR-400, Tokyo, Japan) (Romano *et al.* 2012). The parameter "*L*" varies from 100 for a perfect white to 0 for black; "*a*" represents red when positive values appear, gray when zero and green for negative values. The parameter "*b*" represents yellow when it shows positive values, gray when zero and blue for negative values. The total change in color after dehydration by combined methods (OD + HAD) was assessed according to Eq. (1) of Hunter (1975).

$$\Delta C = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (1)$$

Color Determination through Image Analysis

For color assessment, the dried plums were placed on a white tray, which was later put in a box with standardized illumination DAYLIGHT 60 W. The image was taken with a photographic camera (Samsung S860, Zhuhai, China, 8.1 MP, zoom 6.3–18.9 mm) through the hole in the upper part of the box. This procedure was performed to guarantee that all the images were taken in the same way. The image analysis was performed with the software Photoshop (Adobe Systems Incorporated, San Jose, CA), also used by Riva *et al.* (2005) in the drying by hot air of osmodehydrated apricots.

Storage Effect on Color Assessment

Dried plums were stored at 5C for 12 months in dark-colored high-density polyethylene plastic containers to avoid contact with light. Afterward, the samples were assessed again through image analysis to evaluate the storage effect on color parameters.

Texture Determination

Textural analyses were performed in a TAXT2i Texture Analyser (Stable Micro Systems, UK) using the Texture Expert Exceed software supplied by Texture Technologies Corp., Surrey, UK. The Volodkevich bite jaws (HDP/VB) probe, which simulates the action of an incisor tooth (Wen-Ching *et al.* 2007), was used in measuring the texture of the fruit product because it has been observed that the first bite of the product is performed with the fore teeth. The following conditions were used: an assay speed of 0.1 mm/s; distance 100%; pre-assay speed of 2 mm/s; post-assay speed of 5 mm/s; the catheter used was the teeth; and the samples were displayed sideways on a smooth base. In each measurement, graphics of strength (N) were obtained depending on distance (mm), for which the pair of coordinates belonging to the maximum point that represents the maximum strength of rupture or cutting were determined. For each treatment, 10 measurements were performed. Finally, firmness was determined as the ratio between the force and the distance at the breakpoint.

Determination of Rehydration Ability

Rehydration was carried out in distilled water at 25C with fruit/water ratio of 1/30 (Singh *et al.* 2008). At regular time intervals of 5, 10, 15, 20, 30, 40, 50, 60, 90, 120, 150 and 180 min, portions of dried plums were withdrawn from the Erlenmeyer, drained on absorbent paper and then weighed (analytical balance, Mettler AE240, Greifensee, Suiza, accuracy ±0.0001 g).

Determination of Phenolic Compounds

The extraction of phenolic compounds was made from 2 g of dried plums, previously ground in a grinder, with 5 mL of a methanol/acetic acid with a 40/1 ratio by stirring under hood in shaker at 180 rpm for 30 min. Then the supernatants (phenolic extracts + solvent) were centrifuged for 5 min and the extraction process was repeated twice more. The extracts were stored in caramel flasks at 5C until measurement. For the determination of phenolic compounds, a dilution of the extracts was performed in distilled water (1:25) and a spectrophotometer (Metrolab 1700, UV-vis spectrophotometer, Argentina) was used. All determinations were performed in duplicate.

Because Singleton and Rossi in 1965 developed the colorimetric method to measure the amount of total phenols using the Folin–Ciocalteu reagent, it has been used in different materials (plant foods). To calculate the total phenol content, calibration curves should be performed using different chemical equivalents. In general, the total phenolics are expressed in terms of molar equivalents of gallic acid (Zheng and Wang 2001; Proteggente *et al.* 2002) or (+) catechin (Zielinski and Kozlowska 2000; Vinson *et al.* 2001).

Total Phenols

For the determination of total phenols, a calibration curve with gallic acid standard solution (0.1 mg/mL) was performed, following the guidelines of Singleton and Rossi (1965). To build the curve, volumes were taken of 0, 20, 40, 60, 80, 100, 120, 140 and 160 μL of the standard solution, which were added with distilled water to a final volume of 500 μL. A volume of distilled water of 500 μL was used as a blank. Then, each of the standards was added 250 μL of Folin–Ciocalteu reagent (1 N) followed by homogenization in a sonicator for 5 min. Finally, 1,250 μL of $NaCO_3$ 20% w/v was added and, after 120 min, the extracts were read at 760 nm. Reading of samples was performed on 500 μL of phenolic extracts and the results were expressed as mg gallic acid equivalent per 100 g sample on dry basis plum.

Flavonoids

The total flavonoid contents were determined by a colorimetric assay (Meyers *et al.* 2003). For the determination of flavonoids, a calibration curve with catechin standard solution (0.1 mg/mL) was performed. To build the curve, volumes were taken of 0, 20, 40, 60, 80 and 100 μL of the standard solution, which were added with distilled water to a final volume of 2,500 μL. A volume of distilled water of 2,500 μL was used as a blank. Then, volumes of 500 μL of each standard were taken and were added 1,250 μL of water, followed by 75 μL $NaNO_2$ 5% w/v and allowed to stand for 6 min. Then, 150 μL $AlCl_3$ 10% w/v was added and again let stand for 5 min. Finally, 500 μL NaOH (1 M) was added and the reading was performed at 510 nm within 30 min. Reading of samples was performed on 500 μL of phenolic extracts and the results were expressed as mg catechin equivalent per 100 g sample on dry basis plum.

Statistical Analysis

The influence of the process variables on quality parameters was evaluated through analysis of variance at a significance level of 5%. The analysis was carried out using the software InfoStat (Di Rienzo *et al.* 2008). For comparison between the results obtained by Minolta colorimeter and by image analysis, the paired means analysis was employed through the *t* test.

RESULTS AND DISCUSSION

Evaluation of Water Activity

Figure 2 shows the effect of the combined methods over water activity (a_w) compared with that of untreated plums. Plums showed an initial a_w of 0.966 ± 0.002; after combined drying (OD + HAD), the values were reduced to a range between 0.441 and 0.845 depending on the experimental conditions. The samples osmodehydrated in sorbitol solution at 40% w/w, with a fruit-to-syrup ratio of 1–10, at an osmotic bath temperature of 25C and then dried by air at 80C presented the lower a_w, whereas the samples osmodehydrated in glucose syrup at 40% w/w, with a fruit-to-syrup ratio of 1–10, at an osmotic temperature of 40C and then dried by air at 60C showed the highest water

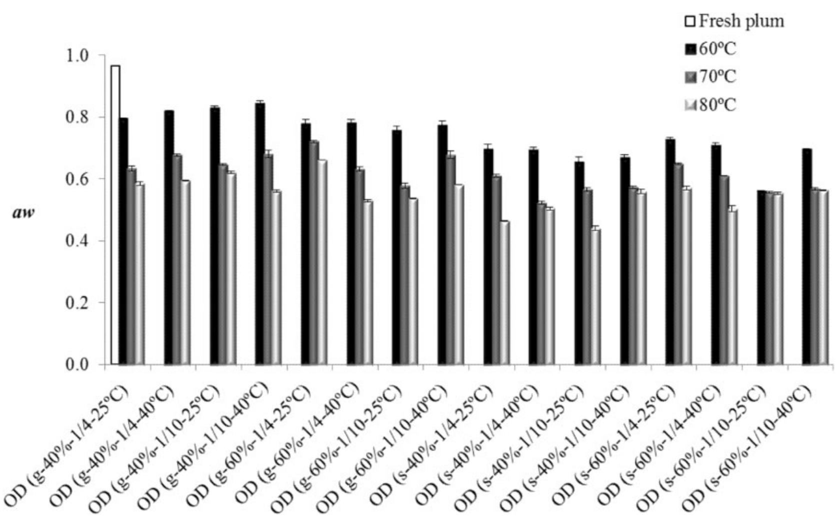

FIG. 2. ACTIVITY (A_W) OF DEHYDRATED PLUMS BY COMBINED METHODS, GROUPED BY OSMOTIC TREATMENT AND DIFFERENTIATED BY BLACK, GRAY AND WHITE BARS WHEN THE DRYING TEMPERATURE IS 60, 70 OR 80C, RESPECTIVELY
Osmotic agent = g, glucose; s, sorbitol. Concentration of the osmotic agent = 40%; 60%. Fruit/syrup ratio = r1/4 = ratio 1–4; r1/10 = ratio 1–10. Temperature osmotic solution = 25C; 40C. Drying temperature = 60C; 70C; 80C.

TABLE 1. MOISTURE VALUES (*X*) OF PLUMS DEHYDRATED BY COMBINED METHODS (OD + HAD) AND THE VALUES OF WATER LOSS (*WL*) AND SOLID GAIN (*SG*) OF OSMODEHYDRATED PLUMS

OD				HAD		
				60C	70C	80C
Osmotic treatment	*WL*	*SG*	*X* (g water g/dry solid)			
g-40%-r1/4–25C	20.910	3.195	2.539 ± 0.044	0.277 ± 0.089	0.124 ± 0.055	0.073 ± 0.027
g-40%-r1/4–40C	18.647	2.840	2.920 ± 0.000	0.328 ± 0.124	0.278 ± 0.006	0.134 ± 0.050
g-40%-r1/10–25C	23.173	5.458	2.920 ± 0.000	0.216 ± 0.029	0.103 ± 0.042	0.079 ± 0.058
g-40%-r1/10–40C	21.939	4.224	2.389 ± 0.000	0.247 ± 0.061	0.164 ± 0.054	0.037 ± 0.009
g-60%-r1/4–25C	23.173	5.458	2.225 ± 0.000	0.224 ± 0.008	0.179 ± 0.048	0.051 ± 0.025
g-60%-r1/4–40C	24.407	6.692	2.076 ± 0.000	0.308 ± 0.082	0.220 ± 0.083	0.077 ± 0.051
g-60%-r1/10–25C	24.613	6.898	2.052 ± 0.855	0.245 ± 0.030	0.069 ± 0.018	0.021 ± 0.014
g-60%-r1/10–40C	25.230	7.515	1.984 ± 0.000	0.261 ± 0.093	0.250 ± 0.002	0.155 ± 0.094
s-40%-r1/4–25C	23.584	5.870	2.174 ± 0.000	0.117 ± 0.015	0.067 ± 0.011	0.031 ± 0.002
s-40%-r1/4–40C	23.790	6.075	2.149 ± 0.105	0.195 ± 0.069	0.098 ± 0.016	0.023 ± 0.012
s-40%-r1/10–25C	22.967	5.252	2.251 ± 0.037	0.206 ± 0.048	0.140 ± 0.067	0.112 ± 0.025
s-40%-r1/10–40C	24.407	6.692	2.076 ± 0.201	0.334 ± 0.049	0.180 ± 0.072	0.119 ± 0.089
s-60%-r1/4–25C	24.407	6.692	2.076 ± 0.000	0.320 ± 0.009	0.163 ± 0.025	0.070 ± 0.039
s-60%-r1/4–40C	25.847	8.132	1.919 ± 0.030	0.248 ± 0.092	0.233 ± 0.038	0.086 ± 0.017
s-60%-r1/10–25C	29.139	11.424	1.614 ± 0.316	0.181 ± 0.017	0.114 ± 0.020	0.077 ± 0.004
s-60%-r1/10–40C	26.464	8.750	1.856 ± 0.290	0.214 ± 0.081	0.122 ± 0.070	0.085 ± 0.018

Osmotic agent = g, glucose; s, sorbitol. Concentration of the osmotic agent = 40%; 60%. Fruit/syrup ratio = r1/4 = ratio 1–4; r1/10 = ratio 1–10. Temperature osmotic solution = 25C; 40C. Drying temperature = 60C; 70C; 80C.
HAD, hot air drying; OD, osmotic dehydration.

activity. Convective drying of osmodehydrated plums allowed the reduction of the levels of a_w through water elimination in both stages and the incorporation, to a lower extent, of soluble solids during the OD. Thus, stable products were obtained from the microbiological perspective for most working conditions (Cheftel and Cheftel 1992; Quintero Chávez *et al*. 2012).

Table 1 shows moisture values (*X*) of dehydrated plums by direct osmosis and dehydrated plums by osmosis followed by HAD, recorded at final time. In addition, the values of water loss and solid gain during OD are included. The values of *WL* and *SG* were between 18.647 and 29.139% and 2.840 and 11.424%, respectively. The samples osmodehydrated in sorbitol solution at 60% w/w, with a fruit-to-syrup ratio of 1–10, at an osmotic bath temperature of 25C presented the greater dehydration, whereas the osmodehydrated in glucose syrup at 40% w/w, with a fruit-to-syrup ratio of 1–4 and osmotic temperature of 40C showed the lower values of *WL* (18.647%) and *SG* (2.840%).

Fresh plums (4.205 g water g/dry solid) once dehydrated by osmosis reached intermediate moistures in the range between 1.614 and 2.920 g water g/dry solid, depending on the type and concentration of the osmotic agent, the fruit/syrup ratio and the process temperature. When HAD was applied to these samples, the final moisture of the portions of plums varied between 0.021 and 0.334 g water g/dry solid. A clear dependence with air temperature was observed. This indicates a direct relationship between the levels of dehydration and the increase of the drying air temperature; these results were also conditioned by the previous osmotic treatment. These results are consistent with those from Pavkov *et al*. (2011) for the drying of previously osmodehydrated halved nectarines.

Figure 2 and Table 1 show that the plums dehydrated by osmosis in sorbitol solutions underwent higher WL and SG and reached lower water activity and moisture values than the samples osmodehydrated in glucose syrup. Despite the similarity in the molecular weight, other variables influenced the behavior of the osmotic agents, such as viscosity, the depressing power on the a_w and the ionic behavior that has origin in the interaction between the solutes and the water and solid matrix of different foods (Quintero Chávez *et al*. 2012; Rodríguez *et al*. 2013).

Comparison of Methods for Determining Color

Color evaluation through the Minolta colorimeter: the fresh plums presented the following values of $L_0 = 22.582 \pm 3.147$, $a_0 = -1.108 \pm 0.646$ and $b_0 = 14.105 \pm 2.330$. These values correspond to the average of six replicates. The initial values of the parameters of color suggest a fruit with a light-colored pulp, being yellow and with a slight green hue represented by negative values of *a*.

Table 2 shows the values of L, a and b after drying by the combined method and the total color change ΔC in comparison with the fresh fruit. The values of L ranged between 21.091 and 29.831, parameter a varied in the range 4.591–9.057 and b between 5.515 and 16.940. At first sight, it could be concluded that, after drying, the plums had increased redness and, in most cases, less yellow compared with fresh fruit. Luminosity, as expected, showed a slight increase because the plum wedges were processed with skin, which color became clearer once dehydrated. On the other hand, parameter "b" did not show a defined behavior after drying, being its analysis not relevant. The same result was obtained by Guiné *et al.* (2010) in the evaluation of color after drying of pears.

The total color change was between 8.978 and 12.721. The samples osmodehydrated in sorbitol solution at 60% w/w, with a fruit-to-syrup ratio of 1–4 at 40C and then dried by hot air at 80C presented the lowest variation, whereas the ones osmodehydrated in glucose syrup at 40% w/w, with a fruit-to-syrup ratio of 1–4 at 25C and then dried by air at 80C presented a higher change in color, being the highest color variation – at equal air drying conditions – for the samples treated in osmotic solutions prepared at 40% w/w and 25C (Table 2).

When comparing the syrups, it is observed that the three indicators were intensified when sorbitol was used as hypertonic solution. Sorbitol has stood out in many scientific works because of its moistening and color-protecting properties (Ozen *et al.* 2002; Riva *et al.* 2005).

The values of L, a and b were higher when the air drying was performed at a higher temperature.

Performing color evaluation through image analysis, the fresh plums presented the following values of $L_0 = 22.800 \pm 2.616$, $a_0 = 32.100 \pm 2.558$ and $b_0 = 32.000 \pm 3.801$; these values belong to the average of 10 replicates.

Table 3 shows the values of L, a and b after drying by the combined method and the total color change ΔC in comparison with the fresh fruit. The values of "L" ranged between 3.10 and 21.20, "a" varied in the range 5.30–30.30 and "b" remained between 3.00 and 26.90. After drying, the samples showed a lower luminosity and redness in comparison with the fresh fruit. On the other hand, the parameter "b" did not show a defined behavior after drying. These results are similar to the ones obtained in the evaluation of color with the Minolta colorimeter.

The total color change ranged between 6.5 and 43.9. The samples osmodehydrated in glucose solution at 40% w/w, with a fruit-to-syrup ratio of 1–10 at 25C and then dried by hot air at 80C showed the lowest variation, whereas the ones osmodehydrated in glucose at 40% w/w, with a fruit-to-syrup ratio of 1–4 at 40C and then dried by hot air at 60C presented the highest variation in color (Table 3).

Many authors have shown that the osmotic treatment, previous to air drying, decreases the total variation in color with respect to the product dehydrated only by convective drying because the solute absorption decreases the activity of enzyme phenolase and, hence, enzymatic browning is reduced during air drying (Mandala *et al.* 2005; Riva *et al.* 2005).

The value of theoretical t for a bilateral assay, with 48 degrees of freedom ($n - 1$) and an error of 5% correspond to ±2.0106. The value of experimental t obtained through the comparison in pairs of values of L, a, b and ΔC, calculated through the Minolta colorimeter and the image analysis, were 24.69, −15.82, −5.40 and −10.93, respectively. Consequently, there are significant differences ($P < 0.05$) between the pairs of values of color parameters a, b, L and ΔC determined through both methods.

Compared with the results determined by the Minolta colorimeter, the image analysis allows quantifying not only color but also the morphometric and densitometry characteristics of the images (volume, surface, superficial texture, thickness of the piece) (Russ *et al.* 1988). This method is useful when, during a process, the product undergoes a modification of its geometry or appearance such as the contraction of the fruit during air drying (Riva *et al.* 2001).

As for the measurement of color, the lack of homogeneity in the appearance of the portions of fruit represents an obstacle for the application of the classical method based on the instruments of reflectance. On the contrary, the image analysis represents an efficient methodology capable of measuring the average chromatic parameters, also in nonhomogenous surfaces. Through simple programs, such as Adobe Photoshop, it is possible to measure the color of digitalized images by expressing the results in the usual chromatic coordinates "L," "a" and "b" (Papadakis *et al.* 2000; Riva *et al.* 2005).

In practice, color heterogeneity was observed in portions of osmodehydrated plums dried by air. This was reflected by the standard deviations among the replicates for values of L, a and b evaluated from the Minolta colorimeter (not shown). But when the image analysis was used, the deviations were not significant; hence, it is concluded that when the appearance is not homogenous, it is advisable to use the image analysis to evaluate color (Rodríguez *et al.* 2013).

Evaluation of Color during Storage through Image Analysis

After 12 months of storage, the color parameter values of the plums dehydrated ranged between $3.20 < L < 16.80$, $5.80 < a < 30.10$ and $3.10 < b < 21.40$. It is observed that the values of L, a and b were not modified during storage.

TABLE 2. VALUES OF *L*, *A*, *B* AND Δ*C* OF PLUMS DEHYDRATED BY COMBINED METHODS EVALUATED THROUGH THE MINOLTA COLORIMETER

Dehydrating conditions	*L*	*a*	*b*	Δ*C*	Dehydrating conditions	*L*	*a*	*b*	Δ*C*
OD (g-40%-1/4–25C) + HAD(60C)	23.5 ± 1.6	6.2 ± 1.2	8.0 ± 1.9	9.6 ± 2.0	OD (s-40%-1/4–25C) + HAD(60C)	21.9 ± 1.8	5.1 ± 0.5	5.5 ± 0.8	10.6 ± 1.7
OD (g-40%-1/4–25C) + HAD(70C)	29.3 ± 2.2	8.6 ± 0.6	16.0 ± 1.7	12.0 ± 2.1	OD (s-40%-1/4–25C) + HAD(70C)	27.8 ± 2.7	9.0 ± 2.9	10.5 ± 4.8	11.9 ± 2.7
OD (g-40%-1/4–25C) + HAD (80C)	29.8 ± 4.0	9.0 ± 1.4	16.9 ± 3.1	12.7 ± 1.0	OD (s-40%-1/4–25C) + HAD (80C)	28.8 ± 2.6	8.5 ± 0.9	15.6 ± 0.7	11.6 ± 2.2
OD (g-40%-1/4–40C) + HAD (60C)	23.9 ± 0.6	5.8 ± 1.1	6.6 ± 1.3	10.3 ± 1.0	OD (s-40%-1/4–40C) + HAD (60C)	24.0 ± 1.3	5.5 ± 0.4	5.7 ± 0.4	10.8 ± 1.2
OD (g-40%-1/4–40C) + HAD (70C)	23.5 ± 3.1	5.2 ± 1.2	6.0 ± 1.4	10.3 ± 2.5	OD (s-40%-1/4–40C) + HAD (70C)	25.0 ± 1.9	7.8 ± 1.2	12.4 ± 2.0	9.5 ± 2.6
OD (g-40%-1/4–40C) + HAD (80C)	25.6 ± 1.5	8.8 ± 0.4	13.4 ± 0.5	10.4 ± 1.4	OD (s-40%-1/4–40C) + HAD (80C)	29.6 ± 2.6	8.0 ± 1.6	16.6 ± 3.1	11.8 ± 2.5
OD (g-40%-1/10–25C) + HAD (60C)	23.4 ± 0.9	6.1 ± 1.6	7.5 ± 2.3	9.8 ± 1.0	OD (s-40%-1/10–25C) + HAD (60C)	22.3 ± 3.4	5.4 ± 2.2	5.7 ± 1.7	10.6 ± 2.5
OD (g-40%-1/10–25C) + HAD (70C)	27.3 ± 2.6	8.1 ± 0.8	13.7 ± 2.2	10.3 ± 1.0	OD (s-40%-1/10–25C) + HAD (70C)	27.9 ± 3.0	8.4 ± 0.7	12.9 ± 2.0	10.9 ± 3.4
OD (g-40%-1/10–25C) + HAD (80C)	25.8 ± 2.0	9.1 ± 0.6	15.2 ± 2.0	10.7 ± 2.5	OD (s-40%-1/10–25C) + HAD (80C)	24.8 ± 4.7	8.5 ± 1.4	14.5 ± 2.1	9.8 ± 2.0
OD (g-40%-1/10–40C) + HAD (60C)	25.4 ± 0.6	7.3 ± 0.6	9.2 ± 0.8	10.1 ± 0.6	OD (s-40%-1/10–40C) + HAD (60C)	23.2 ± 1.8	5.9 ± 1.6	6.8 ± 2.3	10.1 ± 2.5
OD (g-40%-1/10–40C) + HAD (70C)	22.6 ± 2.0	6.8 ± 0.8	8.9 ± 1.9	9.4 ± 2.6	OD (s-40%-1/10–40C) + HAD (70C)	25.1 ± 2.6	7.2 ± 0.8	10.4 ± 2.0	9.4 ± 1.6
OD (g-40%-1/10–40C) + HAD (80C)	24.8 ± 2.9	8.2 ± 0.6	12.5 ± 2.3	9.7 ± 2.5	OD (s-40%-1/10–40C) + HAD (80C)	25.5 ± 4.0	8.1 ± 2.2	12.1 ± 4.5	9.8 ± 1.9
OD (g-60%-1/4–25C) + HAD (60C)	23.5 ± 1.9	6.4 ± 2.4	7.0 ± 1.8	10.4 ± 2.8	OD (s-60%-1/4–25C) + HAD (60C)	21.5 ± 2.4	4.7 ± 0.5	5.7 ± 0.7	10.3 ± 2.3
OD (g-60%-1/4–25C) + HAD (70C)	24.1 ± 2.1	7.5 ± 0.9	11.0 ± 0.6	9.3 ± 1.5	OD (s-60%-1/4–25C) + HAD (70C)	24.5 ± 2.9	7.4 ± 1.2	11.0 ± 3.1	9.3 ± 1.5
OD (g-60%-1/4–25C) + HAD (80C)	25.2 ± 1.9	6.4 ± 0.5	9.2 ± 1.2	9.3 ± 2.1	OD (s-60%-1/4–25C) + HAD (80C)	24.7 ± 3.7	7.0 ± 1.0	9.5 ± 2.5	9.6 ± 1.6
OD (g-60%-1/4–40C) + HAD (60C)	23.2 ± 1.4	5.2 ± 0.7	6.0 ± 1.0	10.3 ± 1.3	OD (s-60%-1/4–40C) + HAD (60C)	21.1 ± 1.5	4.6 ± 1.3	5.7 ± 1.6	10.2 ± 2.0
OD (g-60%-1/4–40C) + HAD (70C)	26.3 ± 2.0	6.3 ± 0.7	9.1 ± 1.9	9.7 ± 2.2	OD (s-60%-1/4–40C) + HAD (70C)	26.0 ± 1.7	6.8 ± 0.6	10.5 ± 2.5	9.3 ± 2.2
OD (g-60%-1/4–40C) + HAD (80C)	23.9 ± 2.1	6.4 ± 1.0	9.0 ± 2.7	9.2 ± 2.9	OD (s-60%-1/4–40C) + HAD (80C)	24.5 ± 3.5	6.8 ± 1.1	10.2 ± 2.7	9.0 ± 2.3
OD (g-60%-1/10–25C) + HAD (60C)	24.3 ± 2.1	7.5 ± 2.3	8.2 ± 2.6	10.6 ± 3.1	OD (s-60%-1/10–25C) + HAD (60C)	24.2 ± 0.8	6.8 ± 0.9	7.1 ± 0.9	10.7 ± 0.8
OD (g-60%-1/10–25C) + HAD (70C)	25.7 ± 4.6	8.4 ± 1.6	11.7 ± 3.2	10.3 ± 1.8	OD (s-60%-1/10–25C) + HAD (70C)	28.4 ± 1.4	9.0 ± 1.3	14.1 ± 1.8	11.7 ± 1.6
OD (g-60%-1/10–25C) + HAD (80C)	23.7 ± 1.2	7.8 ± 1.4	11.0 ± 3.0	9.5 ± 2.4	OD (s-60%-1/10–25C) + HAD (80C)	27.5 ± 1.9	8.0 ± 1.3	11.5 ± 1.1	10.6 ± 2.0
OD (g-60%-1/10–40C) + HAD (60C)	25.2 ± 2.8	7.9 ± 1.2	9.1 ± 1.7	10.6 ± 1.3	OD (s-60%-1/10–40C) + HAD (60C)	22.6 ± 1.2	6.0 ± 1.2	7.0 ± 1.6	10.1 ± 1.7
OD (g-60%-1/10–40C) + HAD (70C)	24.8 ± 2.1	6.5 ± 1.7	8.5 ± 2.9	9.7 ± 1.4	OD (s-60%-1/10–40C) + HAD (70C)	27.1 ± 2.2	9.0 ± 1.2	13.0 ± 4.01	11.1 ± 2.6
OD (g-60%-1/10–40C) + HAD (80C)	25.4 ± 2.7	6.6 ± 2.0	9.0 ± 1.5	9.7 ± 2.4	OD (s-60%-1/10–40C) + HAD (80C)	26.8 ± 1.4	7.2 ± 0.8	10.5 ± 2.3	10.0 ± 2.0

Osmotic agent = g, glucose; s, sorbitol. Concentration of the osmotic agent = 40%; 60%. Fruit/syrup ratio = r1/4 = ratio 1–4; r1/10 = ratio 1–10. Temperature osmotic solution = 25C; 40C. Drying temperature = 60C; 70C; 80C.

HAD, hot air drying; OD, osmotic dehydration.

TABLE 3. VALUES OF *L*, *A*, *B* AND Δ*C* OF PLUMS DEHYDRATED BY COMBINED METHODS EVALUATED THROUGH THE IMAGE ANALYSIS

Dehydrating conditions	*L*	*a*	*b*	Δ*C*	Dehydrating conditions	*L*	*a*	*b*	Δ*C*
OD (g-40%-1/4–25C) + HAD (60C)	4.6 ± 2.5	10.6 ± 6.3	5.4 ± 2.9	38.7 ± 3.9	OD (s-40%-1/4–25C) + HAD (60C)	7.2 ± 4.0	17.0 ± 8.2	8.7 ± 5.6	31.8 ± 6.1
OD (g-40%-1/4–25C) + HAD (70C)	14.0 ± 4.4	25.5 ± 5.2	17.8 ± 5.9	18.0 ± 3.6	OD (s-40%-1/4–25C) + HAD (70C)	16.0 ± 5.9	28.3 ± 7.6	20.0 ± 7.3	14.3 ± 4.8
OD (g-40%-1/4–25C) + HAD (80C)	13.7 ± 4.6	25.3 ± 4.0	17.2 ± 6.0	18.7 ± 2.8	OD (s-40%-1/4–25C) + HAD (80C)	13.8 ± 3.3	27.9 ± 3.7	18.9 ± 4.7	16.4 ± 6.2
OD (g-40%-1/4–40C) + HAD (60C)	3.5 ± 1.4	5.3 ± 2.9	3.0 ± 1.3	44.0 ± 2.7	OD (s-40%-1/4–40C) + HAD (60C)	8.4 ± 3.9	16.2 ± 7.1	8.9 ± 5.5	31.5 ± 5.1
OD (g-40%-1/4–40C) + HAD (70C)	8.0 ± 3.7	17.3 ± 6.3	9.7 ± 5.1	30.6 ± 5.7	OD (s-40%-1/4–40C) + HAD (70C)	9.3 ± 3.6	22.0 ± 8.3	12.0 ± 4.6	26.2 ± 2.6
OD (g-40%-1/4–40C) + HAD (80C)	18.1 ± 8.9	27.2 ± 7.5	20.8 ± 9.9	13.1 ± 4.1	OD (s-40%-1/4–40C) + HAD (80C)	16.2 ± 6.4	23.4 ± 5.1	18.2 ± 4.3	17.6 ± 5.0
OD (g-40%-1/10–25C) + HAD (60C)	5.9 ± 2.8	9.2 ± 2.6	5.3 ± 2.4	39.0 ± 3.8	OD (s-40%-1/10–25C) + HAD (60C)	8.3 ± 4.3	17.1 ± 7.7	9.3 ± 5.9	30.8 ± 4.7
OD (g-40%-1/10–25C) + HAD (70C)	18.0 ± 2.6	30.3 ± 3.8	22.6 ± 3.0	10.7 ± 2.9	OD (s-40%-1/10–25C) + HAD (70C)	12.9 ± 2.2	25.9 ± 3.1	16.0 ± 3.4	19.8 ± 4.4
OD (g-40%-1/10–25C) + HAD (80C)	21.2 ± 3.3	28.4 ± 5.1	26.9 ± 5.1	6.5 ± 4.0	OD (s-40%-1/10–25C) + HAD (80C)	17.9 ± 3.0	29.8 ± 2.4	24.1 ± 4.7	9.6 ± 4.7
OD (g-40%-1/10–40C) + HAD (60C)	3.1 ± 0.3	5.9 ± 1.7	3.0 ± 1.2	43.8 ± 1.1	OD (s-40%-1/10–40C) + HAD (60C)	5.9 ± 2.3	15.0 ± 7.8	7.7 ± 3.2	34.2 ± 5.1
OD (g-40%-1/10–40C) + HAD (70C)	11.2 ± 3.1	22.4 ± 4.0	13.2 ± 3.3	24.1 ± 5.6	OD (s-40%-1/10–40C) + HAD (70C)	11.0 ± 3.5	23.6 ± 4.6	14.3 ± 4.6	22.9 ± 6.9
OD (g-40%-1/10–40C) + HAD (80C)	14.0 ± 6.4	24.8 ± 4.6	18.0 ± 9.0	18.1 ± 4.5	OD (s-40%-1/10–40C) + HAD (80C)	15.9 ± 5.2	27.5 ± 3.0	21.3 ± 6.6	13.5 ± 3.7
OD (g-60%-1/4–25C) + HAD (60C)	6.6 ± 2.4	12.9 ± 5.4	6.1 ± 2.1	36.1 ± 3.7	OD (s-60%-1/4–25C) + HAD (60C)	4.7 ± 2.5	10.7 ± 5.9	4.7 ± 3.9	39.1 ± 6.7
OD (g-60%-1/4–25C) + HAD (70C)	7.6 ± 2.8	17.7 ± 5.6	9.5 ± 3.3	30.7 ± 6.3	OD (s-60%-1/4–25C) + HAD (70C)	9.6 ± 3.9	21.2 ± 6.8	11.5 ± 5.2	26.7 ± 3.0
OD (g-60%-1/4–25C) + HAD (80C)	7.5 ± 3.5	17.5 ± 5.1	9.6 ± 4.2	30.8 ± 5.6	OD (s-60%-1/4–25C) + HAD (80C)	12.3 ± 4.2	24.5 ± 6.0	15.9 ± 6.4	20.7 ± 2.8
OD (g-60%-1/4–40C) + HAD (60C)	4.8 ± 1.4	8.8 ± 2.9	4.1 ± 2.0	40.6 ± 3.2	OD (s-60%-1/4–40C) + HAD (60C)	6.8 ± 3.5	13.5 ± 6.1	7.1 ± 4.3	35.0 ± 3.8
OD (g-60%-1/4–40C) + HAD (70C)	8.4 ± 3.8	17.5 ± 5.0	9.5 ± 4.9	30.4 ± 5.3	OD (s-60%-1/4–40C) + HAD (70C)	11.8 ± 2.3	25.3 ± 3.1	15.3 ± 3.9	21.1 ± 4.9
OD (g-60%-1/4–40C) + HAD (80C)	8.0 ± 3.7	17.3 ± 6.6	9.8 ± 5.1	30.5 ± 3.8	OD (s-60%-1/4–40C) + HAD (80C)	13.5 ± 4.7	26.6 ± 4.1	17.4 ± 6.1	18.2 ± 4.7
OD (g-60%-1/10–25C) + HAD (60C)	10.0 ± 4.0	21.2 ± 4.1	11.0 ± 4.4	26.9 ± 6.5	OD (s-60%-1/10–25C) + HAD (60C)	8.5 ± 3.7	18.1 ± 7.6	9.3 ± 3.9	30.3 ± 6.9
OD (g-60%-1/10–25C) + HAD (70C)	11.4 ± 4.1	23.8 ± 6.4	14.7 ± 5.8	22.3 ± 1.5	OD (s-60%-1/10–25C) + HAD (70C)	14.9 ± 2.6	28.7 ± 3.4	19.6 ± 3.8	15.1 ± 4.9
OD (g-60%-1/10–25C) + HAD (80C)	15.2 ± 4.7	24.3 ± 5.9	18.4 ± 5.8	17.4 ± 5.8	OD (s-60%-1/10–25C) + HAD (80C)	14.8 ± 2.9	26.5 ± 3.1	18.4 ± 4.3	16.7 ± 5.3
OD (g-60%-1/10–40C) + HAD (60C)	8.0 ± 4.4	18.9 ± 8.4	9.9 ± 5.8	29.7 ± 6.7	OD (s-60%-1/10–40C) + HAD (60C)	10.3 ± 4.3	21.4 ± 5.4	12.2 ± 4.8	25.7 ± 4.0
OD (g-60%-1/10–40C) + HAD (70C)	9.5 ± 3.1	20.3 ± 4.9	12.2 ± 4.0	26.6 ± 6.4	OD (s-60%-1/10–40C) + HAD (70C)	13.0 ± 3.7	25.4 ± 3.1	15.7 ± 4.2	20.2 ± 5.7
OD (g-60%-1/10–40C) + HAD (80C)	10.8 ± 3.7	22.0 ± 3.8	12.4 ± 3.4	25.1 ± 4.3	OD (s-60%-1/10–40C) + HAD (80C)	12.4 ± 3.0	25.4 ± 4.4	15.2 ± 4.5	20.9 ± 6.0

Osmotic agent = g, glucose; s, sorbitol. Concentration of the osmotic agent = 40%; 60%. Fruit/syrup ratio = r1/4 = ratio 1–4; r1/10 = ratio 1–10. Temperature osmotic solution = 25C; 40C. Drying temperature = 60C; 70C; 80C.

HAD, hot air drying; OD, osmotic dehydration.

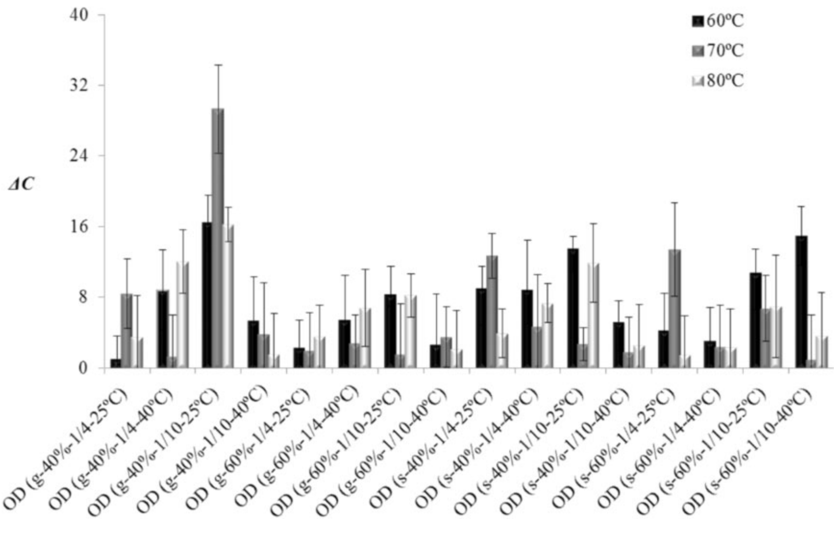

FIG. 3. TOTAL COLOR CHANGE OF DEHYDRATED PLUMS BY COMBINED METHOD (OSMOTIC DEHYDRATION + HOT AIR DRYING) FOR 12 MONTHS OF STORAGE EVALUATED THROUGH THE IMAGE ANALYSIS, GROUPED BY OSMOTIC TREATMENT AND DIFFERENTIATED BY BLACK, GRAY AND WHITE BARS WHEN THE DRYING TEMPERATURE IS 60, 70 OR 80C, RESPECTIVELY
Osmotic agent = g, glucose; s, sorbitol. Concentration of the osmotic agent = 40%; 60%. Fruit/syrup ratio = r1/4 = ratio 1–4; r1/10 = ratio 1–10. Temperature osmotic solution = 25C; 40C. Drying temperature = 60C; 70C; 80C.

Figure 3 represents the total color change in plums in comparison with the values recorded at the beginning of the storage test. The total color change ranged between 0.99 and 29.29. All values of ΔC, but one, were below 16. The lowest variation corresponded to the samples treated in sorbitol at 60% w/w, with a fruit-to-syrup ratio of 1–10, an osmotic temperature of 40C and then dried by air at 70C, whereas the highest variation corresponded to plums treated in glucose syrup at 40% w/w, with a fruit-to-syrup ratio of 1–10, an osmotic temperature of 25C and then dried by air at 70C. Also in the storage, the lowest variation of color is produced when sorbitol is used as osmotic agent (Ozen *et al.* 2002; Riva *et al.* 2005; Rodríguez *et al.* 2013). Finally, the color stability during storage leads to the conclusion that drying by combined methods allows preserving plums without important modifications in their appearance.

Texture Evaluation

Figure 4 shows the firmness of samples after drying treatment (OD + HAD). Fresh plums presented a firmness of 0.858 ± 0.282 N/mm. It is observed that the values of firmness ranged between 1.079 and 3.829 N/mm. The lowest value belongs to the samples osmodehydrated in sorbitol at 40% w/w, with a fruit-to-syrup ratio of 1–10, an osmotic temperature at 25C and dried by air at 60C, whereas the highest value corresponds to plums treated in solution of glucose syrup at 40% w/w, with a fruit-to-syrup ratio of 1–4, an osmotic temperature at 25C and then dried by air at 80C.

The firmness of plums increased in comparison with the fresh fruit for all conditions tested. Several authors have studied the changes in the mechanical properties of food

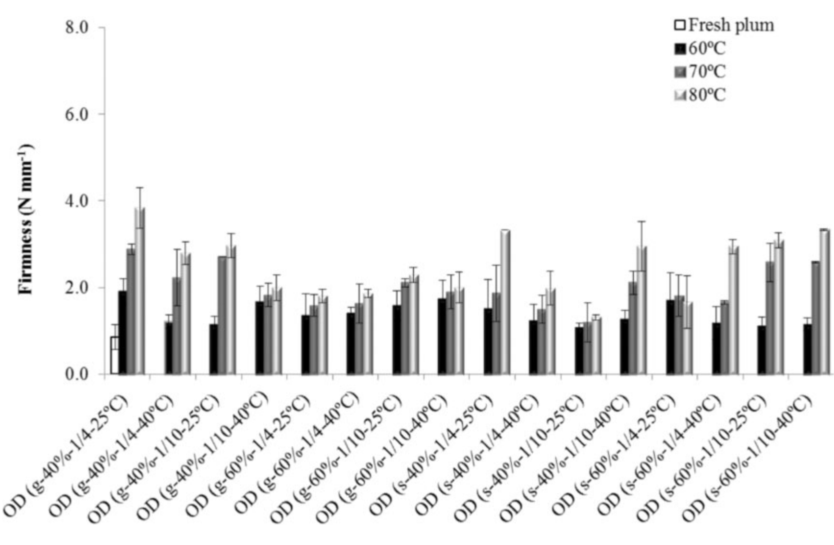

FIG. 4. FIRMNESS OF DEHYDRATED PLUMS BY COMBINED METHODS, GROUPED BY OSMOTIC TREATMENT AND DIFFERENTIATED BY BLACK, GRAY AND WHITE BARS WHEN THE DRYING TEMPERATURE IS 60, 70 OR 80C, RESPECTIVELY
Osmotic agent = g, glucose; s, sorbitol. Concentration of the osmotic agent = 40%; 60%. Fruit/syrup ratio = r1/4 = ratio 1–4; r1/10 = ratio 1–10. Temperature osmotic solution = 25C; 40C. Drying temperature = 60C; 70C; 80C.

during convection drying and, in general, they found that a soft product (fresh) is transformed into a solid (dried). Alternatively, it changed from a predominantly plastic behavior to a more elastic behavior (Telis *et al.* 2005).

When comparing the type of osmotic agent, it is observed that the samples osmodehydrated in glucose syrup present higher firmness than the ones treated in sorbitol, which is important for its moistening properties (Ozen *et al.* 2002; Riva *et al.* 2005).

As for drying temperature, for most conditions, firmness increases in terms of the increment of air temperature. This is because strength and distance in the point of rupture, i.e., firmness, vary according to moisture of the samples; the lower the moisture, the harder the product becomes (higher maximum strength) and shorter (less distance for its rupture), due to the plastifying effect of water (Keqing 2004).

Evaluation of the Rehydration Ability

Figure 5 represent the curves obtained in the rehydration process of plums dried by combined methods under different working conditions. For all conditions, water absorption occurred mostly during the first stages of the rehydration process, decreasing gradually the speed while moisture reaches the equilibrium. These results are consistent with the publications of Keqing (2004) for the rehydration of pears dehydrated by combined methods (OD + HAD) and by Marques *et al.* (2009) during rehydration at 25C of freeze-dried tropical fruits.

From the conditions of the osmotic treatment, it is verified that when the samples were osmodehydrated in sorbitol solution at 40% w/w, with a fruit/solution ratio of 1–4, a higher degree of hydration was obtained. Regarding concentration, Fathi *et al.* (2010) also reported that the rehydration ability of kiwis was higher when osmodehydrated in less concentrated solutions (30% w/w) in comparison with the results obtained in solutions at 60% w/w.

As for the air drying process, it is observed that the rehydration ability decreases with the increment in drying temperature, being rehydration ability slightly higher in plums dried at 60C. The loss in the rehydration ability after drying at high temperatures is related with phenomena of superficial crusting, the collapse of the cell structure and the decrease of the product porosity (Chan *et al.* 2009; Fathi *et al.* 2010). In general, it seems that many conditions that favored dehydration (fruit/solution ratio = 1/10; HAD temperature = 80C), showed by lower values of a_w in plums, hindered later water absorption.

It is evident that the samples did not recover the initial values of water content, being this behavior an indicator of the damage suffered by the product during drying. Also, it can be stated that rehydration is not the inverse process of dehydration (Jamradloedluk *et al.* 2004).

Evaluation of Phenolic Compounds

Figure 6 shows the effect of drying treatment by the combined methods on the total phenol content (A) and flavonoid content (B) compared with fresh plums. The plums that started with an initial content of total phenols of 305.15 ± 60.99 mg gallic acid 100 g/dry solid after combined drying methods (OD + HAD) had values ranging from 114.93 to 688.54 mg gallic acid 100 g/dry solid depending on the experimental conditions. Samples osmodehydrated in solution of glucose syrup 40% w/w, with a fruit-to-syrup ratio of 1–4, a bath temperature osmotic 25C and then air dried at 60C were those that showed less content of total phenols while those osmodehydrated in sorbitol 40% w/w, with a fruit-to-syrup ratio of 1–10, osmotic temperature 25C and then air dried at 80C showed the higher amount of total phenols compared with the fresh plums.

In relation to the drying temperature, it is observed that total phenol content is lower than for fresh fruit when using an air temperature of 60C. Moreover, when plums were dried at 70 or 80C total phenol content was higher than those obtained in fresh plums for most of the tested conditions. Finally, it is observed that plums dried at 70C showed, overall, higher total phenolic content, followed by those dried at 80 and 60C, respectively. The same result was obtained by Yen and Hsieh (1995) and Piga *et al.* (2003).

Regarding flavonoid content, the plums that started with a content of 56.43 ± 18.40 mg catechin 100 g/dry solid, after the combined drying (OD + HAD), values were comprised within the range of 22.64–192.70 mg catechin 100 g/dry solids, depending on the experimental conditions. Samples osmodehydrated in sorbitol solution 40% w/w, with a fruit-to-syrup ratio of 1–4, an osmotic bath temperature of 25C and then air dried at 60C were those that showed less content of flavonoids, whereas those osmodehydrated in glucose 40% w/w, with a fruit-to-syrup ratio of 1–4, a temperature of 25C osmotic solution and then air dried at 70C showed more flavonoids.

In relation to the drying temperature, the same way as for the total phenol content, it is observed that when using a temperature of 60C the content of flavonoids was lower than for the fresh plums for most conditions. Moreover, when dried at 70 or 80C the content of flavonoids was higher than those obtained from fresh plum for most of the tested conditions. These results coincide with the publications of Yen and Hsieh (1995) and Piga *et al.* (2003). Finally, in a comparison between drying temperatures, it is observed that for the same osmotic treatment, plums dried at 70C showed a higher overall content of flavonoids, followed by those dried at 80 and 60C, respectively. These results coincide with those obtained in the determination of total phenols.

A

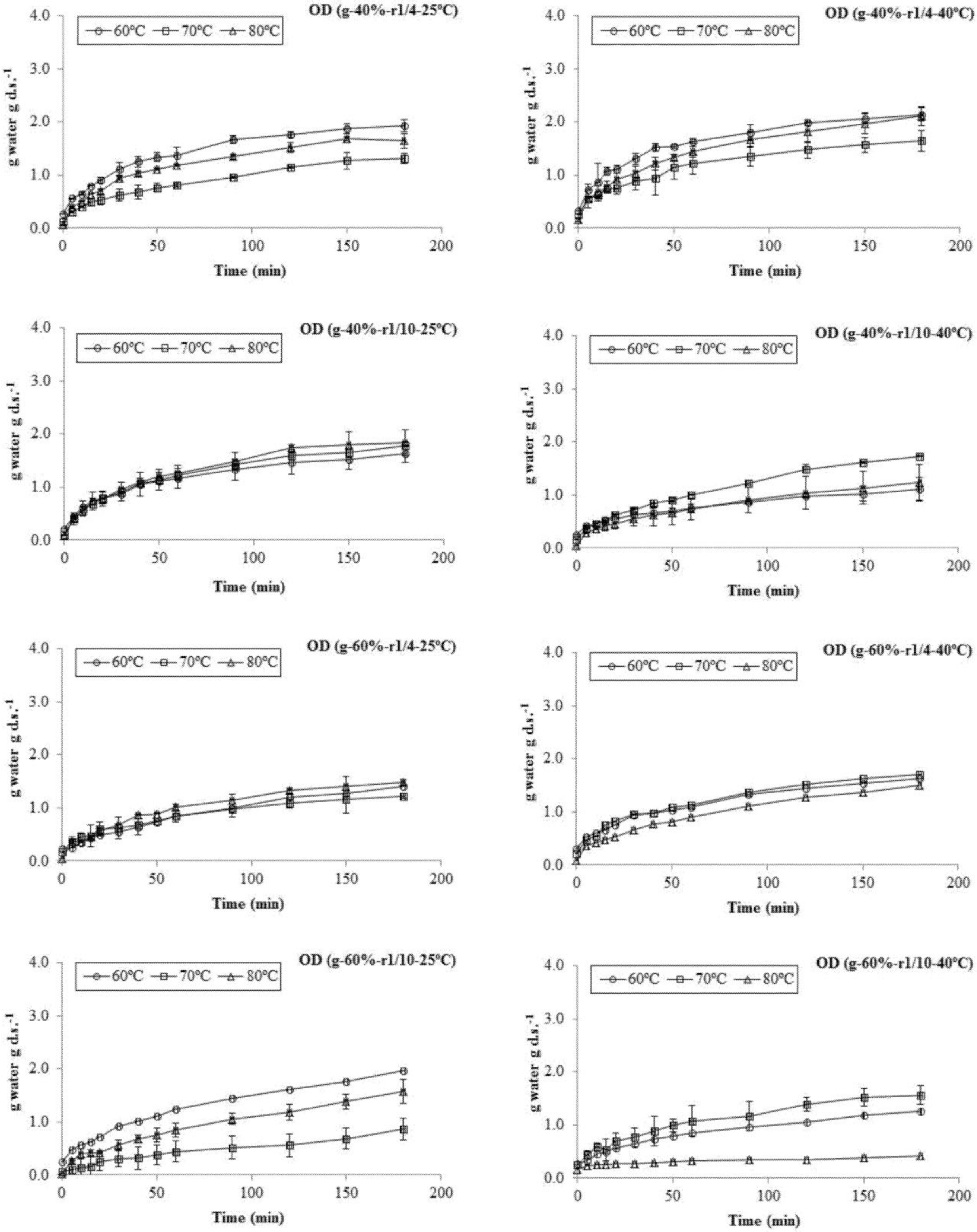

FIG. 5. (A,B) KINETICS OF REHYDRATION OF DRIED PLUMS BY HOT AIR AT 60, 70 OR 80C, GROUPED BY OSMOTIC TREATMENT
Osmotic agent = g, glucose; s, sorbitol. Concentration of osmotic agent = 40%; 60%. Fruit/syrup ratio = r1/4 = ratio 1–4; ratio = r1/10 = ratio 1–10. Temperature osmotic solution 25C; 40C. Drying temperature = 60C; 70C; 80C.

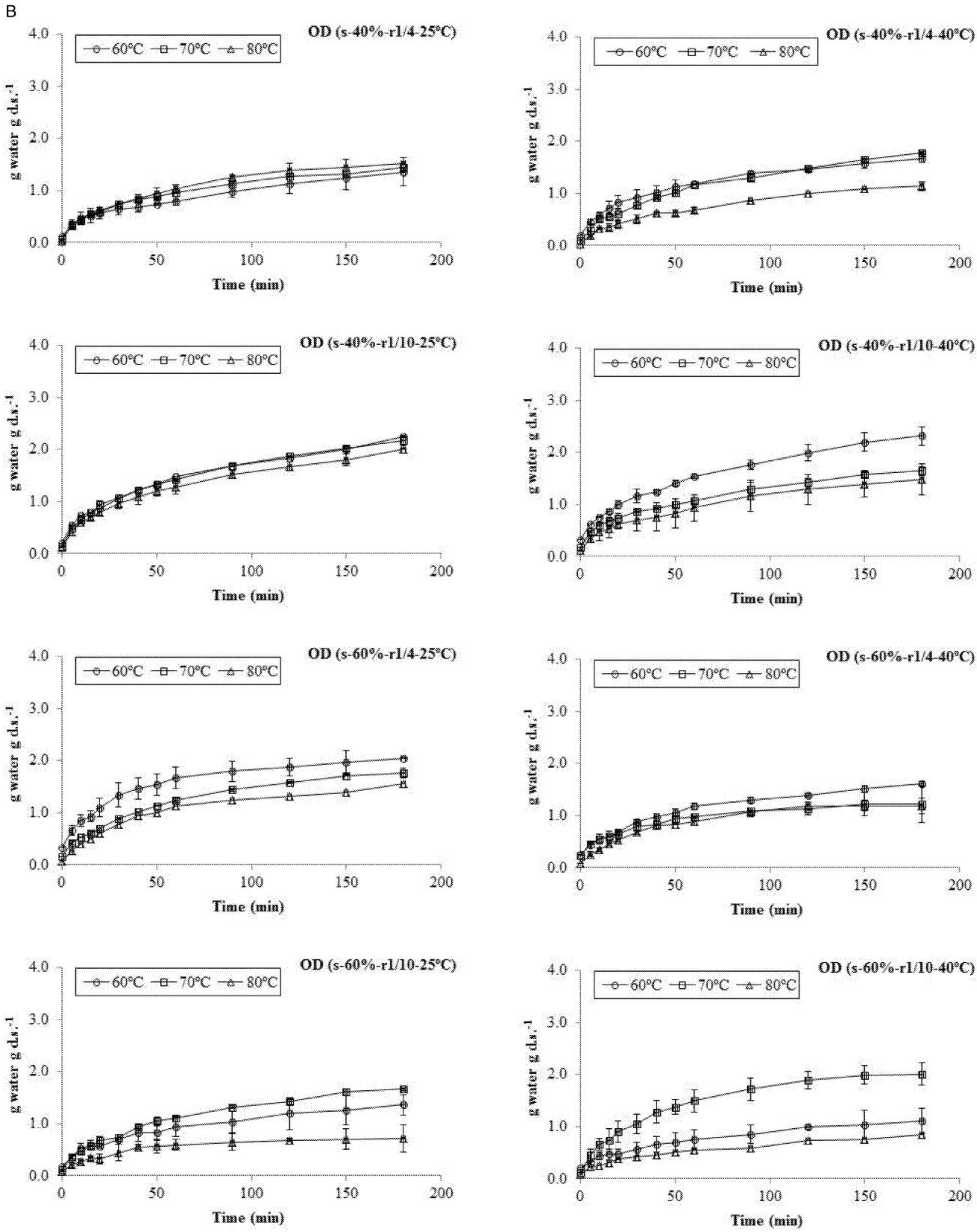

FIG. 5. CONTINUED

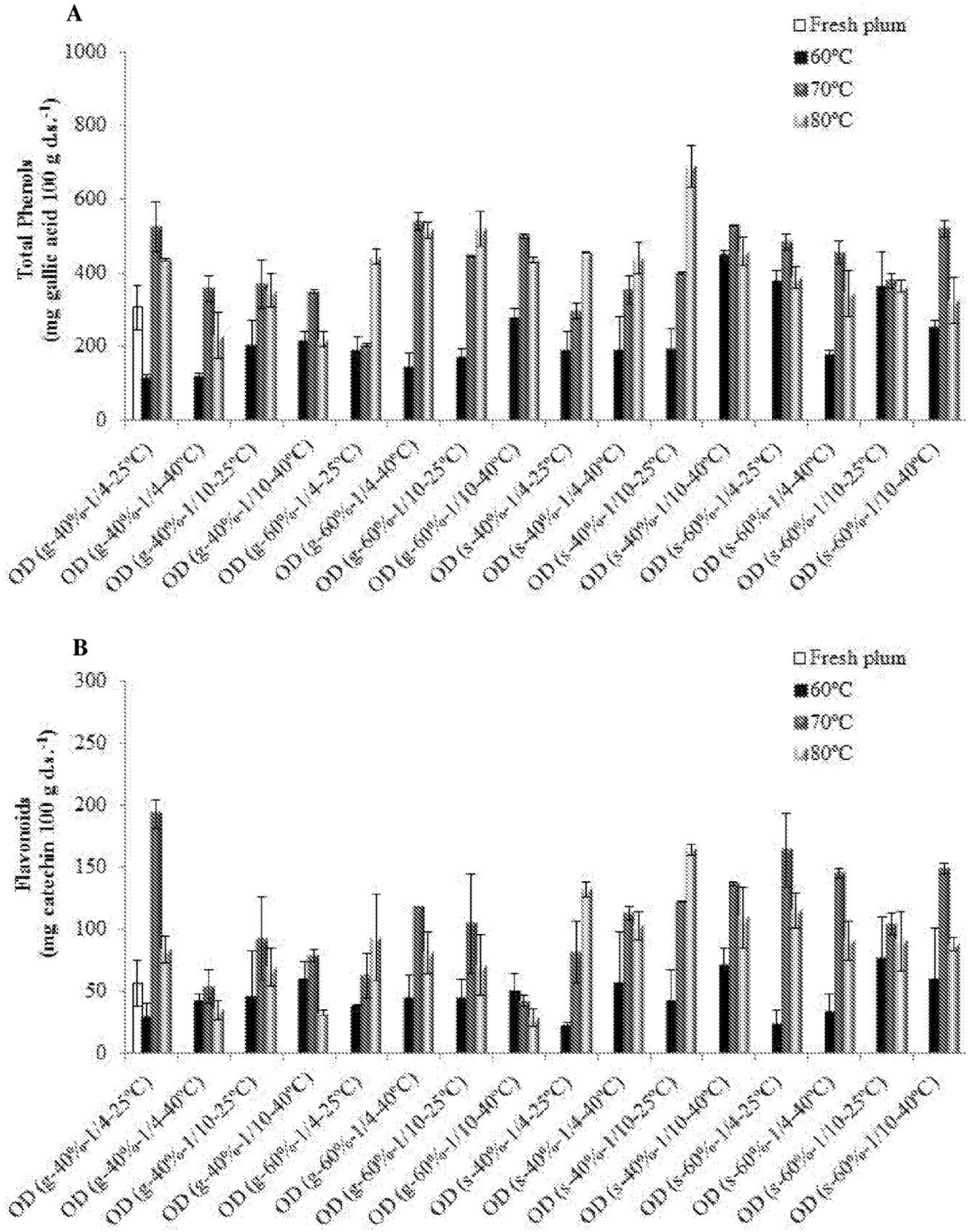

FIG. 6. TOTAL PHENOL (A) AND FLAVONOID CONTENT (B) OF DEHYDRATED PLUMS BY COMBINED METHOD

The cause of the increase of the content of antioxidants in osmo-air dried plums is the generation of caramelization products that have antioxidant properties and, as consequence it, are obtained high antioxidant values. This behavior could be a result of two factors: (1) it is known that polyphenols in an intermediate stage of oxidation initially have greater antioxidant power, but this behavior is temporary and (2) high temperature processes can lead to the formation of new compounds with higher antioxidant activity. This is essentially the case of the Maillard reaction, which derived products are formed by stronger antioxidants as hydroxymethylfurfural (Yen and Hsieh 1995; Piga *et al.* 2003; Ahmad Qasem *et al.* 2013). Moreover, heating weakens cell walls facilitating extraction of antioxidant compounds (Vásquez Parra *et al.* 2013).

Plums dried at 60C have lower phenolic compounds, because at that working temperature, polyphenol oxidase enzymes are active that react on phenolic compounds. Whereas when the process is performed at temperatures higher than 65–70C, polyphenol oxidase enzyme inactivation is achieved preventing degradation of phenolic compounds present in fruits (Piga *et al.* 2003).

Within plum antioxidant compounds, it is known that neochlorogenic acid and chlorogenic acid are predominant in both the polyphenols of fresh fruits such as in those of dried fruits (Nakatani *et al.* 2000; Fang *et al.* 2002). However, gallic acid remains the most widely used as chemical equivalent to determine the total phenol content in broad biological materials due to its satisfactory solubility, good stability, and low cost, among other factors (Chun and Kim 2004).

Optimal Combined Dehydration Conditions

From the earlier results, it follows that the optimum treatment that yielded a higher content of antioxidant compounds was when plums were dried at 70C, regardless of the conditions employed in the osmotic treatment. Also, the use of sorbitol as dehydrating agent had the property to protect the color of fruit that provides a dehydrated product with minimal changes on the organoleptic quality.

CONCLUSIONS

Through the study of different combinations of variables in the combined drying (OD-HAD) of slice plums, it was possible to obtain process conditions, which have achieved a greater degree of dehydration making them stable against microbiological agents and reaction chemical, as well as to obtain products with desirable quality attributes.

With regard to color techniques used, we determined that for heterogeneous samples such as biological systems such as fruits, analysis through imaging allowed a better reproducibility of the data analyzed and it was more appropriate to characterize the appearance of the samples.

Therefore, analyzed all data. It is concluded that the optimal combination of variables to achieve dried plums with high value added are OD in solutions of sorbitol 60% w/w, with a ratio fruit syrup 1 to 10 and a temperature of 25C, followed by air drying at 70C.

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NOMENCLATURE

a	Reddening
a_w	Water activity
b	Yellowing
g	Glucose
HAD	Hot air drying
L	Luminosity
OD	Osmotic dehydration
r1/4	Ratio fruit/solution of 1–4
r1/10	Ratio fruit/solution of 1–10
s	Sorbitol
SG	Solid gain
ΔC	Total variation of color
WL	Water loss
X_0	Initial moisture

REFERENCES

AHMAD QASEM, M.H., BARRAJON CATALAN, E., MICOL, V., CÁRCEL, J.A. and GARCIA PEREZ, J.V. 2013. Influence of air temperature on drying kinetics and antioxidant potential of olive pomace. J. Food Eng. *119*, 516–524.

AIQUAN, J., XUEMING, X. and ZHENGYU, J. 2014. Modelling of dehydration–rehydration of instant rice in combined microwave-hot air drying. Food Bioprod. Process. *92*, 259–265.

ALAKALI, J.S., ARIAHU, C.C. and NKPA, N.N. 2006. Kinetics of osmotic dehydration of mango. J. Food Proc. Preserv. *30*, 597–607.

AOAC. 1980a. *Official Methods of Analysis: 22.013, Moisture in Dried Fruits, 361*, Assoc. of Official Analytical Chemists, Washington, D.C., WA.

AOAC. 1980b. *Official Methods of Analysis: 22.024, Soluble Solids by Refractometer, 363*, Assoc. of Official Analytical Chemists, Washington, D.C., WA.

BADWAIK, L.S., CHOUDHURY, S., BORAH, P.K. and DEKA, S.C. 2012. Optimization of osmotic dehydration process of bamboo shoots in mixtures of sucrose and sodium chloride solutions. J. Food Proc. Preserv. *37*, 1068–1077.

BADWAIK, L.S., CHOUDHURY, S., BORAH, P.K., SIT, N. and DEKA, S.C. 2014. Comparison of kinetics and other related properties of bamboo shoot drying pretreated with osmotic dehydration. J. Food Proc. Preserv. *38*, 1171–1180.

BALASUNDRAM, N., SUNDRAM, K. and SAMMAN, S. 2006. Phenolic compounds in plants and agri-industrial by-products: Antioxidant activity, occurrence, and potential uses. Food Chem. *99*, 191–203.

BARBOSA CÁNOVAS, G.V. and VEGA MERCADO, H. 2000. *Deshidratación de Alimentos* (S.A. Acribia, ed.) p. 296, Zaragoza, España.

CHAN, E.W.C., LIM, Y.Y., WONG, S.K., LIM, K.K., TAN, S.P., LIANTO, F.S. and YONG, M.Y. 2009. Effects of different drying methods on the antioxidant properties of leaves and tea of ginger species. Food Chem. *113*, 166–172.

CHEFTEL, J.C. and CHEFTEL, H. 1992. *Introducción a la bioquímica y tecnología de los alimentos* (S.A. Acribia, ed.) Zaragoza, España.

CHUN, O.K. and KIM, D. 2004. Consideration on equivalent chemicals in total phenolic assay of chlorogenic acid-rich plums. Food Res. Int. *37*, 337–342.

DI RIENZO, J.A., CASANOVES, F., BALZARINI, M.G., GONZALEZ, L., TABLADA, M. and ROBLEDO, C.W. 2008. *InfoStat Versión 2008*, Grupo InfoStat, FCA, Universidad Nacional de Córdoba, Córdoba, Argentina.

DJENDOUBIMRAD, N., BONAZZI, C., COURTOIS, F., KECHAOU, N. and BOUDHRIOUAMIHOUBI, N. 2013. Moisture desorption isotherms and glass transition temperatures of osmo-dehydrated apple and pear. Food Bioprod. Process. *91*, 121–128.

DOYMAZ, I. 2004. Effect of dipping treatment on air drying of plums. J. Food Eng. *64*, 465–470.

FANG, N., YU, S. and PRIOR, R.L. 2002. LC/MS/MS characterization of phenolic constituents in dried plums. J. Agric. Food Chem. *50*, 3579–3585.

FATHI, M., MOHEBBI, M. and RAZAVI, S.M.A. 2010. Genetic algorithm optimization of drying conditions of kiwifruit. 15th International Drying Symposium (IDS 2010), Magdeburg.

FORSIDO, S.F., RUPASINGHE, H.P. and ASTATKIE, T. 2013. Antioxidant capacity, total phenolics and nutritional content in selected Ethiopian staple food ingredients. Int. J. Food Sci. Nutr. *64*, 915–920.

FRANKLIN, M., BU, S.Y., LERNER, M.R., LANCASTER, E.A., BELLMER, D., MARLOW, D., LIGHTFOOT, S.A., ARJMANDI, B.H., BRACKETT, D.J., LUCAS, E.A. *et al*. 2006. Dried plum prevents bone loss in a male osteoporosis model via IGF-I and the RANK pathway. Bone *39*, 1331–1342.

GALLAHER, C.M. and GALLAHER, D.D. 2008. Dried plums (prunes) reduce atherosclerosis lesion area in a polipoprotein E-deficient mice. Br. J. Nutr. *101*, 233–239.

GUINÉ, R.P.F., LIMA, M.J., BARROCA, M.J. and FERREIRA, D. 2010. Analysis of the alterations in the color of pears dried under different systems. 15th International Drying Symposium (IDS 2010), Magdeburg.

HUNTER, R.S. 1975. Scales for the measurements of color difference. In *The Measurement of Appearance* (R.S. Hunter, ed.) pp. 133–140, John Wiley & Sons, New York.

JAMRADLOEDLUK, J., NATHAKARANAKULE, A., SOPONRONNARIT, S. and PRACHAYAWARAKORN, S. 2004. *Modelling of Dehydration and Rehydration Kinetics of Durian*, ICFPTE, The 2nd International Conference on Innovations in Food Processings Technology and Engineering, pp. 267–277, Asian Institute of Technology, Thailand.

KALETA, A. and GÓRNICKI, K. 2010. Evaluation of drying models of apple (var. McIntosh) dried in a convective dryer. Int. J. Food Sci. Technol. *45*, 891–898.

KEQING, D.X. 2004. Optimización del secado por aire caliente de pera (Variedad Blanquilla). Tesis doctoral, Universidad Politécnica de Valencia, Spain.

KHOYI, M.R. and HESARI, J. 2007. Osmotic dehydration kinetics of apricot using sucrose solution. J. Food Eng. *78*, 1355–1360.

MANDALA, I.G., ANAGNOSTARAS, E.F. and OIKONOMOU, C.K. 2005. Influence of osmotic dehydration conditions on apple air-drying kinetics and their quality characteristics. J. Food Eng. *69*, 307–316.

MARQUES, L.G., PRADO, M.M. and FREIRE, J.T. 2009. Rehydration characteristics of freeze-dried tropical fruits. Food Sci. Technol. *42*, 1232–1237.

MEYERS, K.J., WATKINS, C.B., PRITTS, M.P. and LIU, R.H. 2003. Antioxidant and antiproliferative activities of strawberries. J. Agric. Food Chem. *51*, 6887–6892.

MONNERAT, S.M., PIZZI, R.M., MAURO, T.M.A. and MENEGALLI, F.C. 2010. Osmotic dehydration of apples in sugar/salt solutions: Concentration profiles and effective diffusion coefficients. J. Food Eng. *100*, 604–612.

MUDAHAR, G.S., BUHR, R.J. and JEN, J.J. 1991. Infiltrated biopolymers effect on quality of dehydrated carrots. J. Food Sci. *57*, 526–529.

NAGAI, L.Y., BARBOSA SANTOS, A., FARIA, F.A., BOSCOLO, M. and MAURO, M.A. 2015. Osmotic dehydration of mango with ascorbic acid impregnation: Influence of process variables. J. Food Proc. Preserv. *39*, 384–393. doi: 10.1111/jfpp.12243.

NAKATANI, N., KAYANO, S., KIKUZAKI, H., SUMINO, K., KATAGIRI, K. and MITANI, T. 2000. Identification, quantitative determination, and antioxidant activities of chlorogenic acid isomers in prune (*Prunus domestica* L.). J. Agric. Food Chem. *48*, 5512–5516.

ORAK, H.H. 2007. Total antioxidant activities, phenolics, anthocyanins, polyphenoloxidase activities of selected red grape cultivars and their correlations. Sci. Hortic. (Amsterdam) *111*, 235–241.

OZEN, B.F., DOCK, L.L., OZDEMIR, M. and FLOROS, J.D. 2002. Processing factors affecting the osmotic dehydration of diced green peppers. Int. J. Food Sci. Technol. *37*, 497–502.

PAPADAKIS, S.E., ADBULMALEK, S., KAMDEM, R.E. and YAM, K.L. 2000. A versatile and inexpensive technique for measuring color of foods. Food Technol. *54*, 48–51.

PAVKOV, I., BABIĆL, J., BABIĆ, M., RADOJČIN, M. and STOJANOVI, Č. 2011. Effects of osmotic pre-treatment on convective drying kinetics of nectarines halves (*Pyrus persica* L.). J. Proc. Energy Agric. *15*, 217–222.

PIGA, A., DEL CARO, A. and CORDA, G. 2003. From plums to prunes: Influence of drying parameters on polyphenols and antioxidant activity. J. Agric. Food Chem. *51*, 3675–3681.

PIIRAINEN, L., PEUHKURI, K., BÄCKSTRÖM, K., KORPELA, R. and SALMINEN, S. 2007. Prune juice has a mild laxative effect in adults with certain gastrointestinal symptoms. Nutr. Res. *27*, 511–513.

PROTEGGENTE, A.R., PANNALA, A.S., PAGANGA, G., VAN BUREN, L., WAGNER, E., WISEMAN, S., VAN DE PUT, F., DACOMBE, C. and RICE-EVANS, C.A. 2002. The antioxidant activity of regularly consumed fruit and vegetables reflects their phenolic and vitamin C composition. Free Radic. Res. *36*, 217–233.

QUINTERO CHÁVEZ, R., QUINTERO RAMOS, A., JIMÉNEZ CASTRO, J., BARNARD, J., MÁRQUEZ MELÉNDEZ, R., ZAZUETA MORALES, J. and BALANDRÁN QUINTANA, R. 2012. Modeling of total soluble solid and NaCl uptake during osmotic treatment of bell peppers under different infusion pressures. Food Bioprocess Technol. *5*, 184–192.

RIVA, M., CORTELLINO, G., MAESTRELLI, A. and TORREGGIANI, D. 2001. Structure collapse and colour changes in osmo-air-dehydrated peach cubes. Food Sci. Biotechnol. *10*, 598–601.

RIVA, M., CAMPOLONGO, S., AVITABILE LEVA, A., MAESTRELLI, A. and TORREGGIANI, D. 2005. Structure-property relationships in osmo-air-dehydrated apricot cubes. Food Res. Int. *38*, 533–542.

RODRÍGUEZ, M.M., GORI, L., MASCHERONI, R.H. and PAGANO, A.M. 2010. Modeling of dehydration kinetics of European plum (*Prunus domestica* L.) by combined methods. In *IDS 2010, Vol. A, Section II, Fundamentals, Modeling, Simulation, Proceedings of IDS 2010, Oct. 3–6, 2010* (E. Tsotsas, T. Metzger and M. Peglow, eds.) pp. 594–600, Magdeburg, Germany.

RODRÍGUEZ, M.M., ARBALLO, J.R., CAMPAÑONE, L.A., COCCONI, M.B., PAGANO, A.M. and MASCHERONI, R.H. 2013. Osmotic dehydration of nectarines: Influence of the operating conditions and determination of the effective diffusion coefficients. Food Bioprocess Technol. *6*, 2708–2720.

ROMANO, G., ARGYROPOULOS, D., NAGLE, M., KHAN, M.T. and MÜLLER, J. 2012. Combination of digital images and laser light to predict moisture content and color of bell pepper simultaneously during drying. J. Food Eng. *109*, 438–448.

ROMOJARO, A., BOTELLA, A., OBÓN, C. and PRETEL, T. 2013. Nutritional and antioxidant properties of wild edible plants and their use as potential ingredients in the modern diet. Int. J. Food Sci. Nutr. *64*, 944–952.

RUBIO-PEREZ, J.M., VIDAL-GUEVARA, M.L., ZAFRILLA, P. and MORILLAS-RUIZ, J.M. 2014. A new antioxidant beverage produced with green tea and apple. Int. J. Food Sci. Nutr. *65*, 552–557.

RUSS, J.C., STEWART, W. and RUSS, J.C. 1988. The measurement of macroscopic image. Food Technol. *42*, 94–102.

SINGH, G.D., SHARMA, R., BAWA, A.S. and SAXENA, D.C. 2008. Drying and rehydration characteristics of water chestnut (*Trapanatans*) as a function of drying air temperature. J. Food Eng. *87*, 213–221.

SINGLETON, V.L. and ROSSI, J.A. 1965. Colorimetry of total phenolics with phosphomolybdic–phosphotungstic acid reagents. Am. J. Enol. Vitic. *16*, 144–158.

SLEDZ, M., NOWACKA, M., WIKTOR, A. and WITROWA-RAJCHERT, D. 2013. Selected chemical and physico-chemical properties of microwave-convective dried herbs. Food Bioprod. Process. *91*, 421–428.

TARHAN, S. 2007. Selection of chemical and thermal pretreatment combination for plum drying at low and moderate drying air temperatures. J. Food Eng. *79*, 255–260.

TELIS, V.R.N., TELIS-ROMERO, J. and GABAS, A.L. 2005. Solids rheology for dehydrated food and biological materials. Dry. Technol. *23*, 759–780.

TOGRUL, I.T. 2010. Modelling of heat and moisture transport during drying black grapes. Int. J. Food Sci. Technol. *45*, 1146–1152.

VÁSQUEZ PARRA, J.E., OCHOA MARTÍNEZ, C.I. and BUSTOS PARRA, M. 2013. Effect of chemical and physical pretreatments on the convective drying of cape gooseberry fruits (*Physalis peruviana*). J. Food Eng. *119*, 648–654.

VINSON, J.A., SU, X., ZUBIK, L. and BOSE, P. 2001. Phenol antioxidant quantity and quality in foods: Fruits. J. Agric. Food Chem. *49*, 5315–5321.

WEN-CHING, K., WEN-CHIAN, L., YU-TING, T. and CHANG-WEI, H. 2007. Kinetics of winter mushrooms (*Flammulin avelutipes*) microstructure and quality changes during thermal processing. J. Food Eng. *81*, 587–598.

YEN, G.C. and HSIEH, P. 1995. Antioxidative activity and scavenging effects on active oxygen of xylose-lysine Maillard reaction products. J. Sci. Food Agric. *67*, 415–420.

ZHENG, W. and WANG, S.Y. 2001. Antioxidant activity and phenolic compounds in selected herbs. J. Agric. Food Chem. *49*, 5165–5170.

ZIELINSKI, H. and KOZLOWSKA, H. 2000. Antioxidant activity and total phenolics in selected cereal grains and their different morphological fractions. J. Agric. Food Chem. *48*, 2008–2016.

ZOTARELLI, M.F., ALMEIDA PORCIUNCULA, B.D. and BORGES LAURINDO, J. 2012. A convective multi-flash drying process for producing dehydrated crispy fruits. J. Food Eng. *108*, 523–531.