Hort. Environ. Biotechnol. 53(6):565-570. 2012.
DOI 10.1007/s13580-012-0761-4

Research Report

Dehydration of Blueberries Using Maltodextrin and the Physicochemical Properties of Dried Blueberries

Ho Hyun Chun[1], Min Sung Kim[1], Kyung Sook Chung[2], Misun Won[2], and Kyung Bin Song[1*]

[1]*Department of Food Science and Technology, Chungnam National University, Daejeon 305-764, Korea*
[2]*Medical Genomic Research Center, Korea Research Institute of Bioscience and Biotechnology, Daejeon 305-806, Korea*

*Corresponding author: kbsong@cnu.ac.kr

Received June 3, 2012 / Revised October 26, 2012 / Accepted November 2, 2012

Abstract. Frozen blueberries were dehydrated after treatment with 20, 50, and 80% maltodextrin (MD), and the dried samples were compared with hot-air-dried and freeze-dried samples in terms of the microbial contamination, total anthocyanin content, color, texture, and sensory evaluation. The dried blueberries showed significant reductions in the populations of preexisting total aerobic bacteria. The MD-treated samples had lower contents of total anthocyanins than the freeze-dried samples, but the exudate containing anthocyanins released from the MD-treated samples can be used as a natural additive. The MD-treated samples received a better sensory evaluation than the freeze-dried or hot-air-dried samples. These results suggest that dehydration of blueberries using MD is a very efficient method compared with other methods because of enhanced palatability, good color, and preferable texture.

***Additional key words*:** anthocyanin, drying, quality, storage, texture

Introduction

Drying is one of the oldest techniques of preserving fruit, and dried fruit have many advantages, such as convenience in transportation and storage and minimization of microbial deterioration and chemical reactions by reducing the water content of fruit (Chiewchan et al., 2010). Dried fruit are used in ready-to-eat food processing, and their consumption has increased because of their sweet taste and nutritional value, including phenolic compounds, dietary fiber, and minerals (Dermesonlouoglou et al., 2007). For drying, fruit are usually processed in a heated wind tunnel dryer, a hot-air dryer, or a freeze dryer and then infused with sucrose or high-fructose corn syrup (Sinelli et al., 2011).

Blueberries are popular healthy fruit because they are rich in antioxidants, such as phenolic compounds, anthocyanins, and flavonols (Dragović-Uzelac et al., 2010). Fresh blueberries are harvested from late June to early August in Korea, but they deteriorate rapidly within a few days after harvest because of the high moisture content (up to 85%). Such a short shelf life hinders their market availability (Shi et al., 2008a), making it difficult to supply high-quality blueberries year-round. Thus, to meet the market demand for blueberries, production of frozen or dried blueberries is required to extend shelf life; furthermore, freezing and drying of blueberries preserves the quality when there is surplus of harvest. Because free water in frozen blueberries escapes at a much faster rate than from fresh blueberries, the former require less time to dry than fresh blueberries.

The conventional drying methods, freeze drying (Pan et al., 2008), hot-air drying (Maskan, 2001), and osmotic dehydration (Khin et al., 2007) have been used to remove the water content of fruits. Hot-air drying is a simple process that is applicable to perishable fruits. However, hot-air drying can cause loss of quality, resulting in undesirable flavor, discoloration, and inappropriate surface hardening (Vega-Gálvez et al., 2009). In contrast, one of the major disadvantages of freeze drying is cost because the equipment required is expensive and the process is time consuming and labor intensive (Pan et al., 2008).

An alternative drying method, molecular-press dehydration using maltodextrin, which is mainly based on cytorrhysis, can be used (Kim et al., 2009a). Molecular-press dehydration is similar to osmotic dehydration, but size of the dehydrating

agent is different (Kim et al., 2009a). Plant cells can be dehydrated as they are contracted by the diffusion pressure of the maltodextrin molecules applied to the cell wall in solution; yet, polymers cannot pass through the cell wall because of their large size when plant tissues are exposed to the concentrated maltodextrin solution (Kim et al., 2009b; Wang et al., 2011a). Therefore, maltodextrin is suggested to be an effective dehydrating agent for the dehydration of fruits and vegetables (Kim et al., 2009a, 2009b; Wang et al., 2011a).

The objectives of this study were to investigate the effect of maltodextrin as a dehydrating agent for the drying of blueberries and to compare the physicochemical quality of the product with results obtained following freeze drying or hot-air drying.

Materials and Methods

Sample Preparation

Frozen blueberries (Vancouver, WA, USA) were purchased from a local market and were selected for a uniform weight (1.5 ± 0.5 g). Maltodextrin DE 9-12 (Daesang, Gunsan, Korea) was used as a dehydrating agent.

Drying Process

Frozen blueberries (100 g) were dehydrated at 25℃ for 8 h in a polyethylene terephthalate container containing 20, 50, and 80% (w/w) maltodextrin with gentle shaking. After dehydration, samples were centrifuged at 200 g for 5 min and placed in an incubator at 25℃ to eliminate the remaining water. For freeze drying, samples (100 g) were frozen at -70℃ and lyophilized using a freeze dryer (FD-5508, Ilshin Lab Co., Seoul, Korea) for 48 h. For hot-air drying, the same amount of sample was dried using a hot-air dryer (HB-502LP, Hanbaek Co., Bucheon, Korea) at 70℃.

Analysis of Moisture Content

Moisture content of the dehydrated sample was determined according to the method of AOAC (AOAC, 1990). Samples were weighed and placed in an oven (C-DO, Chang Shin Scientific Co., Seoul, Korea) at 105 ± 2℃ for 24 h until a constant weight was reached. Samples were then cooled to room temperature in a desiccator and weighed. Moisture contents of samples were calculated using the sample weights before and after drying.

Microbiological Analysis

Dried samples (20 g) were placed in 180 mL of peptone water (0.1% sterile peptone, w/v) in a sterile stomacher bag. Samples were then homogenized using a Stomacher (MIX 2, AES Laboratoire, Combourg, France) for 3 min, filtered through sterile cheesecloth, and diluted with peptone water for the microbial count. Serial dilutions were performed in triplicate. Total aerobic bacterial counts were determined by plating appropriately diluted samples onto plate count agar (PCA, Difco Co., Detroit, MI, USA), and a 0.1 mL aliquot of each sample was evenly spread on the surface of the plates using a sterile glass rod. Plates were incubated at 37℃ for 48 h. Each microbial count was the mean of three determinations, and was expressed as log CFU/g.

Determination of Total Anthocyanin and Reducing Sugar Content

Total anthocyanin content (TAC) was determined according to the pH-differential method (Nayak and Rastogi, 2010). Anthocyanins from dried samples were extracted with 80% ethanol containing 0.1% citric acid for 8 h. For the separation of the anthocyanins in the exudates from the MD-dehydrated fruits, exudates were centrifuged at 1,000 g for 15 min, and the supernatant was then filtered through Whatman No. 1 filter paper. Exudates were passed through a C-18 Sep-Pak cartridge (Waters, Milford, MA, USA), prewashed with methanol, followed by 0.01% aqueous HCl (v/v). The anthocyanins were adsorbed onto the Sep-Pak column and washed with two volumes of 0.01% aqueous HCl to remove sugars, acids, and other water-soluble compounds. Anthocyanins were recovered with methanol containing 0.01% HCl (v/v).

Absorbances were measured at pH 1.0 and pH 4.5 using a UV–Vis spectrophotometer (UV-2450, Shimadzu Corporation, Kyoto, Japan). The anthocyanin yield (mg·100 g^{-1}) was then calculated using the following equation and expressed as cyanidin-3-glucoside equivalents:

Total anthocyanin content (TAC) = $A \times MW \times DF \times 100 / \varepsilon$,

where A is A_{510}-A_{700}, MW is the cyanidin-3-glucoside molecular weight (449.2), DF is a dilution factor, and ε is the cyanidin-3-glucoside molar absorptivity (26,900).

Reducing sugar content (RSC) was determined according to the 3,5-dinitrosalicylic acid (DNS) method (Miller, 1959). Two mililiters of sample diluted with distilled water was mixed with 2 mL of DNS reagent, followed by boiling at 100℃ for 5 min. After cooling in ice water, the absorbance at 550 nm was measured. The reducing sugar content (mg·g^{-1}) was expressed as glucose equivalents.

Color Measurement

Colors of the dried samples were analyzed using a colorimeter (CR-300 Minolta Chromameter, Minolta Camera Co., Osaka, Japan). Samples were placed on a white standard plate, and Hunter values (L*, a*, and b*) were determined. The Hunter L*, a*, and b* values for the standard plate were L* = 97.70, a* = -0.07, and b* = 1.86. Three measurements were taken at different locations of each sample.

Instrumental Evaluation of the Texture

A texture profile analysis (TPA) was performed at room temperature using a texture analyzer (TA-XT2, Stable Microsystem Ltd., Godalming, UK) equipped with a flat plate-type probe, P/75. During the TPA test, the following settings were used: pre-test speed of 2.0 mm·s^{-1}, test speed of 5.0 mm·s^{-1}, post-speed of 5.0 mm·s^{-1}, and time between the strokes of 5 s. Each sample was subjected to 60% compression and compressed twice to produce a "two-bite" force-time compression curve. The textural parameters, hardness (g), adhesiveness (g·s^{-1}), and chewiness, were interpreted from the resulting deformation and force responses recorded by the software analysis program (version 1.12, Stable Micro System Ltd.) of the texture analyzer. Each measurement was replicated five times.

Sensory Evaluation

Dried samples were analyzed for their freshness, texture, color, appearance, taste, odor, and overall acceptability by 12 trained panelists. The sensory qualities of samples were evaluated using a 9-point hedonic scale method. Sensory scores were as follows: 9-8, very good; 7-6, good; 5-4, fair; 3-2, poor; and 1, very poor.

Statistical Analysis

Statistical analyses were performed using SAS (SAS Institute, Inc., Cary, NC), and the mean values were compared using Duncan's multiple range tests at the 5% level of significance. Data are presented as the mean ± SD of three replications.

Results and Discussion

To examine the effects of the maltodextrin concentration and treatment time on the dehydration of frozen blueberries, moisture contents of dehydrated blueberries were determined after addition of 20, 50, and 80% MD (Fig. 1). Initial moisture content of the frozen blueberries was 85.92%. During the first 4 h of dehydration, the moisture content of the sample treated with 20% MD decreased rapidly, whereas moisture content of the 80% MD-treated samples indicated that the efficiency of the dehydration was maintained up to 8 h. Dehydration rate also increased with increasing MD concentration. Similar to our results, Wang et al. (2011b) reported that the higher the MD concentration, the better the dehydration efficiency during dehydration of purple sweet potatoes.

Osmotic dehydration using high-fructose corn syrup or sucrose solution is known to have a lower dehydration rate than polyethylene glycol or MD treatment because the concentration difference of the dehydration agent between the inside and outside of the cells was small (Wang et al., 2011a). However, the MD treatment, implementing cytorrhysis, has better dehydration efficiency because of the concentration gradient between the inside and outside of cells, resulting in a decrease of the dehydration time.

After 8 h, moisture contents of dehydrated blueberries treated with 20, 50, and 80% MD were 72.8, 69.7, and 59.9%, respectively, and final moisture contents were 23.6, 25.3, and 26.9% after the further treatment at 25℃, respectively. By comparison, the freeze-dried and hot-air-dried blueberries were in the range of 22.1 ± 0.8%, and a difference might be a result of the barrier formed by maltodextrin on the surface of MD-treated samples causing them to retain moisture. Shi et al. (2008b) reported that sugar-infused blueberries can be dried to have somewhat higher moisture content and a similar water activity than other dried blueberries. When compared to the freeze dried and hot-air dried blueberries, MD-treated samples had a reduced moisture content so that less moisture needed to be removed during drying, leading to a decreased drying time.

Populations of total aerobic bacteria in the dried blueberry samples were significantly decreased by drying (Table 1). Initial population of total aerobic bacteria of the frozen

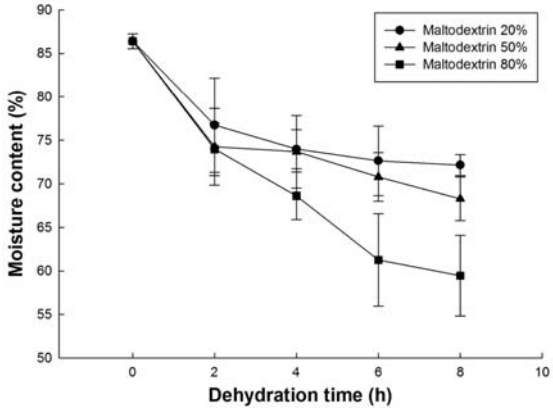

Fig. 1. Moisture content during dehydration of blueberries using maltodextrin at different concentrations. Bars represent standard error.

Table 1. Population of total aerobic bacteria in frozen and dried blueberries.

Samples	Microorganism
	Total aerobic bacteria (log CFU/g)
Control[z]	2.20 ± 0.17a[y]
Maltodextrin 20%	1.58 ± 0.27b
Maltodextrin 50%	1.33 ± 0.30b
Maltodextrin 80%	1.31 ± 0.27b
Freeze drying	1.36 ± 0.10b
Hot-air drying	1.20 ± 0.17b

[z]Frozen bluberry.
[y]Any means in the same column followed by different letters are significantly different ($P < 0.05$).

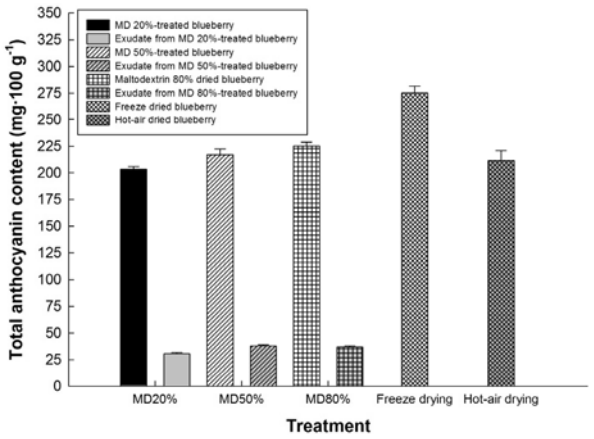

Fig. 2. Total anthocyanin content of the dried blueberries and exudates after different dehydration treatments using MD, freeze drying and hot-air drying. Bars represent standard error.

blueberries was 2.20 log CFU/g (Table 1). Because of the formation of a bacterial biofilm on the surface of fresh blueberries after harvest (Kim et al., 2011), frozen blueberries appear to be more suitable for manufacturing dried blueberries.

Populations of total aerobic bacteria on the 20, 50, and 80% MD-treated, freeze-dried, and hot-air-dried samples were reduced by approximately 1.20-1.58 log CFU/g, indicating a reduction of 0.62-1.0 log CFU/g compared to the control. It is known that drying of foods causes inactivation of microorganisms by decreasing moisture content of the foods (Chiewchan et al., 2010). Considering that 5 log CFU/g is the maximum allowable level of bacteria, these results indicate that drying of blueberries is an efficient method to extend shelf life by inhibiting microbial growth.

Total anthocyanin contents in the dried samples were determined as one of the functional components in blueberries. Total anthocyanin contents of the 20, 50, and 80% MD-treated samples were 203.39, 216.75, and 225.10 mg·100 g^{-1}, respectively, and 275.19 and 211.57 mg for the freeze and hot-air dried samples, respectively (Fig. 2). The 50 and 80% MD-treated samples demonstrated relatively higher total anthocyanin contents compared to hot-air-dried samples.

Table 2. Reducing sugar contents of the MD-treated, freeze dried, and hot-air dried blueberries.

Samples	Reducing sugar content (mg·g^{-1})
Maltodextrin 20%	31.05 ± 0.69ab[z]
Maltodextrin 50%	30.75 ± 0.40b
Maltodextrin 80%	32.64 ± 1.16a
Freeze drying	32.34 ± 0.18a
Hot-air drying	31.53 ± 0.85ab

[z]Any means in the same column followed by different letters are significantly different ($P < 0.05$).

MD-treated samples had lower anthocyanin content than freeze-dried samples mainly due to the release of anthocyanin during the dehydration process. Total anthocyanin content of the exudates from the 20, 50, and 80% MD-treated samples were 30.6, 37.9, and 36.9 mg·100 g^{-1}. As a food colorant, anthocyanins can contribute to the aesthetic value and functional property of foods. Therefore, MD exudates containing anthocyanin can be used as a natural food additive, such as a colorant or functional component (Denev et al., 2010; Dragović-Uzelac et al., 2010). In addition, the hot-air-dried samples exhibited a loss in total anthocyanin content because of exposure to the high temperature. Therefore, our results suggest that MD treatment is a suitable method for drying of blueberries, considering the cost and processing time of freeze drying and the decrease in the total anthocyanin content after hot-air drying.

Regarding the reducing sugar contents in MD-treated, hot-air, and freeze dried samples, they were in the range of 30.8-32.6 mg·g^{-1}, indicating that there were negligible differences among the dried samples (Table 2).

However, there were distinct color differences among the MD-treated, freeze-dried, and hot-air-dried blueberries (Table 3). In particular, L* values of 21.57 and 22.92 in the 50% and 80% MD-treated samples were higher than those of the other dried samples (17.24-19.14), indicating a glossy surface of the MD-treated samples resulting from covering

Table 3. Hunter color values of the MD-treated, freeze dried, and hot-air dried blueberries.

Samples	Color parameter[z]		
	L*	a*	b*
Maltodextrin 20%	17.38 ± 0.32d[y]	0.48 ± 0.05b	0.22 ± 0.10a
Maltodextrin 50%	21.57 ± 0.67b	0.74 ± 0.11b	0.04 ± 0.11a
Maltodextrin 80%	22.92 ± 0.55a	0.55 ± 0.11b	0.07 ± 0.16a
Freeze drying	19.14 ± 0.47c	2.03 ± 0.64a	0.28 ± 0.08a
Hot-air drying	17.24 ± 0.56d	0.63 ± 0.07b	0.28 ± 0.15a

[z]L*, degree of whiteness (0 black to 100 White); a*, degree of redness (-80 greenness to 100 redness); b*, degree of yellowness (-80 blue to 70 yellowness).
[y]Any means in the same column followed by different letters are significantly different ($P < 0.05$).

Table 4. Texture properties of the MD-treated, freeze dried, and hot-air dried blueberries.

Samples	Texture parameter		
	Hardness (g)	Adhesiveness (g·s)	Chewiness
Maltodextrin 20%	1765.10 ± 95.75b[z]	-32.09 ± 9.00b	644.19 ± 4.76c
Maltodextrin 50%	1415.80 ± 63.56bc	-142.02 ± 5.39c	854.54 ± 30.82b
Maltodextrin 80%	1234.69 ± 79.99c	-167.32 ± 20.99c	636.02 ± 7.74c
Freeze drying	730.23 ± 56.92d	-2.55 ± 0.29a	266.34 ± 71.05d
Hot-air drying	6485.69 ± 272.64a	-2.48 ± 0.51a	1201.51 ± 93.72a

[z]Any means in the same column followed by different letters are significantly different ($P < 0.05$).

Table 5. Sensory evaluation of the MD-treated, freeze dried, and hot-air dried blueberries.

Samples	Organoleptic parameter						
	Freshness	Texture	Color	Appearance	Taste	Odor	Overall
Maltodextrin 20%	7.67 ± 0.89a[z]	7.25 ± 1.54a	7.50 ± 1.31a	7.33 ± 1.56b	6.42 ± 1.44b	7.08 ± 1.31a	7.00 ± 0.95bc
Maltodextrin 50%	8.08 ± 0.90a	7.75 ± 1.36a	7.92 ± 1.08a	7.92 ± 1.16ab	6.92 ± 1.31ab	7.33 ± 1.37a	7.75 ± 0.75ab
Maltodextrin 80%	8.67 ± 0.65a	8.17 ± 1.11a	8.75 ± 0.45a	8.58 ± 0.51a	8.00 ± 0.85a	7.58 ± 1.44a	8.42 ± 0.51a
Freeze drying	6.17 ± 1.70b	5.83 ± 1.34b	5.58 ± 1.93b	5.50 ± 1.62c	6.58 ± 1.38b	6.92 ± 1.51a	6.17 ± 1.19c
Hot-air drying	5.50 ± 1.93b	3.92 ± 1.88c	5.67 ± 2.15b	5.83 ± 1.85c	4.83 ± 1.70c	6.42 ± 2.02a	5.00 ± 1.54d

[z]Any means in the same column followed by different letters are significantly different ($P < 0.05$).

of the surface with the dehydrating agent, MD. In addition, a* value of freeze-dried samples was 2.03, whereas the other dried samples were less than l. Freeze-dried samples had higher redness values than other dried samples, whereas the MD-treated and hot-air-dried samples had a dark purple color. Duangmal et al. (2008) reported that a change in the chroma value indicates a change in the amount of anthocyanin. A previous report demonstrated that decreases in a* value reflected the amount of anthocyanins released from the tissue with dehydrating agents (Wang et al., 2011b). Our results are consistent when considering the total anthocyanin content and the change in the a* value of the dried samples.

MD-treated samples showed significant differences in hardness, adhesiveness, and chewiness compared to freeze-dried and hot-air-dried samples (Table 4). Hardness values of the 20, 50, and 80% MD-treated samples were 1765.1, 1415.8, and 1234.7 g, respectively, indicating that hardness decreased as dehydrating agent concentration increased. There was an increase in adhesiveness of the MD-treated samples compared to the freeze-dried and the hot-air-dried samples, indicating more adhesive characteristics after coating surfaces of the samples with maltodextrin. In contrast, hot-air-dried samples showed the highest hardness and chewiness, indicating a very extreme change during the hot-air drying. Conversely, hardness and chewiness of freeze-dried samples were 730.2 g and 266.3 g, which were lower than MD-treated and hot-air-dried samples. Our results are in good agreement with a previous report regarding the pronounced softening of pepper and pumpkin samples by freeze-drying treatments (Guiné and Barroca, 2012), resulting in the lowest hardness and chewiness arising from the sponge-like structure of the fruits. In contrast, during hot-air drying, water was lost rapidly because of the high drying temperature, causing cells to shrink and resulting in high values of hardness and chewiness.

Sensory properties are important for dried blueberries and often directly affect consumer acceptance. The dried samples were evaluated for freshness, texture, color, appearance, taste, odor, and overall acceptability (Table 5). Sensory qualities of the MD-treated samples were visually better than the freeze-dried or hot-air-dried samples (Table 4). In addition, the sensory evaluation results indicate that there are significant ($P < 0.05$) differences among the MD-treated samples. For the 80% MD-treated samples, most of the organoleptic parameters scored greater than 8, except for odor. In contrast, the hot-air-dried samples had the lowest scores for freshness, texture, taste, odor, and overall aspect than the other drying methods. These results are in good agreement with other reports regarding hot-air drying (Kim et al., 2008, 2009a).

MD-treated samples with a dark purple color and proper hardness provided the most acceptable physicochemical properties. In contrast, freeze-dried samples became very brittle and were not preferred by panelists, resulting in lower sensory scores than MD-treated samples. In particular, the MD 80%-treated samples scored 8.17 in the texture rating, indicating that their quality was exceptionally good compared to the hot-air-dried samples. Considering that most of the dried blueberries are commercially subjected to hot-air drying and sugar infusion, MD treatment can be used as an alternative drying method, and the MD-treated blueberries can be used in confectionary or bakery industry.

In summary, MD-treated drying can be used as an alternative drying method. In particular, quality of MD-treated

blueberries was more suitable for color, texture, and sensory evaluation compared with freeze-dried or hot-air-dried samples. In addition, MD exudates containing anthocyanin as a byproduct of dried blueberries can be used as a natural food additive.

Acknowledgement: This research was supported by the joint research project of Agricultural Science and Technology Development (PJ008490042012) through the Rural Development Administration.

Literature Cited

Association of Official Analytical Chemists (AOAC). 1990. Official methods of analysis. AOAC, Washington, DC, USA.

Chiewchan, N., C. Praphraiphetch, and S. Devahastin. 2010. Effect of pretreatment on surface topographical features of vegetables during drying. J. Food Eng. 101:41-48.

Denev, P., M. Ciz, G. Ambrozova, A. Lojek, I. Yanakieva, and M. Kratchanova. 2010. Solid-phase extraction of berries' anthocyanins and evaluation of their antioxidative properties. Food Chem. 123:1055-1061.

Dermesonlouoglou, E.K., M.C. Giannakourou, and P. Taoukis. 2007. Stability of dehydrofrozen tomatoes pretreated with alternative osmotic solutes. J. Food Eng. 78:272-280.

Dragović-Uzelac, V., Z. Savić, A. Brala, B. Levaj, D.B. Kovačevič, and A. Biško. 2010. Evaluation of phenolic content and antioxidant capacity of blueberry cultivars (*Vaccinium corymbosum* L.) grown in the Northwest Croatia. Food Technol. Biotechnol. 48:214-221.

Duangmal, K., B. Saicheua, and S. Sueeprasan. 2008. Color evaluation of freeze-dried roselle extract as a natural food colorant in a model system of a drink. LWT-Food Sci. Technol. 41:1437-1445.

Guiné, R.P.F. and M.J. Barroca. 2012. Effect of drying treatments on texture and color of vegetables (pumpkin and green pepper). Food Bioprod. Process. 90:58-63.

Khin, M.M., W. Zhou, and S.Y. Yeo. 2007. Mass transfer in the osmotic dehydration of coated apple cubes by using maltodextrin as the coating material and their textural properties. J. Food Eng. 81:514-522.

Kim, M.H., M.K. Kim, M.S. Yu, Y.B. Song, W.J. Seo, and K.B. Song. 2008. Drying of green pepper using maltodextrion. Korean J. Food Preserv. 15:694-698.

Kim, M.H., K.S. Kim, Y.B. Song, W.J. Seo, and K.B. Song. 2009a. Characteristics of apple, persimmon, and strawberry slices dried with maltodextrin. J. Food Sci. Nutr. 14:367-372.

Kim, M.H., M.K. Kim, M.S. Yu, Y.B. Song, W.J. Seo, and K.B. Song. 2009b. Dehydration of sliced ginger using maltodextrin and comparison with hot-air dried and freeze-dried ginger. Korean J. Food Sci. Technol. 41:146-150.

Kim, T.J., M.P. Corbitt, J.L. Silva, D.S. Wang, Y.S. Jung, and B. Spencer. 2011. Optimization of hot water treatment for removing microbial colonies on fresh blueberry surface. J. Food Sci. 76:353-360.

Maskan, M. 2001. Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. J. Food Eng. 48:177-182.

Miller, G.L. 1959. Modified DNS method for reducing sugars. Anal. Chem. 31:426-428.

Nayak, C.A. and N.K. Rastogi. 2010. Forward osmosis for the concentration of anthocyanin from *Garcinia indica* Choisy. Sep. Purific. Technol. 71:144-151.

Pan, Z., C. Shih, T.H. McHugh, and E. Hirschberg. 2008. Study of banana dehydration using sequential infrared radiation heating and freeze-drying. LWT-Food Sci. Technol. 41:1944-1951.

Shi, J., Z. Pan, T.H. McHugh, D. Wood, Y. Zhu, R.J. Avena-Bustillos, and E. Hirschberg. 2008a. Effect of berry size and sodium hydroxide pretreatment on the drying characteristics of blueberries under infrared radiation heating. J. Food Sci. 73:259-265.

Shi, J., Z. Pan, T.H. McHugh, D. Wood, E. Hirschberg, and D. Olson. 2008b. Drying and quality characteristics of fresh and sugar-infused blueberries dried with infrared radiation heating. LWT-Food Sci. Technol. 41:1962-1972.

Sinelli, N., E. Casiraghi, S. Barzaghi, A. Brambilla, and G. Giovanelli. 2011. Near infrared (NIR) spectroscopy as a tool for monitoring blueberry osmo-air dehydration process. Food Res. Int. 44:1427-1433.

Vega-Gálvez, A., K.D. Scala, K. Rodríguez, R. Lemus-Mondaca, M. Miranda, J. López, and M. Perez-Won. 2009. Effect of air-drying temperature on physic-chemical properties, antioxidant capacity, color, and total phenolic content of red pepper (*Capsicum annuum*, L. var. Hungarian). Food Chem. 117:647-653.

Wang, S.M., D.J. Yu, and K.B. Song. 2011a. Physicochemical properties of Lotus (*Nelumbo nucifera*) root slices dehydrated with polyethylene glycol. Food Sci. Biotechnol. 20:1407-1411.

Wang, S.M., D.J. Yu, and K.B. Song. 2011b. Quality characteristics of purple sweet potato (*Ipomoea batatas*) slices dehydrated by the addition of maltodextrin. Hort. Environ. Biotechnol. 52:435-441.