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Research Article

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Influence of drying methods on the functional properties of dietary fiber

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ABSTRACT

Citrus by-products are an important potential high source of valuable compounds such as dietary fiber. In this study, dietary fiber was obtained from citrus by-products by water bath extraction. The drying behavior of the citrus by-product samples was investigated under hot-air drying and vacuum drying. The drying experiments were conducted at drying air temperatures of 50, 60, and 70 °C. The drying curves obtained using experimental data were fitted to 10 models reported in literature. The comparison of the correlation coefficient (R^2) and reduced chi-square (χ^2) values of the 10 models shows that the Logarithmic model exhibited the best fitting for hot-air drying, whereas the Wang and Singh model exhibited the best prediction of moisture transfer in vacuum drying. The changes in color and functional properties of the two types of dried dietary fiber were also analyzed and regarded as quality indices that affect the drying quality of the product.

Key words: citrus by-products, dietary fiber; hot-air drying, vacuum drying, functional properties, color

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Nomenclature

a, b, c, k, n, L	constants in models	R^2	coefficient of determination
MR	dimensionless moisture ratio	*t*	drying time, min
M	moisture content, % dry basis	*z*	number of constants
M_e	equilibrium moisture content, % dry basis	*N*	number of observations
M_0	initial moisture content, % dry basis		
L^*	degree of lightness	Subscripts	
a*	degree of redness	exp	experimental
b*	degree of yellowness	pre	predicted

INTRODUCTION

Citrus by-products are some of the solid wastes produced every year by the citrus processing industry. The disposal of these by-products poses extensive environmental problems. Consequently, considerable emphasis has been placed on the recovery, recycling, and upgrading of waste products. Citrus by-products are interesting raw materials that have attracted much attention as a potential sugar, dietary fiber (DF), pectin, and phenolic source (Mark 2009).

DF acts as a bulking agent, normalizing intestinal motility and preventing diverticular disease. Substantial efforts have also been devoted to research on the incidence of a number of non-infectious diseases common in civilized societies: such diseases include coronary heart disease, which can be attributed to a low DF intake. Some types of DF may also be important in reducing colon cancer, lowering serum cholesterol levels, and preventing hyperglycemia in diabetic patients (Garau et al. 2007). In recent years therefore, diverse products containing significant amounts of DF have been developed. The importance of DF in the diet has led to the search for new DF sources that can be used as food ingredients. DF is desirable not only for its nutritional aspects but also for its

functional and technological properties (Schieber et al. 2001). Being aware of the processing history of fiber concentrates is important, particularly the ability of the fiber matrix to maintain its physical properties after it is processed.

Drying has become a widely used food processing method because it enables the extension of the shelf life of fruits and vegetables. However, processing may cause irreversible modifications to cell wall polysaccharides, affecting their original structure. This may induce important changes in the proposed physiological and pharmacological properties of these polymers. Therefore, the final quality of dried by-products is determined by the structural and compositional modifications that may have occurred during the drying treatment (Garau et al. 2007).

Hot-air drying is an ancient process used to preserve food. It enables the production of dehydrated products with an extended shelf life of up to a year. Unfortunately, the quality of a conventionally dried product is usually drastically reduced from compared with that of original foodstuff. Vacuum drying is a unit operation in the chemical and engineering process, in which moist material is dried under sub-atmospheric pressures. The lower pressure enables the reduction of drying temperature and higher quality compared with the classical air conventional process at atmospheric pressure (Arevalo-Pinedo et al. 2006).

The main objectives of the present study are to compare hot-air drying and vacuum drying in terms of process–quality interaction and drying kinetics, as well as evaluate the effects of dehydration on the composition and functional properties of DF obtained from by-products derived from orange fruit processing (orange peel and remaining orange pulp after juice extraction).

EXPERMENTAL SECTION

Sample preparation

Samples of Jincheng Sweet Orange Fruit (Citrus sinensis Osbeck) were obtained from an orchard in the Hubei Province, China. Jinchen Sweet Orange Fruit is commonly used for juice production. Fresh juice by-products (including the peel and remaining pulp), left over after oil and juice extraction, were mixed with a uniformity homogenate and kept in a refrigerator at 4 °C (24 h) before treatment.

Dietary fiber preparation

Citrus by-product (10.00 ± 0.05 g) was mixed with water in a solid–liquid ratio of 1:3, and stirred with a glass stirrer every 5 min in a water bath at 90 °C for 2 h. The extract was filtered through a Whatman No. 1 filter paper. The filtrate was concentrated to 30 mL using a rotary evaporator at 50 °C under vacuum. The concentrate and filter residue were added into a quadruple volume of 95% alcohol and left to stand for 30 min. The deposit was then collected and dried. Prior to further analysis, the DF was milled using a laboratory-type grain mill and passed through a 0.45 mm aperture sieve. (Navarini et al. 1999).

Dryer and drying procedure

(1) Hot-air dying

Hot-air drying experiments were performed in a cabinet-type dryer. The dryer is made of stainless steel sheets formed into a rectangular tunnel with dimensions of 0.6 m × 0.6 m × 1.0 m. The drying tray has an area of 0.5 m × 0.5 m. The dryer was operated at dry bulb temperatures of 0–120 °C. It was adjusted to the selected temperature for about half an hour before the start of the experiment to achieve steady state conditions. After the samples were spread in a single layer on a tray in the dryer, they were dried at 50, 60, and 70 °C with 15% relative humidity and 1.2 m/s air velocity. This air velocity was used to minimize external resistance to mass transfer from the sample surface to the air steam. (Saravacos et al. 2001)

Weight changes in the control and prepared peels and pulp during the drying process were monitored automatically at intervals of 10 min using a digital balance (0.001 g). The samples were dried for 600 min, the period selected from exploratory runs. The drying experiments were carried out in triplicate with peels and pulp obtained from different samples (oranges) to include the variability between the samples. Drying was discontinued when the moisture content of the samples reached 10% (w/w). The product was cooled and packed in low density polyethylene bags, which were then heat sealed. The experiments were repeated three times and the average of the moisture ratio at each value was used to draw the drying curves.

(2) Vacuum drying

Vacuum drying experiments were also performed in a cabinet-type dryer. The equipment was designed to allow for various temperatures and pressures inside the drying chamber as well as various sample shapes and sizes. Vacuum conditions were maintained by a vacuum pump and monitored from a manometer. Two steel plates heated by an

electric resistance lodged between them provided the thermal energy. An automatic regulator controlled the temperature of the plates (Arevalo-Pinedo et al. 2006). For different experiments, the plate temperature was varied at 50, 60, and 70 °C, and the pressure of the chamber was set at 0.7 kPa. Follow-up operations are described in "Dryer and drying procedure (1)".

Theoretical basis

(1) Mathematical modeling

Effectively modeling drying behavior is important in investigating the drying characteristics of DF from citrus by-products. In this study, experimental drying data (both from hot-air and vacuum drying) on DF at different temperatures were fitted to 10 commonly used drying models (see Table 1). In these models, MR represents the dimensionless moisture ratio, that is, $MR = (M - M_e)/ (M_0 - M_e)$, where M is the moisture content of the product at each moment, M_0 is the initial moisture content of the product, and M_e denotes the equilibrium moisture content. The M_e values are relatively small compared with those of M or M_0 for long drying peridos. Thus, $MR = (M - M_e)/ (M_0 - M_e)$ can be simplified into $MR = M/M_0$ (Akgun and Doymaz, 2005).

(2) Correlation coefficients and error analyses

The goodness-of-fit between the tested mathematical models and experimental data was evaluated using the correlation coefficient (R^2), reduced (χ^2), and the root mean square error (*RMSE*). The higher the R^2 values and the lower the χ^2 and *RMSE* values, the better the goodness-of-fit (Ertekin and Yaldiz, 2004). The reduced χ^2 and *RMSE* values can be calculated as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{\exp,i} - MR_{pre,i})^2}{\text{N-z}} \quad \text{(A)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (MR_{pre,i} - MR_{\exp,i})^2} \quad \text{(B)}$$

where $MR_{exp,i}$ is the ith experimental moisture ratio, $MR_{pre,i}$ denotes the ith predicted moisture ratio, N represents the number of observations, and z is the number of constants (Wang et al. 2007 and Kaya et al. 2008). In this study, the nonlinear or linear regression analysis was performed with the statistical software, Matlab 7.6.0 (2008a).

Analytical methods

Total dietary fiber (TDF), soluble dietary fiber (SDF), and insoluble dietary fiber (IDF) contents were determined by enzymatic gravimetric method (AOAC, 2000). Triplicate samples were gelatinized with heat stable a-amylase, and digested with protease and amyloglucosidase to remove the protein and starch present in the samples. The undigested crude protein and ash contents were determined for corresponding corrections.

Crude fat was determined according to method (960.39 of AOAC, 2000); Crude protein was by Kjeldahl procedure method (total nitrogen × 6.25) (928.08 of AOAC, 2000); Ash was determined according to method muffle oven technique (920.153 of AOAC, 2000).

Color measurement

Color changes in samples were analyzed by measuring their reflectance using a colorimeter (Juki, JP7100, Tokyo, Japan). The color values were expressed using CIE Lab^* coordinates, where L^* represents luminosity (0 = black; 100 = white), a^* redness ($a^* > 0$) or greenness ($a^* < 0$), and b^* blueness ($b^* > 0$) or yellowness ($b^* < 0$). Each sample was measured 10 times and the result was presented as the average.

Functional properties

(1) Water retention capacity (WRC) and oil holding capacity (OHC)

WRC is expressed as the mL of water/g of dry fibrous residue powder, and was determined by centrifugation as described elsewhere (Jiménez et al. 2000) with slight modifications. The samples (2.00 g ± 0.02 g) were suspended in water (50 mL) (Jiménez, et al., 2000). After 24 h of equilibration at room temperature (approximately 25 °C), the suspension was centrifuged at 4,200 r/min for 15 min. The supernatants were discarded and the hydrated samples were weighed.

OHC is expressed as the mL of oil/g of dry fibrous residue powder, and was determined under the same conditions as those for WRC using soybean oil (0.925 g/mL density) (Lou, et al. 2009).

(2) Swelling capacity (SWC)
A sample (2.00 g ± 0.02 g) was added into a calibrated cylinder (2 cm diameter), which was hydrated with 30 mL of distilled water at room temperature (approximately 25 °C) for 24 h. The change in volume was recorded and expressed as the volume/g of the original sample (dry weight).

RESULTS AND DISCUSSION

Drying procedure

(1) Comparison of the drying characteristics of hot-air drying and vacuum drying
The moisture ratios versus drying time for the hot-air drying and vacuum drying are shown in Figs. 1 and 2, respectively. The total drying times consumed to reach the final moisture content for the hot-air drying samples were 590, 340, and 190 min at 50, 60, and 70 °C, respectively. Those for the vacuum drying samples were 330, 230, and 160 min at 50, 60, and 70 °C, respectively. Within a certain temperature range (50-70 °C in this study), increasing temperature accelerates the drying process, thereby shortening the drying time. This result is similar to those obtained for drying orange by-products (Garau et al. 2007 and Doymaz 2009).

As can be seen from Fig. 1, it took 110, 80, and 50 min at 50, 60, and 70 °C, respectively, to remove the last 40% of moisture content (wet basis) in the hot-air drying of citrus by-products DF, whereas vacuum drying took only 80, 60, and 40 min (Fig. 2). In comparison with the two drying methods, the drying times in vacuum drying for the removal of the same percentage moisture (40%, wet basis) decreased by 27.27 %, 25.00 %, and 20.00 %. Andrés et al. (2004) observed that hot-air-dried samples present a porous structure and cell walls considerably shrink, leaving wide spaces between neighboring cells. Vacuum-dried samples also reveal a porous structure but these pores are much smaller, and the tissues appear unchanged compared with hot-air-dried samples. Therefore, we can conclude that because of the effect of high temperatures, cell membranes denaturize and phase transitions occur, so that the microstructure of citrus by-products DF treated by hot-air drying is substantially damaged. The bond water in damaged tissues is more easily removed with vacuum drying compared with that in less damaged tissues.

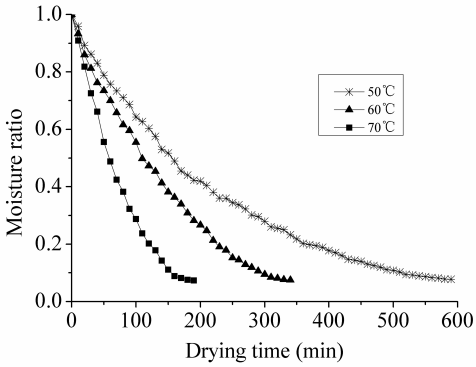

Fig. 1 Hot-air drying curves of citrus juice by-products at different temperature

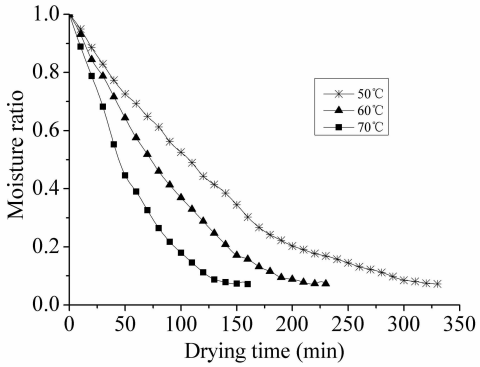

Fig. 2 Vacuum drying curves of citrus juice by-products at different temperature

This illustrates that increasing the drying temperature can enhance the drying rate and decrease the drying time of DF samples. This result agrees with an earlier study on the drying of various vegetables and fruits, such as Thompson seedless grapes, apricots, and carrots (Xiao et al. 2010).

(2) Fitting of the drying curves

The moisture content data observed for the hot-air drying and vacuum drying of the citrus by-products DF were converted into moisture ratio (*MR*) and fitted to the 10 models listed in Table 1. The statistical regression results for the different models, including the drying model coefficients and comparison criteria used to evaluate goodness-of-fit (i.e. R^2, χ^2, and *RMSE*), are listed in Tables 2 and 3. In all cases, the R^2 values were higher than 0.98, whereas the χ^2 and *RMSE* values were lower than 3.58×10^{-3} and 0.04059, respectively. For the hot-air drying samples (Table 2), the Lewis and Logarithmic R^2 values were greater than 0.993, and the corresponding χ^2 and RMSE values were lower than 1.06×10^{-3} and 0.02917, respectively, indicating that the two models fit well with the experimental data.

Table 1 Mathematical models given by various authors for drying curves

No.	Model name	Model	References
1	Lewis	$MR = \exp(-kt)$	Bruce (1985) [24]
2	Page	$MR = \exp(-kt^n)$	Page (1949) [25]
3	Modified Page	$MR = \exp[(-kt)]^n$	White et al. (1981) [26]
4	Henderson and Pabis	$MR = a\exp(-kt)$	Henderson and Pabis (1961) [27]
5	Logarithmic	$MR = a\exp(-kt) + c$	Togrul and Pehlivan (2002) [28]
6	Two-term model	$MR = a\exp(-k_0t) + b\exp(-k_1t)$	Henderson (1974) [29]
7	Approximation of diffusion	$MR = a\exp(-kt) + (1-a)\exp(-k\,b\,t)$	Yaldiz et al. (2001) [30]
8	Wang and Singh	$MR = 1 + at + bt^2$	Wang and Singh (1978) [31]
9	Simplified Fick's diffusion	$MR = a\exp(-c(t/L^2))$	Diamante and Munro (1991) [32]
10	Modified Page equation-II	$MR = \exp(-c(t/L^2)^n)$	Diamante and Munro (1991) [32]

For hot-air drying (Table 2), the average values of χ^2 for the Lewis and Logarithmic models were the lowest and almost the same (4.18×10^{-4} and 3.25×10^{-4}, respectively). However, the average of the *RMSE* (0.015567) of the Lewis model was 1.3937 times as much as that of the Logarithmic model (0.011173). Therefore, the Logarithmic model was the most adequate in describing the hot-air drying processes of DF prepared with citrus by-products. Similarly, for vacuum drying (Table 3), the Wang and Singh model was exhibited the best prediction of the moisture transfer of DF because of the lowest average values of *RMSE* (0.009967) and χ^2 (1.82×10^{-4}), as well as the highest average value of R^2 (0.9988).

Table 2 Statistical results of different drying models for hot-air drying samples

Model No.	Temperature (°C)	Model constants	R^2	χ^2	*RMSE*
1	50	k = 0.1192	0.9989	9.68×10^{-5}	0.00880
	60	k = 0.2323	0.9904	9.53×10^{-5}	0.00873
	70	k = 0.3414	0.9904	1.06×10^{-3}	0.02917
2	50	k = 0.9145; n = 0.1160	0.9989	2.75×10^{-3}	0.04059
	60	k = 0.7125; n = 0.2473	0.9955	5.90×10^{-4}	0.01881
	70	k = 0.5123; n = 0.3370	0.9991	1.44×10^{-4}	0.00929
3	50	k = 0.5911; n = 0.9158	0.9989	1.31×10^{-4}	0.00887
	60	k = 0.6772; n = 0.8263	0.9904	1.27×10^{-3}	0.02765
	70	k = 0.7165; n = 0.7859	0.9904	1.50×10^{-3}	0.02996
4	50	a = 2.2311; k = 0.1253	0.9990	1.18×10^{-4}	0.00843
	60	a = 4.3343; k = 0.2517	0.9912	1.60×10^{-3}	0.02638
	70	a = 6.7342; k = 0.3396	0.9938	9.78×10^{-4}	0.02422
5	50	a = 0.2651; k = 0.1101; c = 0.2035	0.9990	1.67×10^{-4}	0.00818
	60	a = 0.3655 ; k =0.2317 ; c = 0.3369	0.9984	3.32×10^{-4}	0.01152
	70	a = 0.3880; k = 0.2717; c = 0.4766	0.9981	4.77×10^{-4}	0.01382
6	50	a = 0.3680; k0 = 0.0297; b = 0.8048; k1 = 0.0233	0.9988	4.12×10^{-4}	0.00908
	60	a = 0.6502; k0 = 0.0311; b = 0.5568; k1 = 0.0399	0.9915	3.58×10^{-3}	0.02677
	70	a = 0.8904; k0 = 0.0412; b = 0.3775; k1 = 0.0454	0.9961	2.05×10^{-3}	0.02024
7	50	a = 0.2171; k = 0.0355; b = 0.9697	0.9989	2.00×10^{-4}	0.00895
	60	a = 0.4461; k = 0.0297; b = 0.7558	0.9914	1.75×10^{-3}	0.02645
	70	a = 0.6951; k = 0.0165; b = 0.5317	0.9908	2.30×10^{-3}	0.03034
8	50	a = 0.1461; b = 0.1523	0.9884	1.33×10^{-3}	0.02822
	60	a = 0.2816; b = 0.2597	0.9971	3.81×10^{-4}	0.01512
	70	a = 0.3363; b = 0.3804	0.9991	1.41×10^{-4}	0.00919
9	50	a = 0.1159; c = 0.1442; L = 8.518	0.9990	1.81×10^{-4}	0.00850
	60	a = 0.2515; c = 0.2237; L = 12.1177	0.9912	1.79×10^{-3}	0.02679
	70	a = 0.3592; c = 0.3229; L = 16.1181	0.9938	1.55×10^{-3}	0.02493
10	50	c = 0.4729; L = 1.8791; n = 1.2303	0.9985	2.64×10^{-4}	0.01027
	60	c = 0.3727; L = 1.7791; n = 1.3382	0.9944	1.15×10^{-3}	0.02145
	70	c = 0.2733; L = 1.6792; n = 1.4382	0.9922	1.94×10^{-3}	0.02786

In Fig. 3 (a) and (b), two models have been fitted to the experimental data at drying temperature of 50, 60, and 70 °C. From these figures, deviation of the predicted values from the experimental values can be seen for all the models. Similar trends for the deviations have also been observed for other experimental conditions, the details and figures

for which have not been presented here. However, based on the above analysis, these two models can be used for prediction of hot-air and vacuum drying characteristics of citrus by-products DF respectively for all the experimental conditions with fair degree of accuracy.

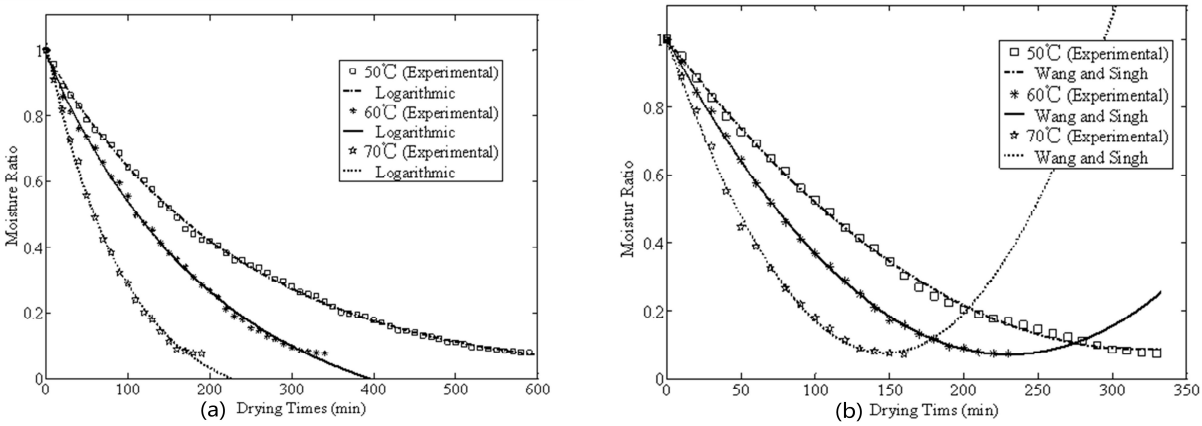

Figure 3. (a) Prediction accuracy comparison for Logarithmic at hot-air drying temperature of 50, 60, and 70 °C. (b) Prediction accuracy comparison for Wang and Singh at vacuum drying temperature of 50, 60, and 70 °C

Composition of samples

The crude protein, crude fat, ash, TDF, SDF, and IDF contents of the drying samples were determined. The results are shown in Table 4. Citrus juice by-products have been reported to be a rich source of DF. Hence, the presence of DF in citrus by-products was investigated. The samples dried using a vacuum dryer had higher TDF contents, indicating that these samples have better physicochemical properties. The analyzed parameters show that the chemical composition of the citrus by-products DF appears to be dependent on the drying method. Drying with a hot-air dryer at 70 °C yielded the lowest TDF content, as well as the highest crude protein and ash contents. Drying with a vacuum dryer at 60 °C generated the highest TDF content, as well as the lowest crude protein, crude fat, and ash contents. Several other vegetables and fruits, such as carrots, apples, pears, and peached, were found to contain a higher amount of DF compared with the edible fleshy parts (Larrauri et al. 1999). The TDF content in citrus by-products was approximately 40.94 g/100 g dry weight. Thus, drying at different temperatures can significantly affect the contents of TDF and SDF because the hot-air drying can loosen the structure of cellulose and lignin, making them more soluble. Vacuum drying may have a similar effect.

Table 4 Compositions of samples (g/100 g dry powder)[a]

Samples	Crude Protein	Ash	Crude Fat	TDF	IDF	SDF
Hot-air Drying T (°C)						
50	4.16 ± 0.18	2.14 ± 0.09	5.32 ± 0.11	57.39 ± 0.09	49.58 ± 0.11	7.81 ± 0.12
60	4.27 ± 0.07	2.03 ± 0.11	5.39 ± 0.09	54.88 ± 0.14	47.61 ± 0.12	7.26 ± 0.08
70	4.42 ± 0.21	2.42 ± 0.05	5.19 ± 0.07	54.46 ± 0.24	47.58 ± 0.17	6.88 ± 0.11
Vacuum drying T (°C)						
50	4.01 ± 0.07	2.29 ± 0.12	4.86 ± 0.18	59.91 ± 0.17	52.36 ± 0.08	7.55 ± 0.06
60	3.93 ± 0.13	1.91 ± 0.14	4.57 ± 0.05	61.63 ± 0.23	53.66 ± 0.21	7.97 ± 0.21
70	3.97 ± 0.07	1.99 ± 0.03	4.76 ± 0.12	60.44 ± 0.31	53.17 ± 0.21	7.27 ± 0.19

[a] The results are expressed as an average ±ES (n=5).

Color of powdered fiber concentrates

Color is one of the more important quality parameters for dehydrated fruits and vegetables. It is an index of the inherent good qualities of a material. Changes in of the color may be attributed to the degradation of the ingredients of the material and generally caused by some degradation reactions in the material. Undoubtedly, possible color changes influence the organoleptic properties of dried orange peel and pulp samples and limit their potential applications (Köse 2010).

L^* and a^*/b^* values are commonly used as indices of color quality. Higher L^* values and lower a^*/b^* values are desired in dried products (Arslan et al. 2008). The color data in terms of L^*, a^*, and b^* values of the dried DF samples are illustrated in Table 5 for all the drying parameters investigated. The data shown in Table 5 are the average values of 10 replications, with a standard deviation of ± 0.008. The highest L^* value (82.77) was obtained at 70 °C for vacuum drying. The lowest L^* value (71.25) was obtained at 70 °C for hot-air drying. When both types of dryers were compared, the results of the color analysis show that lower a^*/b^* values and higher L^* values were obtained in vacuum drying for all the parameters investigated.

Table 5 CIELab* coordinates of orange peel and pulp samples dehydrated at different temperature

	L	a*	b*	a*/b*
Hot-air Drying T (°C)				
50	73.47	5.48	31.66	0.173
60	75.47	1.33	30.84	0.043
70	71.25	5.51	33.14	0.166
Vacuum drying T (°C)				
50	80.70	1.93	34.18	0.056
60	80.82	1.41	19.53	0.072
70	82.77	1.28	20.07	0.064

Functional properties

Functional properties are related to the chemical structure of plant polysaccharides. Therefore, the drying process may alter the physico-chemical properties of original products, modifying their functional properties. The results obtained for WRC, OHC, and SWC are presented in Table 6. WRC is the quantity of water that remains bound to the hydrated fiber following the application of an external force (pressure or centrifugation). It is an important property of DF from both physiological and technological points of view. Drying with high temperatures may cause a reduction in this capacity (Fischer et al. 2009), thus, the fibers dried at a high temperature (70 °C) had a slightly lower WRC (Table 6). This effect may have been caused by the degradation of some dietary fiber components, leading to the loss of the ability to retain water in the powder.

As shown in Table 6, the samples treated by hot-air drying at 50, 60, and 70 °C had WRC values (9.81 ± 0.12, 10.32 ± 0.15, and 9.49 ± 0.11 mL water/g, respectively) similar to those previously reported (Elleuch et al. 2011). Moreover, the samples treated by vacuum drying at 50, 60, and 70 °C had slightly higher WRC values (10.72 ± 0.09, 11.02 ± 0.13, and 10.35 ± 0.20 mL water/g, respectively) compared with those of the samples treated by hot-air drying. The WRC value of vacuum-treated samples was in the range mostly reported for fiber (e.g., 12.72 mL water/g for fiber-rich burdock root powders, 12.6 mL water/g for peach pulp fiber, and approximately 11 mL water/g for lemon fiber (Jiménez et al. 2000 and Lou et al. 2009). The other by-products had lower values than those mentioned above (e.g., cocoa husks, with a WRC value of approximately 5 mL water/g fiber). These values indicate that drying samples can be promoted as a modifier of the viscosity and texture of formulated products, as well as decrease calories.

The results for the OHC of the drying samples are presented in Table 6. High-temperature water bath slightly enhanced the OHC of the samples compared with the untreated citrus by-products. Vacuum drying can improve the OHC of samples (approximately 7 mL oil/g). Some researchers obtained a DF OHC of 0.6–1.8 mL oil/g for apple pomace and citrus peel. The highest reported level was approximately 6 mL oil/g for carrot sarcocarp (Elleuch et al. 2011). Fiber-rich burdock root powder was reported to yield high values (8.50 mL oil/g) (Lou et al., 2009). Thus, DF samples may be appropriate for products for which emulsifying properties are required.

The SWC of the samples are shown in Table 6. The value of the samples treated by hot-air and vacuum drying at 50, 60, and 70 °C were similar with some studies had reported (Jiménez et al. 2000 and Lou et al. 2009). As shown in Table 6, hot-air and vacuum drying had a slightly greater effect.

Table 6 Functional properties of samples[b]

Samples	WRC (mL water/g powder)	OHC (mL oil/g powder)	SWC
Hot-air Drying T (°C)			
50	9.81 ± 0.12	5.92 ± 0.09	6.62 ± 0.03
60	10.32 ± 0.15	6.30 ± 0.04	7.34 ± 0.06
70	9.49 ± 0.11	6.17 ± 0.07	7.13 ± 0.10
Vacuum drying T (°C)			
50	10.72 ± 0.09	6.88 ± 0.04	6.71 ± 0.07
60	11.02 ± 0.13	7.02 ± 0.08	7.38 ± 0.12
70	10.35 ± 0.20	7.05 ± 0.06	7.22 ± 0.05

[b] *Values are means of triplicate assays.*

CONCLUSION

In this study, the drying behaviors of citrus by-products DF in both hot-air and vacuum dryers were compared. Drying air temperature had the most important effect on the drying of DF in both of the drying methods. Among the 10 commonly drying correlations considered, the Logarithmic model represented the best fitting for hot-air drying, whereas the Wang and Singh model exhibited the best prediction of the moisture transfer in vacuum drying. Vacuum treatment accelerated the drying procedure and shortened drying times. When both types of dryers were

compared, the results of the color and functional property analyses showed that vacuum drying had higher drying quality for the prepared DF.

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