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EFFECTS OF BLANCHING AND HOT AIR DRYING CONDITIONS ON THE PHYSICOCHEMICAL AND TECHNOLOGICAL PROPERTIES OF YELLOW PASSION FRUIT (*PASSIFLORA EDULIS* VAR. FLAVICARPA) by-PRODUCTS

Y. DUARTE[1], A. CHAUX[1], N. LOPEZ[1], E. LARGO[1], C. RAMÍREZ[2], H. NUÑEZ[2], R. SIMPSON[2,3,4] and O. VEGA[1]

[1]BIOALI, Research Group, Department of Food Faculty of Pharmaceutical Sciences and Food, Universidad de Antioquia, Medellin Colombia
[2]Chemical and Environmental Engineering Department, Universidad Técnica Federico Santa María, PO Box 110-V, Valparaíso, Chile
[3]Conicyt Regional Gore Valparaíso, Centro Regional de Estudios en Alimentos y Salud (CREAS), R06I1004 Valparaíso, Chile

[4]Corresponding author.
TEL: +56-32-2654302;
FAX: +56-32-2654478;
EMAIL: ricardo.simpson@usm.cl

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ABSTRACT

Passion fruit peel constitutes 50% of the whole fruit; therefore, a method to transform it to an active ingredient would be useful. Hot air drying is the most common process applied to extend the shelf life by reducing water activity. However, the processing conditions must be carefully selected to retain bioactive compounds. The goal of this study was to investigate the effects of blanching, temperature and airflow rate during hot air drying on the physicochemical and technological properties of passion fruit peel. A 3^2 experimental design with replicates in the central point was used. Three temperatures (50–55–60°C) and three airflow rates (2.4–2.7–3.0 m/s) were used, and the drying curves were analyzed to estimate the effective diffusion (D_{eff}) and drying time. The dried peels were milled and their physicochemical properties (total fiber content and total polyphenol content), and technological properties (water holding capacity, the swelling capacity and the oil holding capacity) were measured. The results showed that the shortest drying time (~2.5 h) was obtained at 60°C and 2.7 m/s for both control and blanched fruits. The physicochemical and technological properties were not affected by the drying conditions, because the temperatures used were not high enough to be detrimental. In addition, D_{eff} and the physicochemical and technological properties were not affected by blanching due to preserve the samples a slower freezing process (freezing rate <1 cm/h) was performed, which can produce severe damage at the cellular level facilitating water diffusion and therefore can be considered such as pretreatment.

PRACTICAL APPLICATIONS

Considering that Passion fruit waste constitutes 50% of the whole fruit and that has a high potential, primarily because it is rich in bioactive compounds, such as vitamins, minerals, polyphenolic compounds with a high antioxidant capacity and dietary fiber it is important study an adequate process to allow stabilize and store the passion fruit by-products. Therefore, the passion fruit by-product can be used as active ingredient in the formulation of different kind of foods, specially bakery and pastry products.

INTRODUCTION

Passion fruit is a tropical fruit in the family Passifloraceae and is widely cultivated in Colombia. Most of this fruit is used for juice and drink production, consequently producing a large amount of waste that is primarily composed of seeds, pomace and peel (López-Vargas *et al.* 2013). According to Oliveira

et al. (2002), an entire fruit weighs approximately 173 ± 29 g, of which 53% corresponds to peel, 20.9% to seed and 26% to pulp. Therefore, more than half of the passion fruit is wasted, but the waste has a high potential, primarily because it is rich in bioactive compounds, such as vitamins, minerals, polyphenolic compounds with a high antioxidant capacity and dietary fiber. These polyphenolic compounds and dietary fiber are the most potentially useful active ingredients because they have important beneficial properties related to heath and digestion (Teixeira *et al.* 2015). Some studies of yellow passion fruit by-products have reported a total polyphenolic content of approximately 150 mg gallic acid equivalents (GAE)/100 g of sample, an antioxidant capacity between 1.0 and 7.0 μM Trolox equivalents (TE)/g of sample (Martínez *et al.* 2012) and a total dietary fiber (TDF) of approximately 71.79 g/100 g of sample (López-Vargas *et al.* 2013). Indeed, if we compare passion fruit by-product values to those reported for apple pomace, for which the total polyphenol content (TPC) is 479.71 mg GAE/100 g of sample and the TDF is 76.84 g/100 g of total fiber (Teixeira *et al.* 2015), passion fruit has a significantly lower polyphenol content than apple, but for fiber the values reported for apple more nearly approximate those for passion fruit.

The foregoing discussion indicates that passion fruit by-products provide an interesting opportunity to develop new ingredients rich in bioactive compounds that have important technological properties for use in the food industry to create enriched products.

However, an adequate process to stabilize and store the passion fruit by-products is necessary. A common method is hot air drying, which necessarily requires optimum drying conditions to produce the least possible degradation of the bioactive compounds to produce an ingredient that can be used as a nutritional supplement (Chantaro *et al.* 2008). According to Vieira *et al.* (2015) one of the major concerns about the drying process is identifying optimum conditions for a quality product by analyzing the moisture transfer and the moisture transfer parameters (i.e., the moisture diffusivity and the moisture transfer coefficients).

The goal of this study was to investigate the effects of blanching as a pretreatment, temperature and airflow rate during hot air drying on the physicochemical (TDF, total polyphenols content) and technological properties (water holding capacity (WHC), oil holding capacity (OHC) and swelling capacity (SC)) of yellow passion fruit peel (*Passiflora edulis* var. flavicarpa).

MATERIALS AND METHODS

Materials

Samples consisted of yellow passion fruit peel (*P. edulis* var. flavicarpa) obtained from Alimentos Santana, Medellin, Colombia. The samples were separated from the seeds, washed with distilled water, immersed in a solution of chlorine (50 ppm) and cut into small pieces. Finally, the samples were stored at −20 ± 2°C until use in the drying process.

Proximate Analysis of Passion Fruit Peel

The ash, protein and fiber content of the passion fruit peel were determined according AOAC methodology (AOAC 1997). The moisture and fat content were determined according GTC1 (GTC, 2005). The protein content was determined with the micro-Kjeldahl method, the fat content by the Soxhlet method, and the TDF by nonenzymatic gravimetric methods. Carbohydrates were estimated by difference. The result was expressed as g/100 g of dry sample.

Pretreatment: Blanching of Passion Fruit Peel

Prior to the drying process, the samples were slowly thawed at 4°C overnight in a refrigerator and leached water was removed. The samples were blanched (pretreated) by immersing them in distilled water at 90°C for 1 min (skin-water ratio was 1:3) and then the samples were immersed in cold water (4°C) for 5 min.

Hot Air Drying Process of the Passion Fruit Peel

Air drying of the control (control) and blanched passion fruit peel was performed in a pilot dryer. The sample was placed on a 50 cm × 25 cm plate. The dryer was set to one of three temperatures (50, 55 or 60 ± 1°C), and one of three air velocities (2.4, 2.7 and 3.0 m/s). Weight changes of control and pretreated passion fruit peel during the drying process were monitored automatically at 2 min intervals with a digital balance (0.001 g). Samples with a thickness of 0.005 m were dried to constant weight. The dried peel was stored in a polyethylene bag at 25°C prior to size reduction.

Mathematical Modeling of Drying Curves

A dimensionless moisture ratio (MR_t) was calculated from the drying curves as:

$$MR_t = \frac{X_t - X_e}{X_0 - X_e} \quad (1)$$

where X_t is the moisture content at any time t (g water/g dry basis), X_e is the moisture content at the equilibrium (g water/g dry basis) and X_0 is the initial moisture content (g water/g dry basis). Values of X_e are considered relatively small compared to X_t or X_0. Thus, $(X_t - X_e)/(X_0 - X_e)$ can be simplified to (X_t/X_0) (Ramirez *et al.* 2011).

Fick's law of diffusion was used to describe the water loss during the air drying of the passion fruit skins. The solution

of Fick's law was used for one-dimensional transport, with the assumptions that moisture migrates only by diffusion, that negligible shrinkage occurs and that the diffusion coefficients and temperature are constant, as given by Crank (1975):

$$MR_t = \frac{8}{\pi^2}\sum_{i=1}^{\infty}\frac{1}{(2i-1)^2}\exp\left(\frac{-(2i-1)^2\pi^2 D_{eff}\, t}{4L^2}\right) \quad (2)$$

where D_{eff} is the effective moisture diffusion coefficient (m^2/s), t is the drying time (s) and L is the half thickness of the slice (m).

For long drying times, only the first term of Eq. (2) becomes relevant for evaluating MR_t. Therefore, it is possible to simplify the previous expression as follows:

$$MR_t = \frac{8}{\pi^2}e^{\left(\frac{-D_{eff}\times\pi^2\times t}{4L^2}\right)}. \quad (3)$$

Obtaining Fruit Passion Peel Flour

The passion fruit peel flour was obtained by milling the dried skins using a disc mill model LV15 M (Condux-Werk Hanau, Hanau, Germany) for 5 min. The milled samples were sieved for 15 min in a Rotap Pinzuar PS 32, following an ASTM Standard sieve series: mesh No. 10, 14, 20 and 40.

Passion Fruit Peel Flour Characterization. Twenty flour samples were obtained from the different drying conditions that are summarized in the experimental design presented in Table 1. A representative subsample was taken from each sample for flour characterization based on a moisture content analysis (M), the water activity (A_w), the TDF and the total phenolic content (TPC). Additionally, technological properties such as the WHC, the OHC and the SC were studied:

Moisture content (M) was determined according to AOAC Official Methods 934.06 (AOAC, 1997) by drying 5 g of sample in an oven (Binder) at 105°C to constant weight. The results were expressed as the percentage of moisture (%RH).

Water activity (A_w) was measured by a water activity meter (Novasina, TH 200 Axair AG, Lachen, Switzerland) using 1.0 g of sample at 25 ± 2°C.

TDF was determined by a gravimetric nonenzymatic method according to AOAC Official methods 993.21(AOAC 1997). Briefly, 500 mg of flour were weighed and 25 mL of distilled water were added and the mixture was incubated for 90 min at 37°C. Then, 100 mL of ethanol (95 mL/100 mL) were added and the solution was stored at 25°C for 1 h. The precipitate was washed twice with ethanol at 78 mL/100 mL, twice with ethanol at 95 mL/100 mL and once with 10 mL of acetone, then the precipitate was filtered with a vacuum filtration system. Finally, the precipitate was dried at 105°C for 2 h. The results were expressed as g of TDF/100 g of sample

TABLE 1. SUMMARY OF THE EXPERIMENTAL DESIGN FOR THE ANALYSIS OF THE EFFECT OF PRETREATMENT AND AIR DYING ON THE PHYSICOCHEMICAL AND TECHNOLOGICAL PROPERTIES OF PASSION FRUIT PEEL

	Factors		
Run	Temperature (°C)	Airflow rate (m s^{-1})	Pretreatment
2	50	2.4	0
6	50	2.7	0
1	50	3.0	0
14	55	2.4	0
7	55	2.7	0
11	55	2.7	0
8	55	3.0	0
15	60	2.4	0
13	60	2.7	0
16	60	3.0	0
19	50	2.4	1
10	50	2.7	1
4	50	3.0	1
3	55	2.4	1
9	55	2.7	1
20	55	2.7	1
18	55	3.0	1
5	60	2.4	1
17	60	2.7	1
12	60	3.0	1

TPC was determined based on the method of Folin–Ciocalteau proposed by Togashi *et al.* (2007). An extract was obtained by following the method described by Contreras *et al.* (2011) with some modifications. In general, 1 g of flour was dissolved in 8 mL of a methanol/water (50:50) solution. The sample was vortexed gently with a BV1000 Vortex Mixer (Benchmark scientific, Edison, NJ) for 1 min, then placed in a shaker (Incubator 1000, Heidolph Instrument GmbH&Co.KG, Schwabach, Germany) at 25°C for 1 h. The mixture was centrifuged at 5000 rpm for 10 min and supernatant was recovered and stored in the dark. The precipitate was mixed with an acetone-water solution (70:30) and treated by the same process as before. All the supernatant was mixed and put in a volumetric balloon of 25 mL and stored at −20°C overnight. Then 20 μL of extract were mixed with 1580 μL of distilled water and 100 μL of Folin–Ciocalteau reagent; after 2 min 300 μL of sodium carbonate (20 g/100 mL) were added and the final mixture was stored in the dark for 1 h. The absorbance of the solution was measured in a spectrophotometer (CARY 50 BIO, UV-vis) at 725 nm and the absorbance was compared with a calibration curve based on gallic acid. The

results were expressed as mg equivalents of gallic acid (GAE)/dry sample mass (g).

WHC was measured by a modification of the method proposed by Chau and Huang (2003). The sample (0.1 g) was mixed with 10 mL of distilled water and shaken before being incubated for 24 h. The mixture was then centrifuged at 2,500 rpm for 30 min. Finally, the volume of the supernatant was measured. The results were expressed as mL of water/g of sample.

OHC was obtained by mixing 1 g of sample with 10 mL of vegetal oil (PREMIER sunflower oil, Colombia, density = 0.90 g/mL) for 30 min at 25°C. Then, the oil mixture was centrifuged at 2,500 rpm for 30 min. The supernatant volume was measured (Benítez *et al.* 2011). The results were expressed as mL of oil/g of sample

SC was determined according to Chantaro *et al.* (2008). Briefly, 0.1 g of sample was put into a cylinder and the volume occupied was measured, then the sample was mixed with 10 mL of distilled water and incubated for 18 h. Finally, the volume occupied by the sample at the end of 18 h was measured. The results were expressed as mL of water/g of sample.

Experimental Design and Statistical Analysis

The experimental design was based on two factor: air drying temperature and airflow rate, with 3 levels (−1, 0, 1), replicates at the central point and a significance level of 95%, was used. The air drying temperatures were 50, 55 and 60°C, and the airflow rates were 2.4, 2.7 and 3.0 m/s. The response variables were drying time, the total fiber content (TFC), the TPC, the WHC, the SC and the OHC. The experiments contained a control (0) and a blanching pretreatment process (1). Ten runs were carried out for the control and the pretreated samples. The response variables for each treatment were analyzed by an analysis of variance, and the means were compared using Duncan's test at a 95% of significance level using STATGRAPHICS Centurion XVI software (Statistical Graphics Corporation, Version 16.0.07, Rockville, USA).

RESULTS AND DISCUSSION

Proximate Analysis of Yellow Passion Fruit Peel

The results obtained for the physicochemical characterization of yellow passion fruit peel are summarized in Table 2. Similar results have been reported by López-Vargas *et al.* (2013), Martínez *et al.* (2012), Pantoja and Da Silva (2010) and Gutiérrez *et al.* (2002) for waste products of passion fruit. The most remarkable result is the high TDF content (63.40 g/100 of sample dry basis) compared to other fruit peels such as grapefruit (44.2–62.6%) orange (57%), mandarin (56%), lemon (53.8%) and pineapple (51.5%) (Elleuch *et al.* 2011; Chau and Huang 2003; Gutiérrez *et al.* 2002).

TABLE 2. SUMMARY OF THE PROXIMATE ANALYSIS OF PASSION FRUIT PEEL

Compounds	g/100 g of sample dry basis
Ash	7.50 ± 0.07
Proteins	4.82 ± 0.03
Fat	0.87 ± 0.04
TDF	63.40 ± 0.10
Carbohydrates	23.41 ± 0.10

Results expressed as mean ± standard deviation.

Effect of the Pretreatment and Drying Conditions on the D_{eff} and the Drying Time

In Fig. 1, two drying curves are presented, which correspond to the minimum and maximum temperatures used in this experiment (50 and 60°C) at the same airflow rate (2.4 m/s). A simple analysis of the drying curves show that, at 60°C, for example, the sample attained a MR of 0.2 at approximately 2 h, while the sample dried at 50°C required more time (3 h). This time reduction due to the increased drying temperature has also been reported by Da Silva *et al.* (2013), Ramallo and Mascheroni (2012), Roberts *et al.* (2008) and Garau *et al.* (2006) for passion fruit, pineapple, grape and orange waste products, respectively. In general, the drying times in this study ranged between 12 and 13 h for all of the drying conditions applied, and the longest drying time occurred at the lowest temperature.

Many studies indicate a positive effect of blanching on the drying rate, because hot water induces a weakness in the cell which increases the water migration, which produces an increase in the diffusion of the water. However, Fig. 2 shows that the pretreatment did not increase the drying rate. This

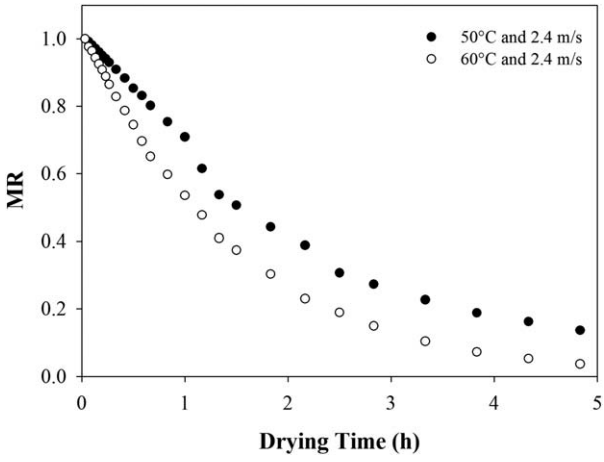

FIG. 1. EFFECT OF TEMPERATURE ON THE DRYING CURVE OF YELLOW PASSION FRUIT PEEL

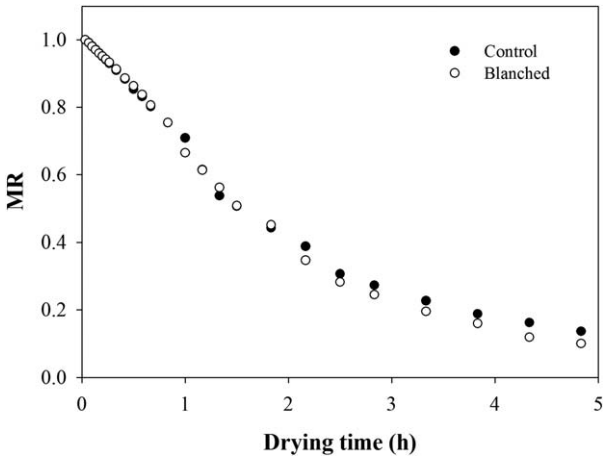

FIG. 2. DRYING CURVE FOR CONTROL AND BLANCHED PASSION FRUIT PEEL DRIED AT 50°C AT AN AIRFLOW RATE OF 2.4 M/S

can be attributed to the effect on the structure of freezing and thawing of the passion fruit peel, which was the method used to preserve the peel. For example, Ramirez *et al.* (2011) studied the effect of freezing and thawing as a pretreatment at the structural level and how it affects the drying kinetics. The results showed that freezing and thawing induces massive damage at the cellular level, which facilitates water diffusion during drying and notably increases the drying rate. For this reason, blanching did not significantly improve the water migration during drying, which implies that blanching is more effective as pretreatment for fresh samples or those have not been stored frozen.

The other operating condition studied was the airflow rate during the drying process. In general, the airflow rate affected the final moisture content of the samples, which can be explained because an increase in the airflow rate produces an increase in the convection coefficient, and therefore an increase in the heat transferred to the sample, which increases the water temperature of the structure (Michalewicz *et al.* 2011). However, other authors (Kouhila *et al.* 2002; Lahsasni *et al.* 2004; Akpinar 2006; Cassini *et al.* 2006) suggested that a 1.5 m/s airflow rate was enough to remove the resistance generated on the food surface, which facilitated water diffusion.

The diffusion coefficient (D_{eff}) was obtained for the all drying curves from the application of Crank's solution for the second Fick's law. The model was fitted with the long time drying curve, which was determined by the linearization of drying curve. The results of D_{eff} for the blanched and control samples are presented in Table 3. The D_{eff} for a 3 mm thick passion fruit peel ranged between 0.91×10^{-10} and 1.66×10^{-10} m^2/s, which was the lowest value obtained for the control at 50°C, with an airflow rate of 2.4 m/s, while higher D_{eff} values were obtained for the control samples at 60°C and a 2.7 m/s air rate flow rate.

Figure 3A,B shows the effect of the airflow rate on the effective diffusion of yellow passion fruit peel for control and blanched samples, respectively. The results showed that an increase in airflow rate did not necessarily produce an increase in water diffusion, as can be observed at an airflow rate of 3.0 m/s. Similar results were observed for both control and blanched samples. Similar results were also obtained by Babalis and Belessiotis (2004) who found an optimum airflow rate between 1.3 and 2.0 m/s when thin layers of figs were dried at different airflow rates. According to Babalis and Belessiotis (2004), a range of 1–2 m/s for the drying air rate is commonly used in industrial driers for agricultural products and gives the best cost/efficiency performance for figs.

Table 3 shows the drying times obtained under different drying conditions. In general, a relationship exists between the drying time and effective water diffusion rate that is highly related to the drying conditions. For example, at the lowest drying temperature (50°C), the drying time was greater than 3.3 h with a maximum time of 4.8 h at 50°C and 2.4 m/s. At the highest temperature (60°C), the drying time was less than 3.30 h and a minimum of 2.5 h was attained at 60°C and 2.7 m/s. The results obtained for the

TABLE 3. EFFECT OF THE AIR TEMPERATURE AND THE AIRFLOW RATE ON THE EFFECTIVE WATER DIFFUSION (D_{eff}) OF PASSION FRUIT PEEL IN CONTROL AND BLANCHED SAMPLES

		$D_{eff} \times 10^{-10}$ (m^2 s^{-1})				Drying time (h)	
Temperature (°C)	Airflow rate (m s^{-1})	Control	R^2	Blanched	R^2	Control	Blanched
50	2.4	0.91	0.989	0.98	0.997	4.80	4.30
50	2.7	1.10	0.997	1.34	0.993	3.80	3.30
50	3.0	0.99	0.971	0.99	0.979	4.30	4.30
55	2.4	1.40	0.998	0.98	0.958	3.80	4.30
55	2.7	1.47	0.937	1.51	0.999	2.80	3.30
55	3.0	1.38	0.998	1.22	0.999	3.30	3.30
60	2.4	1.11	0.998	1.37	0.995	3.30	2.80
60	2.7	1.66	0.998	1.63	0.996	2.50	2.80
60	3.0	1.42	0.999	1.28	0.999	3.30	2.80

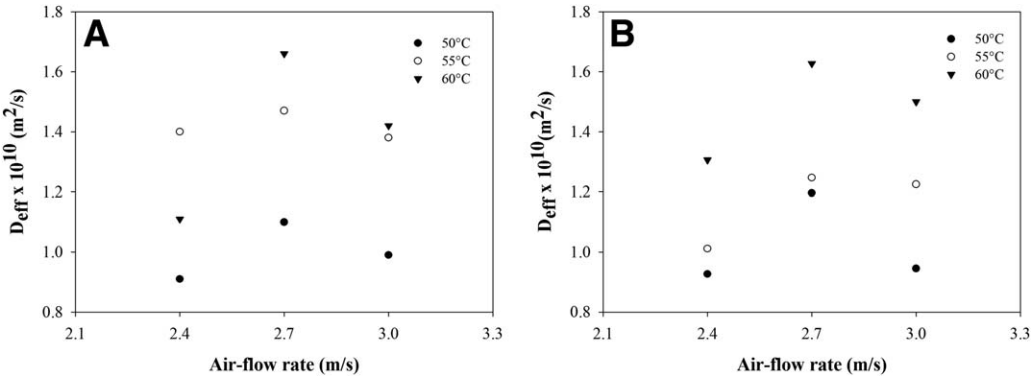

FIG. 3. (A) EFFECT OF THE AIRFLOW RATE ON THE EFFECTIVE WATER DIFFUSION ((D_{eff}) FOR CONTROL. (B) EFFECT OF THE AIRFLOW RATE ON THE EFFECTIVE WATER DIFFUSION (D_{eff}) FOR BLANCHED SAMPLES

drying time exhibit a similar trend to that obtained for the D_{eff}, mainly for unblanched samples, for which the lowest drying times were obtained at an airflow rates of 2.7 m/s, not 2.4 or 3.0 m/s. For example, for control samples dried at 50°C, the drying time was 4.8 h at 2.4 m/s, and 4.3 h for 3.0 m/s, while for 2.7 m/s the drying time was 3.8 h. For blanched samples, an effect of the airflow rate was not evident, especially at the highest drying temperature (60°C), where the drying time was 2.8 h independent of the airflow rate.

The lowest drying time was obtained at the highest temperature (60°C) for the control and blanched samples. For the control, for example, the lowest time (2.5 h) was obtained at 60°C and 2.7 m/s, while for the blanched samples, the lowest drying time (2.8 h) was obtained at 60°C independent of the airflow rate.

In general, if we compare the D_{eff} and the drying times obtained from the blanched and unblanched samples there are not evident differences between them. This could be because the passion fruit peel was stored frozen by slower freezing rate (<0.1 cm/h) considering that the target temperature was −20 ± 2°C and thawed overnight (4°C) prior to laboratory use. According to Ramirez *et al.* (2011), freezing/thawing of apple parenchyma produced severe cell damage which was observed microscopically and quantitatively analyzed by image analysis. This damage produced an important time reduction during the hot air drying process, which was evidenced by an increase in the D_{eff} from 1.04 to 1.35×10^{-10} m^2/s. Considering this, blanching as a pretreatment for passion peels should not produce important changes at the structural level; therefore, no significant differences with respect to the control will be noted.

The effect of freezing/thawing on the passion fruit peel structure can be verified by analyzing the data fit to a second Fick's law model. According to Simpson *et al.* (2015), when the apple structure is damaged, which implies that the cellular structure has collapsed and allows easy water movement, the fit of a Fick's model improves greatly. This can be observed in Table 3, where the values of R^2 are very close to 1, indicating a very good fit. This was evident for both the control and the blanched samples; therefore, it is highly probable that the cellular damage due to freeze/thawing is more important than that from blanching.

The final moisture content and water activity for the control and blanched samples reached values that allow preservation, avoiding microbiological decomposition. For example, the moisture content of the control samples was 10.26 ± 1.7% and the water activity was 0.49 ± 0.02, while for blanched samples, the values were 9.85 ± 0.7% and 0.49 ± 0.02, respectively.

Effect of Pretreatment and Drying Condition on TFC of Passion Fruit Peel Flour

The TFC present in flour obtained from control and blanched dried passion fruit peel is presented in Table 4. For

TABLE 4. TFC OF PASSION FRUIT PEEL AT THE END OF THE DRYING PROCESS AT DIFFERENT TEMPERATURES AND AIRFLOW RATES FOR CONTROL AND BLANCHED SAMPLES

Temperature (°C)	Airflow rate (m s^{-1})	Control TFC (%)	Blanched TFC (%)
50	2.4	62.95 ± 0.44^{aA}	65.78 ± 0.08 ^{aB}
50	2.7	62.92 ± 0.02^{aA}	65.35 ± 0.89^{acB}
50	3.0	63.30 ± 0.44^{aA}	69.19 ± 0.34^{bB}
55	2.4	63.85 ± 1.14^{aA}	67.77 ± 1.62^{bB}
55	2.7	62.40 ± 0.05^{aA}	66.24 ± 0.32^{aB}
55	3.0	64.94 ± 0.27^{aA}	65.91 ± 0.98^{adB}
60	2.4	64.89 ± 1.03^{aA}	69.25 ± 0.14^{bB}
60	2.7	64.64 ± 2.48^{aA}	63.45 ± 0.06^{eA}
60	3.0	63.24 ± 0.02^{aA}	66.84 ± 0.26^{aB}

Values are expressed as the mean ± standard deviation. Means in same row with different capital letters are significantly different ($P \leq 0.05$); means in same column with different small letters are significantly different ($P \leq 0.05$).

the control samples, the fiber content ranged between 62.40 ± 0.05% at 55°C and 2.7 m/s to 64.94 ± 0.27% at 55°C and 3.0 m/s, while for the blanched samples the values ranged between 63.45 ± 0.06 at 60°C and 2.7 m/s to 69.25 ± 0.14% at 60°C and 2.4 m/s. In general, the TFC did not follow a trend with drying temperature or airflow rate. For example, in the statistical analysis, control samples dried at 50°C with the three airflow rates exhibited nonsignificant differences in TFC ($P > 0.05$). In the case of the blanched samples, the results exhibited greater variability, but no trend with respect to air temperature or airflow rate was observed upon statistical analysis.

However, blanching significantly affected ($P < 0.05$) the TFC compared to the control, increasing the value from 63.3% (control) to 69.2%. This result can be attributed to some low molecular weight components present into cell such as: minerals, vitamins and sugars are leaching from the cell structure to the water used during blanching process (Phillips and Palmer 1991; Wennberg *et al.* 2006; Chantaro *et al.* 2008). Similar results were observed by Sengkhamparn *et al.* (2013) for pitaya (*Hylocereus undatus*) flour, for which blanching in water at 95°C for 1 min increased the crude fiber content of dried samples of pitaya peel from 28.45 ± 0.42 to 30.15 ± 0.75 g/100 g dry weight basis. The same trend was observed by Chantaro *et al.* (2008) where fiber content for fresh carrot peel was of 45.45 g/100 g dry weight and to blanched peel TFC was increased to 69.85 g/100 g dry weight.

The fiber content of the passion fruit peel was higher than that reported by Ajila *et al.* (2008) for mango peel flour (51.2 ± 1.08 g/100 g dry wt basis) and lower than that reported by Yapo and Koffi (2008) for yellow passion fruit (73.5 ± 1.2 g/100 g dry wt basis) and LÓpez-Vargas *et al.* (2013) for yellow passion fruit (71.79 g/100 g dry wt basis).

For control samples, the maximum values of TFC (approximately 64%) were obtained at 60°C (independent of the airflow rate), and for blanched samples the maximum TFC value (69.25%) was obtained at 60°C and 2.4 m/s.

Effect of Air Drying Conditions on the TPC of Passion Fruit Flour

The TPC obtained from flour from control and blanched passion fruit peel is presented in Table 5. For the control, the values ranged between 4.41 ± 0.01 mg GAE/g at 55°C at an airflow rate of 3.0 m/s to 5.62 ± 0.05 mg GAE/g at 50°C at 2.4 m/s. Most of the data showed no significant differences ($P > 0.05$) among the different drying conditions, except for a couple of conditions, indicating that a trend that cannot be established between the drying temperature, the airflow rate and TPC.

For blanched peels, the results ranged from 3.24 ± 0.10 mg GAE/g at 60°C at 3.0 m/s to 4.80 ± 0.31 mg GAE/g at 55°C at 2.4 m/s. In this case, the results are similar to the control. The majority of the data exhibited no significant differences except for some conditions at 55 and 60°C. However, if we compare the control and blanched samples, the results show a significant detrimental effect of blanching on the TPC, which can be attributed to the leaching of polyphenol from the peel during immersion due to extraction by the hot water. These significant differences mainly occur at the lowest (50°C) and highest drying temperatures (60°C).

TABLE 5. TPC OF PASSION FRUIT PEEL AT THE END OF THE DRYING PROCESS AT DIFFERENT TEMPERATURES AND AIRFLOW RATES FOR CONTROL AND BLANCHED SAMPLES

Temperature (°C)	Airflow rate (m s^{-1})	Control TPC (mg GAE/g)	Blanched TPC (mg GAE/g)
50	2.4	5.62 ± 0.05^{aA}	3.82 ± 0.06^{aB}
50	2.7	4.88 ± 0.74^{bB}	4.05 ± 0.92^{aB}
50	3.0	4.61 ± 0.12^{bA}	3.69 ± 0.06^{aB}
55	2.4	5.04 ± 0.09^{cA}	4.80 ± 0.31^{bA}
55	2.7	4.64 ± 0.44^{bA}	3.95 ± 0.05^{aA}
55	3.0	4.41 ± 0.01^{bA}	4.08 ± 0.16^{aB}
60	2.4	4.66 ± 0.30^{bA}	3.86 ± 0.01^{aB}
60	2.7	4.89 ± 0.26^{bA}	4.81 ± 0.43^{bA}
60	3.0	4.57 ± 0.27^{bA}	3.24 ± 0.10^{cB}

Values are expressed as the mean ± standard deviation. Means in same row with different capital letters are significantly different ($P \leq 0.05$); means in same column with different lower case letters are significantly different ($P \leq 0.05$).

The TPC reported in this study for the control and the blanched samples are close to those obtained by LÓpez-Vargas *et al.* (2013) for yellow passion fruit (2.98 mg GAE/g) and higher than those reported by Vasco *et al.* (2008) (0.61 ± 0.32 mg GAE/g).

WHC and SC of Passion Fruit Flour

The WHC is an important technological property related to the hydration capacity, mainly for food materials rich in protein and/or fiber and whose main function is to regulate the viscosity of a food product. The WHC results obtained for non-pretreated samples ranged from 4.34 ± 1.10 mL of water/g of sample for a drying process at 50°C and 3.0 m/s to 12.42 ± 1.35 mL of water/g of sample at 60°C and 3.0 m/s. No significant differences were found, probably because of the great variability of the results. However, higher values of WHC were observed at 60°C at airflow rates of 2.7 and 3.0 m/s (Table 6).

The results obtained for blanched samples ranged from 5.71 ± 0.23 mL of water/g of sample at 60°C at 3.0 m/s to 13.46 mL of water/g of sample at 60°C at 2.7 m/s. The statistical analysis indicates that no significant differences occurred for the WHC at 60°C, for which a maximum value of 13.46 mL of water/g of sample and a minimum of

TABLE 6. WHC OF PASSION FRUIT PEEL AT THE END OF THE DRYING PROCESS AT DIFFERENT TEMPERATURES AND AIRFLOW RATES FOR CONTROL AND BLANCHED SAMPLES

Temperature (°C)	Airflow rate (m s^{-1})	Control WHC (mL/g)	Blanched WHC (mL/g)
50	2.4	7.63 ± 1.54^{aA}	6.70 ± 1.22^{aA}
50	2.7	5.75 ± 2.86^{aA}	8.52 ± 1.00^{aA}
50	3.0	4.34 ± 1.10^{aA}	8.70 ± 1.36^{aB}
55	2.4	4.64 ± 3.77^{aA}	6.96 ± 0.24^{aA}
55	2.7	9.45 ± 3.12^{aA}	10.07 ± 1.44^{aA}
55	3.0	7.86 ± 0.07^{aA}	6.71 ± 1.50^{aA}
60	2.4	6.44 ± 3.71^{aA}	6.70 ± 1.79^{aA}
60	2.7	11.58 ± 2.54^{aA}	13.46 ± 0.01^{bA}
60	3.0	12.42 ± 1.35^{aA}	5.71 ± 0.23^{cB}

Values are expressed as the mean ± standard deviation. Means in same row with different capital letters are significantly different ($P \leq 0.05$); means in same column with different lower case letters are significantly different ($P \leq 0.05$).

5.71 mL of water/g of sample for 2.7 and 3.0 m/s occurred, respectively.

Similar results were found for passion fruit by Martinez *et al.* (2012) (13.5 ± 0.15 mL of water/g of sample). Regarding other by-products, orange yielded values of 9.63 ± 0.25 mL of water/g of sample (Crizel *et al.* 2013), mango, 6.4 ± 0.10 mL of water/g of sample and pineapple, 14.6 ± 0.25 mL of water/g of sample (Martinez *et al.* 2012).

In general, the temperature affected the WHC; the minimum values were obtained at 50 and 55°C, and higher values were obtained at 60°C. Most likely, higher temperatures increased the cracks and pores in the flour structure and promoted the entry of water into the matrix, where it was entrapped by the fiber. Blanching did not significantly affect the WHC ($P < 0.05$). Akter *et al.* (2010) reported no significant differences in WHC among blanched and control persimmons fruit peel dried at 60, 70 and 80°C.

The SWC is a technological property that is also related to the hydration capacity of fiber in passion fruit flour due to cellulose components present in the residue (Martinez *et al.* 2012). The results are presented in Table 7. The values of the SWC ranged between 4.47 ± 0.50 mL of water/g of sample to 16.95 ± 3.25 mL of water/g of sample for the control samples and from 9.68 ± 0.18 mL/g to 18.12 ± 2.35 mL of water/g of sample for the blanched samples. However, a relationship between the SWC and temperature or the airflow rate could not be established. However, the highest values of SWC (14.72–16.95 mL of water/g of sample) were obtained for the control samples at the highest temperature. For the blanched samples, at 55°C a significant increase in the SWC was evident, with a maximum of 18.12 mL of water/g of sample at 55°C and 3.0 m/s. The lack of any clear trend could be because the cellulose compounds associated with the SWC were not affected by the drying conditions. Similar effects of the drying temperature on the SWC were reported by Chantaro *et al.* (2008) for fiber from carrot peel. They also reported a significant effect of a blanching pretreatment that increased the SWC, unlike our results, probably because different cellulose compounds were present in carrots and passion fruit.

OHC

The OHC is a technological property related to the capacity of a substance to retain oil. This capacity is relevant mainly in the frying industry, because the inclusion of a substance with a high OHC in a product could improve oil retention during frying, which prevents fat leaching to the food surface and, more importantly, could benefit digestion by reducing the oil in the digestive tract. Additionally, OHC can control the loss of fat during cooking, which favors flavor retention (Crizel *et al.* 2013).

For the control samples, the OHC values ranged from 2.98 ± 0.09 g of oil/g of sample at 50°C and 3.0 m/s to 5.16 ± 0.34 g of oil/g of sample at 50°C and 2.7 m/s. Following the same trend as the other technological properties, the OHC was the same for all drying conditions, with significant differences with respect to the airflow rate under certain conditions, mainly at 50 and 60°C. For blanched samples, the range of OHC was 3.48 ± 0.08 g of oil/g of sample at 55°C and 2.4 m/s to 5.15 ± 0.54 g of oil/g of sample at 55°C and 3.0 m/s (Table 8), and no significant differences were found between different runs ($P > 0.05$).

No significant differences were present between the control and the blanched samples ($P > 0.05$), except for those experiments performed at 50°C and 3.0 m/s and 55°C and 2.4 m/s, where significant differences were found. Nevertheless, these differences could be due to variability in the

TABLE 7. SC OF PASSION FRUIT PEEL AT THE END OF DRYING PROCESS AT DIFFERENT TEMPERATURES AND AIRFLOW RATES FOR CONTROL AND BLANCHED SAMPLES

Temperature (°C)	Airflow rate (m s^{-1})	Control SC (mL/g)	Blanched SC (mL/g)
50	2.4	9.34 ± 0.13^{aA}	10.12 ± 1.04^{aA}
50	2.7	9.40 ± 0.13^{aA}	14.44 ± 0.69^{bB}
50	3.0	9.12 ± 0.20^{aA}	10.77 ± 3.66^{aA}
55	2.4	9.89 ± 0.12^{bA}	9.68 ± 0.13^{aA}
55	2.7	4.47 ± 0.50^{cA}	15.89 ± 2.52^{bB}
55	3.0	7.67 ± 2.70^{abA}	18.12 ± 2.35^{bB}
60	2.4	16.64 ± 2.91^{eA}	13.29 ± 0.85^{aA}
60	2.7	14.72 ± 2.22^{eA}	14.82 ± 0.58^{bA}
60	3.0	16.95 ± 3.25^{eA}	9.71 ± 0.01^{aA}

Values are expressed as the mean ± standard deviation. Means in same row with different capital letters are significantly different ($P \leq 0.05$); means in same column with different lower case letters are significantly different ($P \leq 0.05$).

TABLE 8. OHC OF PASSION FRUIT PEEL AT THE END OF DRYING PROCESS AT DIFFERENT TEMPERATURES AND AIRFLOW RATES FOR CONTROL AND BLANCHED SAMPLES

Temperature (°C)	Airflow rate (m s^{-1})	Control OHC (g/g)	Blanched OHC (g/g)
50	2.4	3.14 ± 0.14^{aA}	4.14 ± 0.62^{aA}
50	2.7	5.16 ± 0.34^{bA}	4.79 ± 0.40^{aA}
50	3.0	2.98 ± 0.09^{cA}	4.64 ± 0.57^{aB}
55	2.4	4.37 ± 0.17^{dA}	3.48 ± 0.08^{aB}
55	2.7	4.95 ± 0.51^{dA}	4.92 ± 0.50^{aA}
55	3.0	4.09 ± 0.50^{dA}	5.15 ± 0.54^{aA}
60	2.4	4.31 ± 0.53^{dA}	4.52 ± 1.15^{aA}
60	2.7	5.07 ± 0.63^{bA}	4.86 ± 0.29^{aA}
60	3.0	4.93 ± 0.49^{dA}	5.06 ± 0.64^{aA}

Values are expressed as the mean ± standard deviation. Means in same row with different capital letters are significantly different ($P \leq 0.05$); means in same column with different lower case letters are significantly different ($P \leq 0.05$).

measurements, not indicating a clear effect of the drying conditions.

Even though a wide range in OHC values was seen, the variability was not related to changes in the temperature or the airflow rate. Additionally, the blanching process did not produce a significant effect on the OHC. The OHC values reported in this study are higher than those reported by Martinez *et al.* (2012) for passion fruit dried at 60°C for 12 h (0.9 ± 0.03 g of oil/g of sample) but similar to those reported by Crizel *et al.* (2013) for orange peel dried at 60°C for 4 h (3.63 ± 0.29 g of oil/g of sample).

CONCLUSIONS

The air drying conditions used in this study did not affect the physicochemical and technological properties of passion fruit flour. This implies that a range of temperature of 50–60°C and an airflow rate of 2.4–3.0 m/s are appropriate for drying this residue. However, the shortest drying time (2.5 h) was achieved at a temperature of 60°C and an airflow rate of 2.7 m/s.

Moreover, a blanching pretreatment did not produce a significant increase of D_{eff}, a significant decrease in the drying time, or have any significant effects on the technological properties, because the passion fruit peel by-product was stored frozen prior to use in the assays used in this study. The thawing process can induce extensive damage at the cellular level, which could be considered a pretreatment itself because it increased the D_{eff} values with a consequent reduction of the drying time.

Therefore, to produce a stable passion fruit flour with a high content of bioactive compounds using a hot air drying a process, a temperature of 60°C with an airflow rate of 2.7 m/s is recommended. If the by-product is stored frozen, pretreatment with blanching is not necessary.

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