

Effects of Dehydrating Agents on the Physicochemical Properties of Dried Plum (*Prunus salicina* L.) Slices

Min-Sung Kim · Ji-Hoon Kang · Kyung -Sook Chung · Misun Won · Kyung Bin Song*

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Abstract Plum (*Prunus salicina* L.) slices were dehydrated with red algae extract (RAE) at a concentration of 30% (w/w), and the dried samples were compared with maltodextrin (MD)-treated and hot-air dried samples in terms of physicochemical properties such as rehydration ratio, ascorbic acid, microstructure, and color. The rehydration ratios and colors of RAE-treated plum slices were better than those of MD-treated and hot-air dried samples. The ascorbic acid contents of RAE-treated samples were higher and their microstructures were finer than those of MD-treated or hot-air dried samples. These results suggest that plum slices can be dehydrated with RAE without loss of quality.

Keywords dehydration · maltodextrin · plum · quality · red algae extract

Introduction

Plum (*Prunus salicina* L.) is one of popular fruit, and it is a good source of vitamins and minerals. Fresh plums can be dehydrated for long-term storage, and dried plums are easy to be packed and transported. Consumption of dried plum may lower the risk of chronic diseases and relieve constipation, and this effect is mainly associated with biologically active components like phenolic compounds, carotenoids, vitamins C, and dietary fiber that are naturally present in the fruit (Stacewicz et al., 2001).

Fruit is usually dried under sunlight, which is weather dependable and prone to microbial contamination (Mathioulakis et al., 1998),

or hot-air dried, which may cause destruction of nutrients. Thus, it is necessary to develop a new industrial drying process (Goyal et al., 2007).

Molecular press dehydration (MPD), which is based on cytorrhysis phenomenon, is similar to osmotic dehydration (Atarés et al., 2008; Singh et al., 2008), which is a simple method for drying of fruit, except the molecular size of dehydrating agent. MPD occurs outside the plant cell walls, since the size of dehydrating agent like maltodextrin (MD) is larger than the pores of plant cell wall unlike osmotic dehydration (Kim et al., 2009a; 2009b; 2009c). Previous studies suggest that MPD makes dried products better than freeze-drying or hot-air drying in terms of rehydration ratio, texture, and sensory property (Kim et al., 2009a). However, the cost of dehydrating agent like MD can become a problem. Therefore, a new inexpensive dehydrating agent should be developed.

Red algae extract (RAE) such as *Gelidium corneum* is a byproduct of red algae pulp processing (Song et al., 2010), and it contains non-starch polysaccharides like agarose, which can be used as a dehydrating agent at a low cost. Therefore, the objectives of this study were to examine RAE as a dehydrating agent for plum slices, and to compare the dried plum slices with MD-treated and hot-air dried product in terms of rehydration ratio, ascorbic acid content, microstructure, and color of the dehydrated products.

Materials and Methods

Materials. Plum (*P. salicina* L.) samples (6×7 cm, 120–130 g) were obtained immediately after harvest in Okcheon, Korea, and stored at 4°C. Before dehydration, the plums were sliced using a food slicer to ensure uniform thickness (1±0.5 mm). RAE was prepared according to the method of Song et al. (2010). Red algae was extracted with hot water (1:20, w/v) at 120°C for 3 h after the addition of 20% oxalic acid to oxidize, and the extract was lyophilized using a freeze dryer (FD-5508, Ilshin Lab Co, Korea).

M.-S. Kim · J.-H. Kang · K. B. Song
Department of Food Science and Technology, Chungnam National University, Daejeon 305-764, Republic of Korea

K. -S. Chung · M. Won
Medical Genomic Research Center, Korea Research Institute of Bioscience and Biotechnology, Daejeon 305-806, Republic of Korea

*Corresponding author (K. B. Song: kbsong@cnu.ac.kr)

Dehydration process. Plum slices (100 g) were dehydrated at 25°C in low density polyethylene bags containing 30% (w/w) RAE or MD (DE 14-20, Shandong Baolingbao Biotech., China) powder, which was added to the slices, with gentle shaking, respectively. The concentration (30%) of dehydrating agent was chosen based on previous studies (Kim et al., 2009a; Yu et al., 2012) and preliminary study (data not shown). The optimal concentration of 30% was used considering the efficiency of dehydration as well as cost of dehydrating agent. Dehydrated samples were washed with minimal amount of water to remove the adsorbed RAE or MD on the surface, centrifuged at 376×g for 5 min, and then placed in an incubator at 25°C to eliminate any remaining water. For hot-air drying, samples were dried using a hot air dryer (HB-502LP, Hanbaek Co, Korea) at 70°C.

Analysis of moisture content. Samples were weighed and placed in an oven (C-DO, Chang Shin Scientific Co., Korea) at 105±2°C for 24 h until a constant weight was reached.

Measurement of rehydration ratio. Dried samples (1 g) were immersed in 100 mL distilled water at 25°C for 1 h. After rehydration, the samples were drained for 2 min to remove excess water. All samples were weighed under the same experimental conditions. All measurements were carried out in triplicate, and rehydration ratios were calculated as the ratio of grams of water absorbed per sample weight.

Determination of ascorbic acid content. Ascorbic acid contents of samples were determined according to the method of Yurena et al. (2006) with a modification. The samples (1.5 g) were mixed with 2.5 mL of the extracting solution containing 3% metaphosphoric acid and 8% acetic acid, homogenized using a homogenizer (IKA-Werke, Germany) at 5,000 rpm for 1 min, and then centrifuged at 9,000×g at 4°C for 20 min. The supernatant (2 mL) was taken and titrated with indophenol solution until a distinct rose pink color appeared and persisted for more than 5 s. All measurements were performed in triplicate.

Color measurement. The colors of samples were analyzed using a colorimeter (CR-300; Minolta Camera Co., Japan). Samples were placed on a white standard plate, and the Hunter values (L^* , a^* , and b^*) were determined. Each sample was measured 5 times at different locations. The Hunter L^* , a^* , and b^* values for the standard plate were $L^*=96.75$, $a^*=-0.19$, and $b^*=2.00$. The total color difference (E) was defined using the following equation:

$$\Delta E = [(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]^{1/2},$$

where L^* , a^* , and b^* are the measured values of the dehydrated plums, and L_0^* , a_0^* , and b_0^* are the values of the raw plum.

Microstructure analysis. Dried plum samples were fixed and coated with fine aurum powder. The cross section of plum samples was scanned using a scanning electron microscope (LEO 1455VP, Angstrom Scientific Inc., England) at 15 kV.

Statistical analysis. Analysis of variance (ANOVA) and Duncan's multiple range tests were performed to analyze the data using SAS statistical software (SAS Institute, Inc., USA). All results are expressed as mean ± standard deviation.

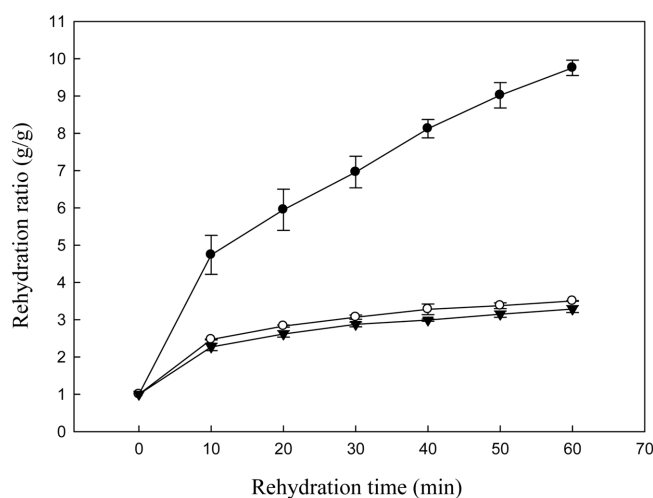


Fig. 1 Rehydration ratio of dried plum slices. Bars represent standard deviation. ●: RAE 30% treated, ○: MD 30% treated, ▼: Hot-air drying

Results and Discussion

Moisture contents of dried plums. The initial moisture content of fresh plum was 91.1 g/100 g. After dehydration, the moisture content of the dried plum was around 10%. The final moisture contents of RAE-treated, MD-treated, and hot-air dried were 10.0, 13.6, and 9.8 g/100 g, respectively, representing that there was not much difference among samples in terms of moisture content of dehydrated plums.

Rehydration ratios of dried plums. Rehydration capacity is an important property of dried plum, because it reflects the molecular structure of the dried product. Rehydration is a diffusion process, where water molecules move from the outside of the cells into the inside, and the rehydration capacities of the samples depend on the dehydration method used (Severini et al., 2005). The rehydration ratios of the dried samples (Fig. 1) were similar to the results of previous reports on apple, persimmon, strawberry, carrot, and ginger slices (Kim et al., 2009a; 2009b; 2009c). The rehydration ratios of RAE-treated samples were higher than those of MD-treated or hot-air dried samples after 10 min of rehydration. After 60 min of rehydration, the rehydration ratios of MD-treated and hot-air dried plums were 3.5 and 3.3 g/g respectively, and significantly lower than those of RAE-treated samples (9.8 g/g), which reflects the water content of fresh plum. This difference is due to the difference in water removal rate depending on the type of dehydrating agent and degree of tissue damage during drying (Prakash et al., 2004). The water removal rate of hot-air drying is very fast, resulting in tissue damage of samples (Korokida and Marinos-Kouris, 2003). These results indicate that MD-treated and hot-air dried samples had low water diffusion through the surface during rehydration (Kim et al., 2009a). As a result, RAE-treated samples had higher rehydration ratios than those of MD-treated or hot-air dried samples, resulting in better preservation of

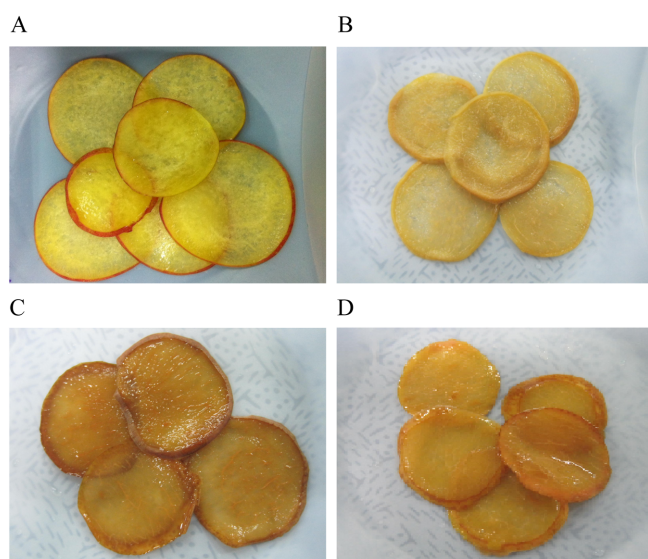


Fig. 2 Photos of plum slices after rehydration. Raw plum (A), RAE-treated plum (B), MD-treated plum (C), hot-air dried plum (D)

Table 1 Ascorbic acid content of dried plum slices

Treatment	Ascorbic acid content (mg/100 g)
Control ¹⁾	62.00±2.83 ²⁾
RAE (30%)	51.94±1.78 ^b
MD (30%)	34.67±1.89 ^c
Hot-air drying	29.50±3.54 ^c

¹⁾Raw plum.

²⁾Means in the same column followed by different letters are significantly different by Duncan's multiple range test ($p < 0.05$).

cellular matrix. In particular, it is apparent that RAE had better efficiency in dehydration of plums than MD, mainly due to different chemical characteristics and molecular weight of RAE. Photos of dried plum slices after rehydration also indicate that RAE-treated samples preserve the quality of fresh plums (Fig. 2). **Ascorbic acid content.** Ascorbic acid contents in fresh and dried plums are shown in Table 1. Ascorbic acid content was 62.0 mg/100 g for fresh plum, whereas they were 51.9 for RAE-treated, 34.7 for MD-treated, and 29.5 mg/100 g for hot-air dried. A similar value, 68 mg/100 g, was reported for fresh plum (Jeong, 2010). Overall, dehydrated plums had lower contents of ascorbic acid compared to the fresh one, but the RAE-treated plums had the highest content of ascorbic acid. The reason for higher amount of ascorbic acid may be attributed to the rapid dehydration by RAE compared to MD, resulting in less loss of ascorbic acid during dehydration. In particular, the lowest ascorbic acid content of hot-air dried samples was mainly due to the destruction of ascorbic acid during hot-air drying (Timoumi et al., 2007).

Microstructure of dried plums. The microstructures of RAE-treated, MD-treated, and hot-air dried plum are presented in Fig. 3. SEM shows that the RAE-treated and MD-treated samples had shrinkage, whereas hot-air dried samples had crack and disturbed surface. In particular, the RAE-treated sample had the least

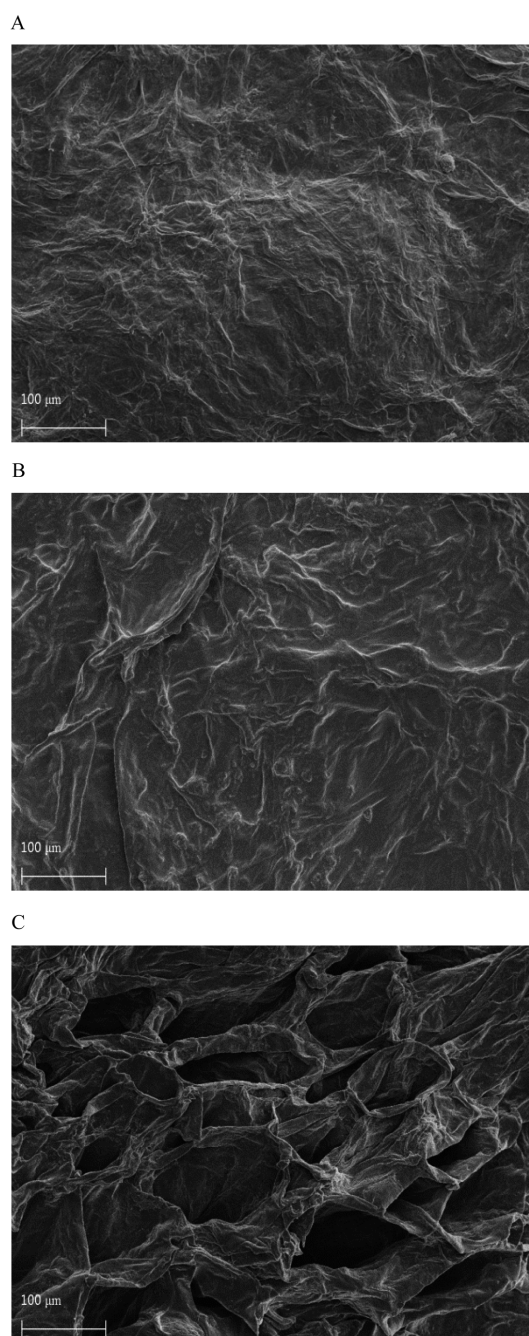


Fig. 3 Scanning electron micrographs of dried plum slices. RAE-treated plum (A), MD-treated plum (B), hot-air dried plum (C)

shrinkage, although it did look similar to the MD-treated. This difference reflects the different rehydration capacity of the dried plums. Hot-air drying usually leads to destruction of tissues and cell wall collapse (Vega et al., 2008; Therdthai and Zhou, 2009). These results could indicate that the RAE-treated sample had the best quality among the dehydrated plums.

Color measurement. Plant tissues can be discolored due to pigment destruction and enzymatic or oxidative browning. The

Table 2 Hunter color values of dehydrated plum slices

	Color parameter			
	L*	a*	b*	ΔE
Control ¹⁾	70.10±0.51 ^{a2)}	-3.01±0.01 ^d	20.70±0.30 ^e	0.00±0.00
RAE (30%)	69.70±0.08 ^a	2.13±0.06 ^c	21.92±0.90 ^b	5.37±0.34 ^c
MD (30%)	60.24±0.56 ^b	2.86±0.27 ^b	22.68±0.80 ^b	11.67±0.17 ^b
Hot-air drying	52.61±0.90 ^c	8.00±0.14 ^a	27.46±0.03 ^a	21.74±0.20 ^a

¹⁾Raw plum

²⁾Means in the same column followed by different letters are significantly different by Duncan's multiple range test ($p < 0.05$).

color parameters of the fresh and dried plum samples were compared (Table 2). There was an unambiguous color difference between the fresh and hot-air dried samples. The Hunter L^* , a^* , and b^* values of fresh plum samples were 70.10, -3.01, and 20.70, respectively. In contrast, hot-air dried samples were 52.61, 8.00, and 27.46. These results indicate that hot-air drying causes dark color due to pigment destruction, which is in good agreement with the results of other studies, where browning causes change in L^* and a^* values (Krokida and Marinos-Kouris, 2003). Similar results were also reported for dried strawberry, persimmon, ginger, and other vegetables treated with maltodextrin (Kim et al., 2009a; 2009b; 2009c). In contrast, RAE-treated samples had less color changes in L^* (69.70), a^* (2.13), and b^* (21.92) values compared to the fresh plums than those of MD-treated or hot-air dried samples. In addition, E value of the RAE-treated samples was 5.4, while MD-treated and hot-air dried samples were 11.7 and 21.7, respectively, resulting in more color change compared to the control.

Overall, the results in the present investigation suggest that RAE is an effective dehydrating agent for plum slices. The physicochemical properties of dehydrated plum slices represent that the plums dehydrated by RAE was the best compared to MD-treated and hot-air dried samples. In particular, RAE-treated plums had better rehydration ratio, which represents good recovery to the fresh plum by rehydration, and higher amount of ascorbic acid as a typical functional component than MD-treated or hot-air dried plums.

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