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Comparative Quality Assessment of Different Drying Procedures for Plum Fruits (*Prunus domestica* L.)

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Abstract

Samimi Akhijahani H., Arabhosseini A., Kianmehr M.H. (2017): Comparative quality assessment of different drying procedures for plum fruits (*Prunus domestica* L.). Czech J. Food Sci., 35: 449–455.

Different drying methods for plum fruits were compared in this case study. Samples were dried at a temperature of 70°C using the method of hot air drying as well using hybrid solar drying at three levels of air velocity (0.5, 1, and 2 m/s) and open sun drying. The dried samples were then compared on the basis of changes in colour, shrinkage and rehydration. The effect of air velocity on colour change was significant ($P < 0.05$) at the three different levels (0.5, 1, and 2 m/s), whereas effects on shrinkage and rehydration ratio were not significant ($P < 0.05$). The best conditions for plum drying with respect to values of colour change, shrinkage, rehydration ratio and the drying costs were obtained for the plums dried using a hybrid solar dryer at an air velocity of 1 m/s.

Keywords: colour; rehydration; shrinkage; hybrid solar dryer

The plum (*Prunus domestica* L.) is one of the main orchard fruit crops. Dried plums are used to treat liver disease, high levels of uric acid, oral thrush and festering rash. Dried plums soaked in water for half an hour are highly effective for the treatment of constipation. The East Azerbaijan province is the biggest plum producer in Iran. Plums are widely consumed both fresh and after processing, and the production of dried plums, for example, creates job opportunities. Solar drying could be a possible solution for the dehydration of food and agricultural products (Kant *et al.* 2016; Samimi 2016). The main concern of farmers relating to the solar drying method is the long drying process and the low quality of the dried product. The main quality parameters of dried plums on the market are colour, shape (shrinkage) and size. The change in colour in foodstuffs during thermal processing is caused by chemical reactions that take place in the food, such as pigment degradation (especially carotenoids and chlorophylls), browning reactions such as condensation of amino components and oxidation of ascorbic acid (Lozano & Ibarz 1997). The RGB colour model is one of the most widely used models for colour and image processing of dried samples. In this model, each sensor measures separately the colour intensity of red (R), green (G), and blue (B). The final colour parameter values can be used as quality indicators to evaluate deterioration due to thermal processing (Demirhan & Ozbekwhole 2009). The kinetics of colour changes in vegetables and fruits have been studied by various researchers in fruits such as banana, apple, apple slices (Ghasemkhani *et al.* 2016), kiwifruit (Maskan 2001), pineapple puree (Chutintrasri & Noomhorm 2007), basil (Demirhan & Ozbekwhole 2009), and longan (Chunthaworn *et al.* 2012).

Shrinkage is also an important parameter for determining the quality of dried fruits; shrinkage in dried fruit causes a reduction in the quantitative

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and qualitative characteristics of the product such as volume and water absorption. Several researchers have investigated the shrinkage of foodstuffs such as root vegetables (Suzuki *et al.* 1976), kiwi fruit (Maskan 2001), rhubarb (Nikjooy & Jahanshahi 2014), potato (Shekofteh *et al.* 2012), and apple slices (Ghasemkhani *et al.* 2016). Rehydration is a complex process aimed at restoring the properties of raw materials when a dry material comes into contact with water. It has been shown that the swelling of biological materials is often proportional to the amount of absorbed water (Maskan 2001). Rehydration is used for quality determination of dried products and is affected by drying temperature, moisture content and structural compounds (Taiwo & Adeyemi 2009). These factors lead to changes in the structure and composition of plant tissues, such as a reduction in the strength of the cell wall and the loss of solutes (Garcia-Segovia *et al.* 2011). Rehydration kinetics have been studied for various dried products such as banana slices (Taiwo & Adeyemi 2009), apple slices (Ghasemkhani *et al.* 2016), aloe vera (Vega-galves *et al.* 2009), potato (Cunningham *et al.* 2008), mango (Maldonado *et al.* 2010), and tomatoes (Goula & Adamopoulos 2009). In this research the quality parameters, colour, shrinkage and rehydration behaviour of dried plum were investigated under three drying conditions (hot air drying, hybrid solar drying and sun drying).

MATERIAL AND METHODS

Sample preparation. Fresh plums were purchased from a local farm in Azarshahr city, East Azerbaijan province, Iran. The sound and mature plums (Santorize variety grown in North western Iran) were packed and stored in the refrigerator at 5°C; for each experiment, the required amount of plum was taken from the refrigerator, washed in distilled water and placed in an alkaline solution (potassium bicarbonate solution and distilled water at 75°C) for 5 min and then transferred to a sealed container containing sulphur fumes for 12 h (Doymaz 2005). The initial moisture content was found to be 78.3% (w.b) using the AOAC (1984) standard. Three trays,

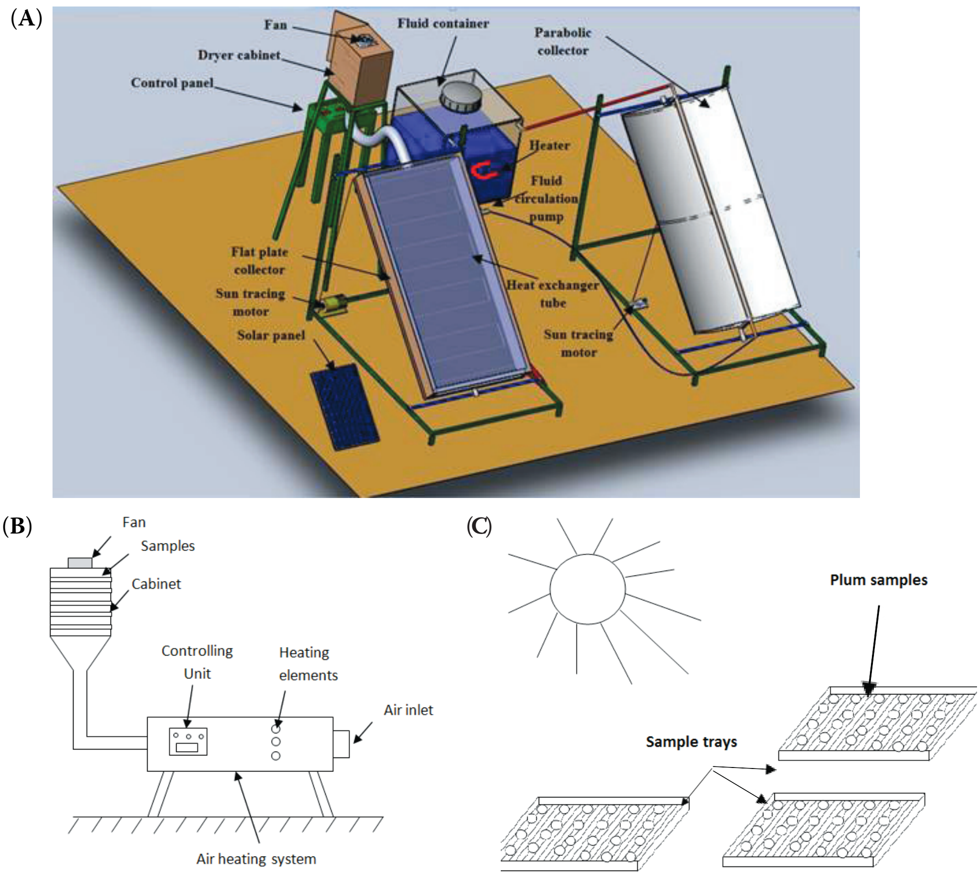

Figure 1. Schematic diagrams of the three plum drying processes: (**A**) hybrid solar dryer, (**B**) hot air dryer, and (**C**) sun drying

doi: 10.17221/440/2016-CJFS

each containing 180 g of sample, were used for the three different methods of drying.

The moisture ratio of plums during the drying experiments was determined using the following Equation 1 (Samimi *et al.* 2016):

$$MR = M/M_0 \quad (1)$$

where: MR – moisture ratio; M – moisture content at any time (kg water/kg dry mater); M_0 – initial moisture content (kg water/kg dry mater)

In the hot air dryer and the hybrid solar dryer, the air velocity was set at three levels of 0.5, 1 and 2 m/s and controlled by a digital anemometer (Yk-2005AM; Lutron, Taiwan) with an accuracy of 0.1 m/s. The schematic diagrams of the hot air dryer, hybrid solar dryer and the sun drying method are shown in Figure 1.

The hot air dryer was installed indoors and the hybrid solar dryer was installed outside so as to be exposed to solar radiation. The relative humidity of the ambient air was measured hourly with a digital hygrometer (HT.3600; Lutron, Taiwan), with an accuracy of 0.1%; values ranged between 18–24% during the day and 56.1–72.4% at night. An automatic temperature controller (DL-9601A; Lutron, Taiwan) with an accuracy of ± 0.1°C was used to set the drying air temperature.

Colour measurement. The difference between the fresh and dried samples was viewed as one of the most important factors in product quality. Colour parameters were determined for the samples dried using the three methods. A 400 × 400 × 600 mm^3

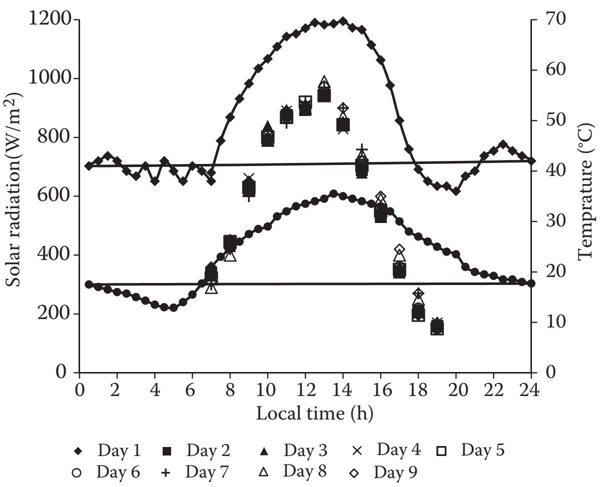

Figure 2. Variation in solar radiation on different experiment days, average ambient temperature and cabinet temperature during the experiment

wooden box with two 23 W fluorescent lamps was used to image the samples (Nadian *et al.* 2015). A digital camera (Canon A3200 IS) with a resolution of 10 mega pixels was used to take pictures. The background was black (Figure 2). Colour image processing was carried out using the Image Processing Tools in Matlab v2013. The changes in RGB colour were calculated using Equation 2:

$$\Delta E_{RGB} = \sqrt{\left((R - R_0)^2 + (G - G_0)^2 + (B - B_0)^2\right)} \quad (2)$$

where: ΔE_{RGB} – colour change of the product; R_0, G_0, B_0 – reference colour parameters for the fresh samples just before drying

The dried products were stored at room temperature under stable conditions for one hour. Five images were captured for each sample.

Shrinkage. The volume change of plums was estimated as the shrinkage and was calculated from dried samples using Equation 3 (Taiwo & Adeyemi 2009):

$$S_b = 1 - V/V_0 \quad (3)$$

For each mode, the samples were weighed using a digital balance with an accuracy of 0.01 g and placed in a beaker containing 200 cc of toluene. The displaced toluene was considered as the volume of the sample before drying (V_0) and after drying (V). Five replicates were performed for each experimental condition.

Rehydration. In order to calculate the rehydration of the samples, about 30 g of dried sample were placed in a beaker (covered by glass wool) containing 200 cc distilled water at boiling temperature for 3 minutes. The dried samples were submerged in distilled water and were withdrawn after specific periods of time (10-min intervals for lukewarm water and 10–15 s intervals for boiling water), blotted with paper tissue and weighed again. The rehydration ratio (RR) was calculated using Equation 4 according to Cunningham *et al.* (2008):

$$RR = W_r/W_d \quad (4)$$

where: W_r – weight (g) of the rehydrated sample; W_d – weight of the dry sample (g)

RESULTS AND DISCUSSION

Figure 3 shows the variation in solar radiation and temperature of ambient air experienced by the plums over the course of the day. As solar radiation increases over the course of the day, values of outlet

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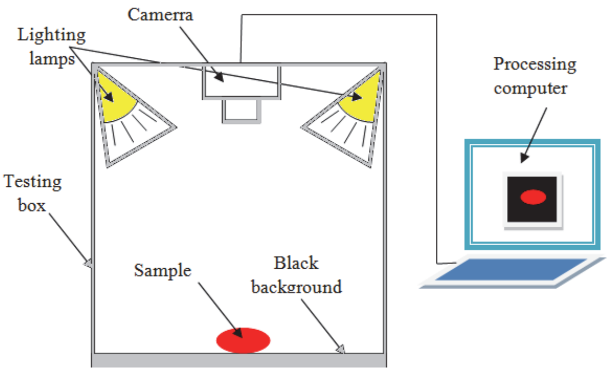

Figure 3. A schematic diagram of the wooden box used for image capturing

temperature increase as well. After sunset, the values decrease and the next element of the hybrid system begins the heating process of the drying cabinet.

Figure 4 shows that in hot air drying mode, 46, 37, and 30 h were required to dry plums at 0.5, 1, and 2 m/s, 88, 52, and 72 h were required at 0.5, 1, and 2 m/s for hybrid solar drying, while 244 h were required for sun drying. The drying time was lower at the air velocity of 1 m/s than at other air speeds in the hybrid solar drying mode. Under these conditions, drying air has relatively more time to contact the absorber plate and to increase air flow temperature; this, in turn, allows the heat and air velocity to dry the plum faster as a result of increasing water molecule temperature. In hot air drying, meanwhile, a low drying time was achieved with an air velocity of 2 m/s, which led to lower contact time with the absorber plate and increasing air flow temperature.

Figure 5 illustrates the variation in colour changes for samples dried by the hybrid solar dryer and hot air dryer at different levels of air velocity as well as sun-dried samples. The statistical analysis showed a significant influence of the drying procedure on colour change ($P < 0.05$). The ANOVA of colour change of the dried samples showed that the effect of air velocity on plum colour change was not significant in either drying mode ($P < 0.05$). The biggest plum colour change (26.13 ± 1.31) occurred in sun drying mode and took about ten days. The changes in colour as a result of longer drying times can either be due to pigment degradation or browning reaction; further, sometimes both processes occur during the dehydration of fruits (Nikjooy & Jahanshahi 2014; Samimi 2016).

For all drying modes, the maximum change in colour was related to the red (R) parameter. As shown in Figure 6, the effect of air velocity on sample shrinkage was not significant ($P > 0.05$). The variation in shrinkage was significant for both the hot air and the hybrid solar dryers ($P < 0.05$). The lowest shrinkage was observed for the hot air dryer and the highest for the sun drying method. The difference in shrinkage between the hot air dryer and the hybrid solar dryer was not significant ($P > 0.05$). The shrinkage values varied from 18.42 ± 1.39% to 19.25 ± 2.14% for the

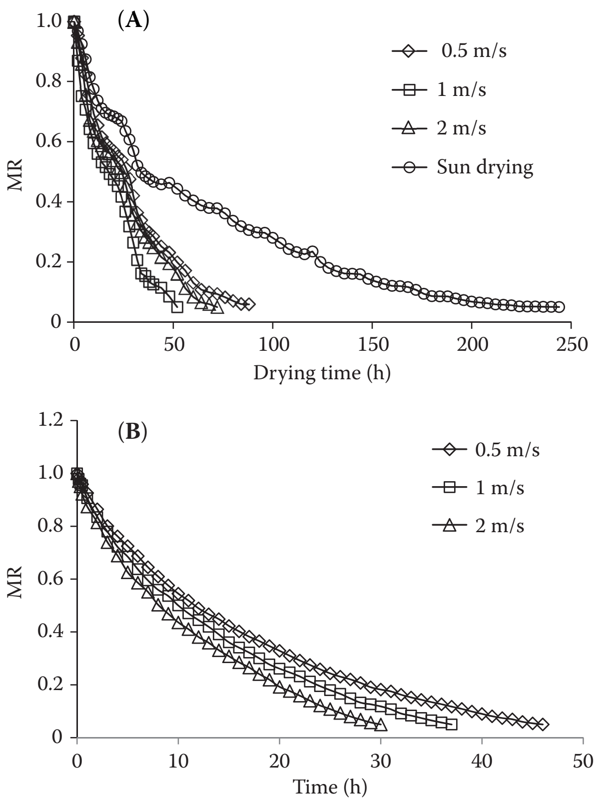

Figure 4. Drying kinetics of plums (moisture ratio versus drying time) in different modes of (A) hybrid solar drying and sun drying and (B) hot air drying at different air velocities

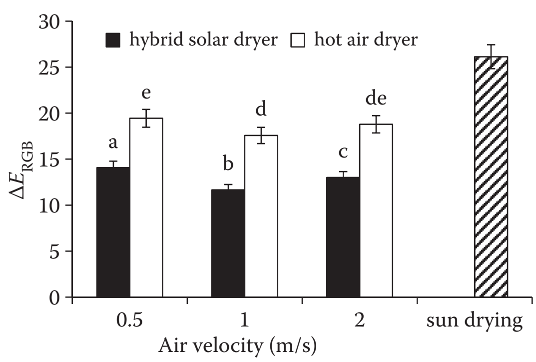

Figure 5. The colour variations of plums dried using different drying methods and different air velocities according to the RGB model

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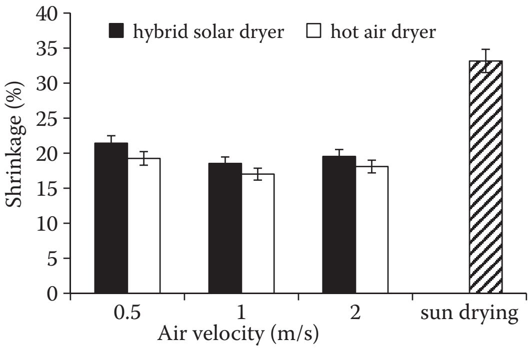

Figure 6. Plum shrinkage variation in response to different drying methods and different air velocities

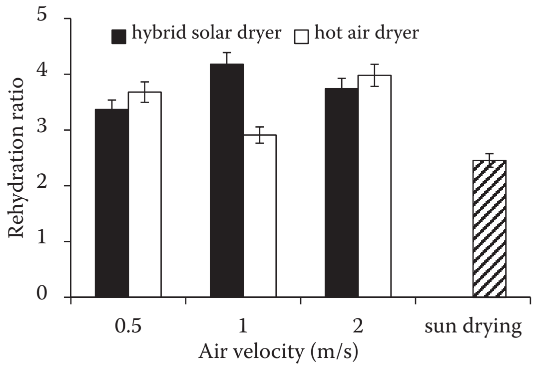

Figure 7. Plum rehydration ratio variation in response to different drying methods and different air velocities

hot air dryer and from 18.53 ± 1.81% to 20.42 ± 2.19% for the hybrid solar drier. At higher temperatures, the drying time was shorter and the materials were less exposed because of thermal effects, meaning that the rate of moisture removal at higher drying temperature was much faster and caused less shrinkage in dried samples (Jokić *et al.* 2009). The shrinkage in observed when using the hot air drying method was lower than for the other methods. Similar results were obtained for the hot air drying of potato (Wang & Brennan 1995), apple slices (Ghasemkhani *et al.* 2016) and rhubarb (Nikjooy & Jahanshahi 2014).

The shape and size of the dried plums significantly differed from fresh plums due to the shrinkage resulting from the removal of large quantities of water. Figure 7 shows that the effect of air velocity on the rehydration of dried plum samples was not significant ($P > 0.05$). In contrast, the drying procedure (hot air drying and hybrid solar drying) significantly influenced the rehydration properties of the plum samples.

The volumes of the dried plums after hybrid solar drying was higher than for the other drying modes. The maximum rehydration value was observed for the samples dried using the hot air-drying mode. The shrinkage of samples occurred faster in the hot air dryer system than in the other drying modes. This is because there are enough pores that absorb water molecules and so allow the fruit to assume its initial shape; in other drying modes, the rehydration was low. It seems that this may be due to damage to the structure and cells of the plums caused by the drying process, and due to the volume shrinkage, which reduces the available intercellular space that can be filled with water (Krokida & Marinos-Kouris 2003). The lowest value of rehydration was observed for the sun drying mode, because the relative humidity of ambient air was high at night and more natural rehydration occurred during the drying period. The rehydration ratio of the samples increased with increasing drying temperature. This could be due to the fact that at higher drying temperatures the samples are dried very fast resulting in less shrinkage. Similar results have been reported for rhubarb (Nikjooy & Jahanshahi 2014), apple slices (Ghasemkhani *et al.* 2016), and banana slices (Taiwo & Adeyemi 2009). The rehydration ratio was reported to be low for natural dried apple, potato, carrot, banana, pepper, garlic, mushroom, onion, leek, pea, corn, pumpkin and tomato (Krokida & Marinos-Kouris 2003).

The colour and shape of the plums dried using the hybrid solar dryer were closer to the original values than plums dried using the other methods; hence, this method is recommended for the drying of plums (Figure 8).

Consumer demand has increased for those processed products that keep more of their original characteristics such as colour and shape. Price is the other parameter that affects consumer decisions. Consumers would like to buy a quality product at an

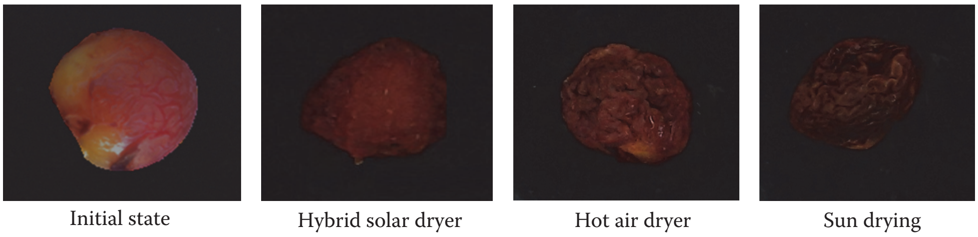

Figure 8. Fresh plums and plums dried using the three different drying modes

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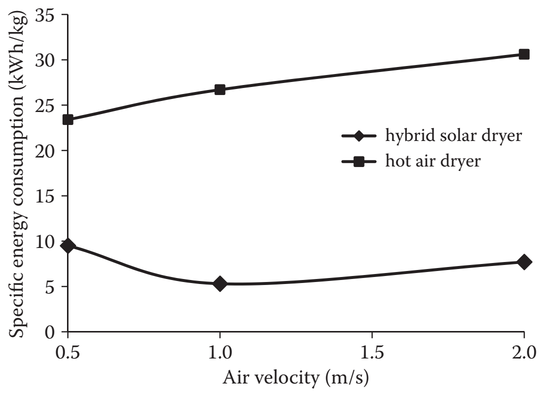

Figure 9. Specific energy required for the drying of plums using different air velocities and two different drying methods

affordable price (Ziotis & Papadas 2011). Table 1 shows the price of dried plums in US dollars per kilogram (USD/kg) for different drying conditions. The price of the dried plums produced using the hybrid solar dryer was higher than when using the other methods. The hybrid solar dryer with an air velocity of 1 m/s was the most expensive method due to the lower drying time, colour change and shrinkage and higher rehydration ratio that are the main factor for selling the dried products. The least expensive method was sun drying.

The total cost of the product is an important factor when determining the price of dried products (Ziotis & Papada 2011). The energies consumed in drying one kilogram of plums using both drying modes at three levels of air velocity are shown in Figure 9. The energy consumed to produce one kilogram of dried plums using hot air drying was much higher than what was required using the hybrid solar dryer. The energy consumed in drying is directly related to the drying time, so for a shorter drying time, the energy consumption is lower. In the hybrid solar dryer at 1 m/s, the drying time is lower than that using other methods; thus, the energy required to dry one kilogram of plums decreases as well (Figure 9). The costs of one kilogram of dried plums (USD/kg) generated using the three different drying conditions are shown in Table 2.

Table 1. Suggested price (USD/kg) of dried plums under different drying conditions

Air velocity (m/s)	Drying mode		
	hot air	hybrid solar	sun
0.5	7.52 ± 0.67	8.33 ± 1.14	
1	8.55 ± 0.13	9.51 ± 0.73	5.42 ± 0.34
2	9.12 ± 0.94	8.73 ± 0.95	

Table 2. Costs of one kilogram of dried plums under different drying conditions

Air velocity (m/s)	Drying model		
	hot air	hybrid solar	sun
0.5	6.45	6.13	
1	7.15	7.01	4.42
2	7.75	6.23	

By comparison of Tables 1 and 2, the hybrid solar dryer was selected as the best mode for producing dried plum fruits. Under these conditions, the price received by the product's manufacturer is ordinarily 2 USD/kg. Also, in addition to producing a marketable product, the use of the hybrid solar dryer ensures that large amounts of electrical energy can be saved.

CONCLUSION

The air velocity showed a significant effect ($P < 0.05$) on the colour change of plum fruits in both hot air and hybrid solar drying methods. The results also showed that air velocity had no significant effect on shrinkage and the rehydration ratio of dried plum fruit either for the hot air drying method or for the hybrid solar dryer ($P < 0.05$). Considering the colour change, shrinkage and rehydration values and the cost of various dried plums, the best condition for drying plums is the hybrid solar dryer at an air velocity of 1 m/s. The open sun drying method resulted in dried plums which were lower in quality than those achieved using other methods, and, therefore, it is not a suitable method for drying plums.

References

Chunthaworn S., Achariyaviriya S., Achariyaviriya A., Namsanguan K. (2012): Color kinetics of longan flesh drying at high temperature. Procedia Engineering, 32: 104–111.

Chutintrasri B., Noomhorm A. (2007): Color degradation kinetics of pineapple puree during thermal processing. Lebensmittel-Wissenschaft & Technologie, 40: 300–306.

Cunningham S.E., McMinn W.A.M., Magee T.R.A., Richardson P.S. (2008): Experimental study of rehydration kinetics of potato cylinders. Food and Bioproducts Processing, 86: 15–24.

Demirhan E., Ozbek B. (2009): Color change kinetics of microwave-dried basil. Drying Technology, 27: 156–166.

doi: 10.17221/440/2016-CJFS

Doymaz I. (2005): Influence of pretreatment solution on the drying of sour cherry. Journal of Food Engineering, 78: 591–596.

Garcia-Segovia P., Andres-Bello A., Martinez-Monzo J. (2011): Rehydration of air-dried Shiitake mushroom (*Lentinus edodes*) caps: comparison of conventional and vacuum water immersion processes. Food Science and Technology, 44: 480–488.

Ghasemkhani H., Keyhani A., Aghbashlo M., Rafiee S., Mujumdar A.S. (2016): Improving exergetic performance parameters of a rotating-tray air dryer via a simple heat exchanger. Applied Thermal Engineering, 94: 13–23.

Goula A.M., Adamopoulos K.G. (2009): Modeling the rehydration process of dried tomato. Drying Technology, 27: 1078–1088.

Jokić S., Mujić I., Martinov M., Velić D., Bilić M., Lukinac J. (2009): Influence of drying procedure on colour and rehydration characteristic of wild asparagus. Czech Journal of Food Sciences, 27: 171–177.

Kant K., Shukla A., Sharma A., Kumar A., Jain A. (2016): Thermal energy storage based solar drying systems: a review. Innovative Food Science and Emerging Technologies, 34: 86–99.

Krokida M.K., Marinos-Kouris D. (2003): Rehydration kinetics of dehydrated products. Journal of Food Engineering, 57: 1–7.

Lozano J.E., Ibarz A. (1997): Colour changes in concentrated fruit pulp during heating at high temperatures. Journal of Food Engineering, 31: 365–373.

Maskan M. (2001): Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. Journal of Food Engineering, 48: 177–182.

Maldonado S., Arnau E., Bertuzzi M.A. (2010). Effect of temperature and pretreatment on water diffusion during rehydration of dehydrated mangoes. Journal of Food Engineering, 96: 333–341.

Nadian M.H., Rafiee S., Aghbashlo M., Hosseinpour S., Mohtasebi S.S. (2015): Continuous real-time monitoring and neural network modeling of apple slices color changes during hot air drying. Food and Bioproducts Processing, 94: 263–274.

Nikjooy S., Jahanshahi S.S. (2014): Effect of hot-air drying conditions on the quality of rhubarb (*Rheum ribes* L.). International Journal of Agriculture and Crop Science, 7: 230–236.

Samimi-Akhijahani H. (2016): Design, construction and evaluation of hybrid solar dryer using fluid circulation. [Doctoral Thesis]. Tehran, University of Tehran.

Samimi-Akhijahani H., Arabhosseini A., Kianmehr M.H. (2016): Effective moisture diffusivity during hot air solar drying of tomato slices. Research in Agriculture Engineering, 62: 15–23.

Shekofteh M., Eskandari-Cherati F., Kamyab S., Hosseinpor Y. (2012): Study of shrinkage of potato sheets during drying in thin-layer dryer. Research Journal of Applied Science Engineering Technology, 4: 2677–2681.

Suzuki K., Kubota K., Hasegawa T., Hosaka H. (1976): Shrinkage in dehydration of root vegetables. Journal of Food Science, 41: 1189–1193.

Taiwo K.A., Adeyemi O. (2009): Influence of blanching on the drying and rehydration of banana slices. African Journal of Food Science, 3: 307–315.

Vega-Galvez A., Notte-Cuello E., Lemus-Mondaca R., Zura L., Miranda M. (2009): Mathematical modelling of mass transfer during rehydration process of aloe vera (*Aloe barbadensis* Miller). Food and Bioproducts Processing, 87: 254–260.

Wang, N., Brennan, J.G. (1995). A mathematical model of simultaneous heat and moisture transfer during drying of potato. Journal of Food Engineering, 24: 47–60.

Ziotis N., Papadas T. (2011): Supply of money and food prices: the case of Greece. Agricultural Economics Review, 12: 36–44.

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