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Ultrasound-assisted drying of orange peel in atmospheric freeze-dryer and convective dryer operated at moderate temperature

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Abstract: Atmospheric freeze-drying (AFD) at -10 °C and moderate temperature convective drying (MTD) at 50 °C without and with ultrasound application (20.5kW/m^3) were carried out. Alcohol insoluble residue (AIR) and its swelling capacity (SC), water retention capacity (WRC) and fat retention capacity (FRC) were measured in the dried product. Ultrasound significantly shortened the drying time in both processes, the intensification effect being more significant in atmospheric freeze-drying (57 % and 27 % reduction in atmospheric freeze-drying and convective drying, respectively). As regards AIR and WRC, no effect was observed of either the drying temperature or ultrasound application. On the contrary, SC was significantly lower in AFD samples. The FRC of MTD samples was similar to that of the fresh ones and higher than the values obtained for atmospheric freeze-dried samples. Therefore, convective drying at moderate temperature preserved the AIR properties better than atmospheric freeze-drying.

Keywords: By-product; process intensification; fiber; alcohol insoluble residue

1. INTRODUCTION

Citrus fruits are among the most-heavily harvested fruits in the world. Most of the production is destined for to the juice industry, where approximately 50% of the total fruit weight is discarded, generating a large amount of waste. These residues, mainly peels, can be used as a source of valuable bioactive compounds [1] with commercial and technological applications, such as dietary fiber [2, 3] used to fortify food products. In this sense, citrus peels have a high moisture content which made them very susceptible to the degradation reactions. Drying processes represent an optional means of producing a stable and high quality by-product, which becomes raw matter for later processing with convective drying, at high (HTD) or moderate temperatures (MTD), being the most commonly-used conventional technique. However, this operation may induce undesirable structural damage, color alterations and content reduction of nutritional compounds [4, 5]. As a result, there is growing interest in applying alternative techniques, which imply higher quality products, such as atmospheric freeze-drying (AFD) [5]. AFD consists of water removal by sublimation at atmospheric pressure using drying air at low temperature and relative humidity, keeping the product frozen while being dried [5, 6]. This process is dependent on the air drying characteristics (temperature, velocity and relative humidity) and the food properties (dimensions, porosity, initial moisture content, etc) [7]. AFD can be used to dry different foods, obtaining high quality dried products [6, 8].

Both elevated air temperatures (HTD and MTD) and long processing times (AFD) can cause quality loss in foods, affecting, for example, the properties of the fiber. In order to reduce these impacts caused by convective drying processes, combined techniques, such as the application of power ultrasound (US), may be considered. US can induce a reduction in the external and internal mass transfer resistance with only a mild thermal effect [5]. In a solid porous product, US causes a series of rapid compressions and expansions (sponge effect) facilitating the exit of water through the microchannels created by the propagation of the waves [6, 8]. The influence of US application has been addressed in order to shorten the processing time of fruits and vegetables [10-12].

Therefore, the main objective of this study was to address the influence of process characteristics, atmospheric freeze-drying (AFD) and convective drying at moderate temperature (MTD), and power ultrasound application on the drying kinetics and functional properties of orange peel.

2. MATERIAL AND METHODS

2.1. Raw Material

Valencia Late var. oranges (*Citrus sinensis*) were purchased in a local market (Valencia, Spain). Homogeneity of size and color was the criterion considered when choosing the fruits. The oranges were washed and superficially dried. Rectangular shell samples (containing only flavedo and albedo tissue) of 48±1 x 26±1 x 3.18±0.04 mm were obtained using sharp knives. The initial moisture content was measured by placing the samples in a vacuum oven at 70 °C and 200 mmHg until constant weight [13].

2.2. Drying experiments

Two convective drying techniques were examinated, AFD (water removal by sublimation) and MTD (water removal by evaporation), and the influence of ultrasound application was addressed in both cases. Every kind of drying condition considered was tested in triplicate.

2.2.1. Atmospheric freeze-drying experiments

Before the AFD process, 18 orange peel samples were placed in a tree-shaped sample holder, previously described [5, 6], that ensured free-flowing air around them and a homogenous ultrasonic treatment. The set was covered with a plastic waterproof film and placed in a blast freezer (HIBER, model ABBBF051, Italy) at -35±1 °C for 1 h. This was long enough to reach a temperature of -18 ºC in the center of the samples. Immediately after this, the samples were unwrapped and transferred to an ultrasound-assisted convective dryer with air recirculation adapted to work at low temperatures [6]. The drying chamber is a cylinder (internal diameter 100 mm, height 310 mm, thickness 10 mm) attached to a piezoelectric transducer (21.9 kHz) that produces an internal high intensity ultrasonic field. The drying air is recirculated in the system, controlling both the air velocity and temperature by means of two PID control algorithms. The drying experiments were performed at -10±1°C and 1 m/s, without (AFD) and with (AFD-US; 20.5 kW/m^3) ultrasound application. In order to keep the relative humidity low (maximum value of 15%, measured with a KDK sensor, Galltec+Mela, Germany), the air is forced to flow through a tray containing desiccant material (Activated Alumina AC14, Alfphachem, Spain) which is periodically regenerated. The drying kinetics were determined from the initial moisture content of orange peel samples and the variation in sample weight during the process. The experiments were performed until the samples lost 60% of their initial weight.

2.2.2. Convective drying experiments at moderate temperature

Fresh orange peel samples (18 pieces) were placed in a similar sample holder to that used in AFD experiments. MTD experiments were performed at a temperature of 50 °C and an air velocity of 1m/s, without (MTD) and with (MTD-US; 20.5 kW/m^3)

ultrasound application until the samples lost 60% of their initial weight. The ultrasonically-assisted dryer used for this purpose has been described previously [14]. The characteristics of the drying chamber and the ultrasonic field applied were similar to those tested for AFD experiments.

2.3. Modeling of drying kinetics

The modeling of the experimental data permits the comparison and quantification of the influence of the process variables on the kinetics; the theoretical models, like the diffusion-based models, are the most adequate for this purpose because they permit insight to be gained from the phenomena involved in the drying. However, the different mechanisms of moisture removal involved in the experiments considered, evaporation in MTD experiments and sublimation in AFD ones, makes the application of this kind of model difficult. Moreover, while the moisture movement inside the MTD samples can be assumed to be due to diffusion in the overall volume, in the AFD samples it only takes place in the external dried layer whose thickness increases at the expense of the internal frozen core. Since the main aim of this study was not the development of a model but rather the quantification of the influence of process variables on drying kinetics, the empirical Weibull model, a model widely used in drying [15], was considered (Equation 1)

$$\Psi = \frac{X_{eq} - X_t}{X_{eq} - X_0} = e^{\left(-\frac{t}{\beta}\right)^{\alpha}} \qquad (1)$$

Where Ψ is the dimensionless moisture content; X_t is the moisture content (kg water/kg dm) at a drying time t (s); X_0 is the initial moisture content of samples (kg water/kg dm); X_{eq} is the moisture content at equilibrium, which was determined from the relative humidity of the drying air and the orange peel isotherm reported by Garau et al. [16]; and α and β are the parameters of the Weibull model. The parameter α is the shape factor and represents a behavior index of the product: the higher its value, the lower the initial velocity of the process. Values of more than 1 predict downtimes in the process and when the value is 1, the Weibull model becomes a first order kinetic model. *β,* on the other hand, is related with the kinetics of the process, showing a reverse relationship with the drying rate. This parameter includes the effects on the kinetics of variables, such as the temperature, air velocity or, in this case, ultrasound application.

The Weibull parameters were identified by minimizing the sum of squared difference between the experimental and calculated moisture contents of the samples. For this purpose, the SOLVER tool of Microsoft Excel (Excel from Microsoft Office Professional Plus 2016 TM) was used to apply the optimizing method of the Generalized Reduced Gradient.

The percentage of explained variance (% VAR) was used to evaluate the fit of the model, following Equation (2).

$$VAR = \left[1 - \frac{S^2_{calc}}{S^2_{ex}}\right].100 \qquad (2)$$

Where S^2_{calc} and S^2_{ex} are the calculated and experimental variances, respectively [5].

2.4. Alcohol insoluble residue (AIR)

In order to evaluate the product's functional properties, the alcohol insoluble residues (AIR) were obtained according to Garau et al. [17], with some adaptations. For this purpose, 1.5 g of the ground dried sample (5 g in the case of the fresh sample) were placed in an ethanol-water solution (85% v/v) and homogenized with an ultraturrax (mod. T25, dispersion tool S25N-18 G; IKA Labortechnik). After a boiling-cooling cycle, the sample was filtered. These steps were repeated twice with 85 and 96% v/v ethanol-water solutions. The residue contained in the filter was washed with acetone (99% v/v) and kept in a vacuum oven at 60 °C for moisture removal. The AIR was expressed as g AIR/100 g dm.

2.5. Functional Properties of AIR

The swelling capacity (SC), water retention capacity (WRC) and fat retention capacity (FRC) were determined for the purposes of addressing the influence of the kind of water removal mechanism (evaporation or sublimation) and ultrasound application during drying on the quality of the dried orange peel. All of the determinations were carried out in triplicate, at least.

2.5.1. Swelling capacity (SC)

The SC was measured according to Daou and Zhang [18], but adapted to the product. To this end, 0.2 g of AIR were placed in a graduated test tube, 10 mL of distilled water were added and the tubes were left to stand for 24 h at room temperature (25±1 ºC). The SC was calculated from the difference between the final and initial volumes of the sample and expressed as mL /g of AIR dm.

2.5.2. Water retention capacity (WRC)

The WRC was measured according to Garau et al. [17]. For this purpose, the AIR samples (0.2 g) were hydrated in 10 mL of distilled water for 24 h in centrifuge tubes. Afterwards, the samples were centrifuged (Medifriger BL-S, Selecta, Spain) at 10,000 r.p.m. for 15 min at 25 ºC. The excess supernatant was decanted and the WRC expressed as g water/g of AIR dm.

2.5.3. Fat retention capacity (FRC)

The AIR samples (0.2 g) were immersed in 10 mL of sunflower oil for 24 h at room temperature (25±1 ºC) and then centrifuged (Medifriger BL-S, Selecta, Spain) at 6,000 r.p.m. for 15 min at 25 ºC, according to Garau et al. [17]. The FRC was expressed as g oil/g of AIR dm.

2.6. Statistical analysis

For the statistical analysis, α, β, AIR, SC, WRC, and FRC were considered as dependent variables and the drying process (AFD or MTD) and the application of ultrasound as factors. The analysis of variance (one way ANOVA) was calculated using Statgraphics Centurion XVI (StatPoint Technologies, Inc), to check the significance ($p<0.05$) of the differences between the values of each dependent variable. The Least Significant Difference (LSD) intervals were also estimated to determine the significance of the differences between treatments. Moreover, the values from the replicates of the different kinds of experiments carried out were averaged and represented as mean and standard deviation.

3. RESULTS AND DISCUSSION

3.1. Experimental drying kinetics

The initial moisture content of the orange peel was 2.47±0.08 (kg water/kg dm), similar to that found by Tasirin et al. [2]. The air drying temperature and ultrasound application influenced the length of the drying process (Figure 1). The average time required to reach a moisture content of 0.5 kg of water/kg of dm in the MTD experiment (3.8±0.3 h) was 95% shorter than that needed in the AFD experiment (93±18 h). The increase in the process temperature and the liquid state of water promote a higher heat transfer rate between the heat source, which is the drying air, and the product, leading to faster moisture removal [19]. During low temperature drying, there is less energy available to promote moisture loss through the sublimation process and transport the moisture from the product to the surface. However, losses in nutritional and technological properties can occur as the drying temperature rises [11, 20].

Ultrasound application led to an intensification of the drying process, promoting a significantly shorter drying time in every condition analyzed ($p < 0.05$) (Figure 1). Thus, in the AFD-US experiment, the processing time required to reach 0.5 kg of water/kg dm (40±6 h) was 57% shorter than in the AFD (93±18 h). In the case of the MTD experiments, the application of ultrasound meant that by 23% shorter drying time was required to attain the same moisture content (3.0±0.4 h for MTD-US vs. 3.8±0.3 h for MTD). The most significant effect of US application occurred at low temperatures. This can be explained by the fact that the mechanical energy generated by US is constant in every case, and the lower the drying temperature, the higher the proportion that it represents in relation to the total energy available in the drying system [11, 21, 22].

The influence of temperature and ultrasound application was also found in the evolution of the drying rate. Thus, as can be observed in Figure 2, the drying kinetics occurred in the falling rate period for every condition considered. As the drying progressed, however, the drying rate fell more quickly in the MTD experiments than in the AFD and in the ultrasonically-assisted samples than in the conventional ones (MTD-US and AFD-US compared to MTD and AFD, respectively).

3.2. Modeling

The Weibull model fitted the experimental evolution of the moisture content during drying adequately, as shown by the similar trend of the calculated and experimental drying kinetics (Figure 1) and the values of the percentage of explained variance achieved, over 99 % in every case (Table 2).

The figures identified for the shape factor, α, demonstrated the differences between the MTD and AFD experiments. Thus, in the case of the AFD experiments, α was lower than 1.0, indicating the process was mainly controlled by the internal resistance to mass transfer. At this temperature, -10 ºC, the moisture movement inside the material is very slow, and the influence of external resistance becomes negligible. On the contrary, the values of α identified in the MTD experiments were over 1.0, indicating the existence of downtimes during the process. Thus, the low air velocity used, 1 m/s, did not reduce the boundary layer thickness enough to compensate for the faster internal moisture transport that took place at 50ºC (MTD experiments) compared to -10ºC (AFD experiments). Therefore, in the MTD conditions tested, both internal and external resistances influenced the moisture removal. The application of ultrasound did not significantly affect the shape factor, meaning that ultrasound was not observed to exert any significant influence on the relative importance of internal and external resistances.

The identified values of the β parameter also demonstrated the big difference between the two drying temperatures tested, being two orders of magnitude larger in the AFD experiments than the MTD ones (Table 1). The reverse relationship between this parameter and the kinetics must be highlighted. These results show that there is big resistance to mass transport in the low temperature process, leading to a long processing time. During AFD, the removal of the moisture in the orange peel took place by sublimation, whereas in MTD this process was by evaporation. This, and the differences in the amount of energy available in the system due to the different drying-air temperatures, may explain the differences in the magnitude.

Ultrasound application also significantly affected the drying velocity in both kinds of drying experiments. Thus, the β parameter identified in ultrasonically-assisted AFD experiments was 38% lower than the one identified in the non-assisted ones. In the case of the MTD experiments, the reduction was 31%. These results showed that the increase in drying kinetics produced by ultrasound was greater at the lowest drying temperature tested. This coincides with what has been reported by other authors [22, 23] and can be explained, as pointed before, by the fact that the mechanical energy supplied by US is constant in every experiment. So, at low temperatures, the proportion of ultrasonic energy in relation to the total energy available is greater than at higher temperatures [22]. Ultrasound can affect external mass transport, by inducing microstirring at interfaces, and internal mass transport, due to the mechanical stress provoked by the compression and expansion acoustic forces. In the latter, it must be taken into account that while ultrasound influences the whole sample in the case of MTD experiments, it only affects the external dried layer in the AFD because no movement of molecules can take place in the frozen core. In any case, the Weibull model does not permit a clear distinction between the ultrasound effects on internal and external resistances.

3.3. Alcohol insoluble residue (AIR)

The average AIR value of the fresh sample (52.89±3.08 g AIR/100 g dm) was similar to that reported by Garau et al. [17] (48.30 g AIR/100 g dm). The small difference observed can be attributed to the different variety of orange (Canoneta vs. Valencia Late variety) and the natural variability of the raw matter. The drying processes considered did not produce changes in the AIR content of the samples. Thus, the AIR values measured in the samples dried under the different conditions were not significantly ($p<0.05$)

different from those measured in the fresh samples. In this sense, Garau et al. [17] reported no influence of drying temperature on the AIR of orange peel.

3.4. Functional properties

The functional properties can be correlated with the quality of dietary fiber and the processing, such as drying, can affect both the physical properties of the fiber's matrix and also the hydration capacity [24]. For that reason, and for the purposes of evaluating the effects caused by the processing on the structure of the cell wall-forming polysaccharides of orange peel samples, the swelling capacity (SC), water retention capacity (WRC) and fat retention capacity (FRC) were measured.

Drying produced a marked reduction in the SC of the AIR from orange peel (Figure 3). Thus, the SC was by 65% lower in the AIR from the MTD experiments (18.52±1.45 mL/g AIR dm) than in the AIR from the fresh samples (52.53±1.13 mL/g AIR dm). The application of US in these conditions (MTD-US) did not significantly affect the observed SC (17.34±1.01 mL/g AIR dm). The swelling capacity is an important property of fibers and is related with a satiating effect. Therefore, maintaining this characteristic may not only be beneficial for human health but may also lead to improvements in the food industry applications [25].

As for the AIR from the AFD experiments (10.51±5.61 mL/g AIR dm), the SC reduction was significantly greater than that observed in the AIR from the MTD and MTD-US experiments ($p<0.05$). Garcia-Amezquita et al. [26] reported a higher SC in the powder of orange peel obtained by convective drying at 55 ºC than in the powder of orange peel obtained by vacuum freeze-drying. The lower values of the SC during the AFD experiments can be attributed to the structural changes caused by the formation of the ice crystals in the food matrix, which leads to a gradual collapse in the tissue organization and cellular destructuration during the long process time needed by this kind of drying. Besides, the effect of ultrasound application in these conditions (AFD-US) produced an AIR with a SC (16.98±1.50 mL/g AIR dm) similar to that observed in the MTD and MTD-US experiments. This can be explained by the fact that the ultrasonic effects are more pronounced in a more rigid and porous matrix, such as that provided by the freezing and sublimation of the orange peel during the atmospheric freeze-drying process. These effects significantly shorten the drying time and this may contribute to the lower degree of degradation of the SC in the AFD-US than in the AFD experiments.

The water retention capacity (WRC) was also analyzed in the AIRs of both fresh and dried orange peel. Thus, the average measured WRC (g of water/g AIR dm) values were 18.12±1.71 for the fresh sample, 18.43±3.70 for the AFD; 16.86±3.01 for the AFD-US, 19.23±1.19 for the MTD and 19.18±1.01 for the MTD-US. The determination of Least Significance Intervals ($p<0.05$) demonstrated that the small differences between treatments were non-significant ($p<0.05$). Abou-Arab et al. [27] reported small differences in the WRC of orange peel powder obtained from solar, convective and microwave drying (no temperature data is provided). Garcia-Amezquita et al. [26] also found small differences in the WCR between hot air dried (55 ºC) and vacuum freeze-dried orange peel. These results could indicate that the different drying conditions tested do not significantly affect the WRC, which is of interest, as the processed product is similar to the fresh one. The WRC is an important factor because, according to Nesrine et al. [28], it allows these by-products to be used as functional ingredients by reducing the amount of calories ingested, preventing syneresis in dairy products and modifying the viscosity and texture of others.

The FRC values were affected by the processing (Figure 4), as it has been previously reported by Garau et al. [17]. After drying, the AFD experiments showed a significant 31% reduction in the FRC (6.5±0.5 g of oil/g AIR dm) compared to the fresh sample (9.5±0.4 g of oil/g AIR dm), while the reduction in the MTD experiments (9.4±0.8 g of oil/g AIR dm) was negligible. The differences between the AFD and MTD experiments were significant ($p<0.05$), indicating a trend toward a better fat retention capacity in the samples processed at higher temperatures. Similar behavior has been found by Garcia-Amezquita et al. [26] after the freeze-drying and convective drying (55º C) of orange peel. In the same sense, Garau et al. [17] also observed a higher FRC in the orange peel samples dried at 50 °C than in others dried at lower temperatures. The application of power ultrasound promoted an increase by 17% in the FRC value of the AIR from the AFD-US experiments (7.6±0.8 g of oil/g AIR dm) compared to the AFD ones, these differences not being significant ($p<0.05$) probably due to the great variability. The shortening of the atmospheric freeze-drying process produced by ultrasound could limit FRC degradation. On the contrary, the FRC observed in the AIR from the MTD and MTD-US experiments was the same (9.4±0.8 g vs. 9.4±0.3 of oil/g AIR dm, respectively). The results show that convective drying at moderate temperature was more effective than atmospheric freeze-drying as a means of preserving the FRC of the AIR obtained from orange peel. In atmospheric freeze-drying conditions, ultrasound application could contribute to this preservation. This preservation is important for industrial applications because it can promote flavor retention, increase the yield of food products and impart greater stability to the products and emulsions [28].

4. Conclusions

The process characteristics linked to temperature and ultrasound application significantly influenced both the orange peel drying kinetics and the quality of the alcohol insoluble residue obtained from dried products. The processing time was highly dependent on the mode of moisture removal (sublimation or evaporation) and ultrasound application. Even with the intensification of the process resulting from the application of ultrasound, atmospheric freeze-drying required a very long time to reach the expected final moisture content. The drying conditions tested were found to exert no significant influence on either the alcohol-insoluble residue obtained from dried product or their WRC. On the contrary, atmospheric freeze-drying generated samples with slightly reduced SC and FRC when compared to those obtained with convective drying at 50 °C. Ultrasound application did not significantly affect the fiber quality. Therefore, in the case of orange peel, the AFD did not represent a viable alternative to convective drying at moderate temperatures, neither in terms of drying time nor fiber quality. Moreover, ultrasound application enhanced the drying rate without reducing the functional properties of the fiber. This could be linked to energy saving and consequently to a reduction in process costs. However, this requires further research.

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6. NOMENCLATURE

Acronyms

AFD	Atmospheric freeze-drying
AIR	Alcohol insoluble residues (g AIR/100 g dm)

FRC	Fat retention capacity (g oil/g of AIR dm)
HTD	High temperature drying
MTD	Convective drying at moderate temperature
PID	Proportional-Integral-Derivative
SC	Swelling capacity (mL water/g of AIR dm)
US	Ultrasound
WRC	Water retention capacity (g water/g of AIR dm)

Variables

dm	Dry matter
S^2_{calc}	Calculated variance
S^2_{ex}	Experimental variance
t	Time (s)
X_{eq}	Moisture content at equilibrium (kg water/kg dm)
X_t	Moisture content at time t (kg water/kg dm)
X_0	Initial moisture content (kg water/kg dm)

Greek Letters

α	Shape factor of Weibull model
β	Kinetics factor of Weibull model (s^{-1})
Ψ	Dimensionless moisture content

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FIGURE CAPTIONS

Figure 1. Experimental and calculated evolution of dimensionless moisture during drying of orange peel at: (A) -10 °C without (AFD) and with ultrasound application (AFD-US); (B) 50 °C without (MTD) and with ultrasound application (MTD-US).

Figure 2. Evolution of drying rate during drying of orange peel at: (A) -10 °C without (AFD) and with ultrasound application (AFD-US); (B) 50 °C without (MTD) and with ultrasound application (MTD-US).

Figure 3. SC – Swelling capacity of AIRs from fresh and dried orange peel. Same letter shows homogeneous groups determined by Least Significant Difference ($p<0.05$) intervals.

Figure 4. FRC – Fat retention capacity of AIRs from fresh and dried orange peel. Same letter shows homogeneous groups determined by Least Significant Difference ($p<0.05$) intervals.

TABLE CAPTIONS

Table 1. Weibull model parameters (α and β) identified for the drying of orange peel (Valencia Late var.) at different temperatures, without and with ultrasound (20.50kW/m^3; 21.9 kHz) application.

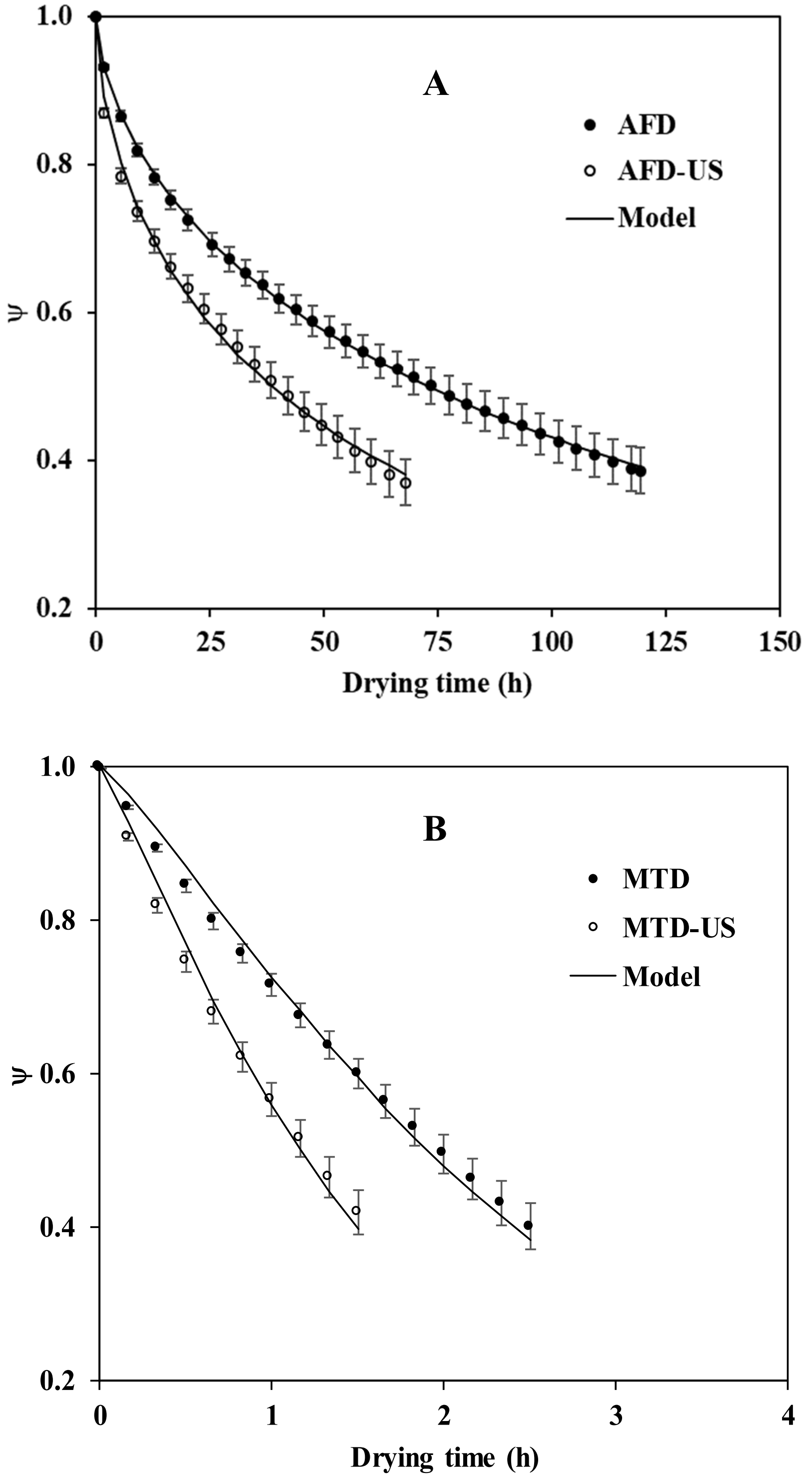

Figure 2. Experimental and calculated evolution of dimensionless moisture during drying of orange peel at: (A) -10 °C without (AFD) and with ultrasound application (AFD-US); (B) 50 °C without (MTD) and with ultrasound application (MTD-US).

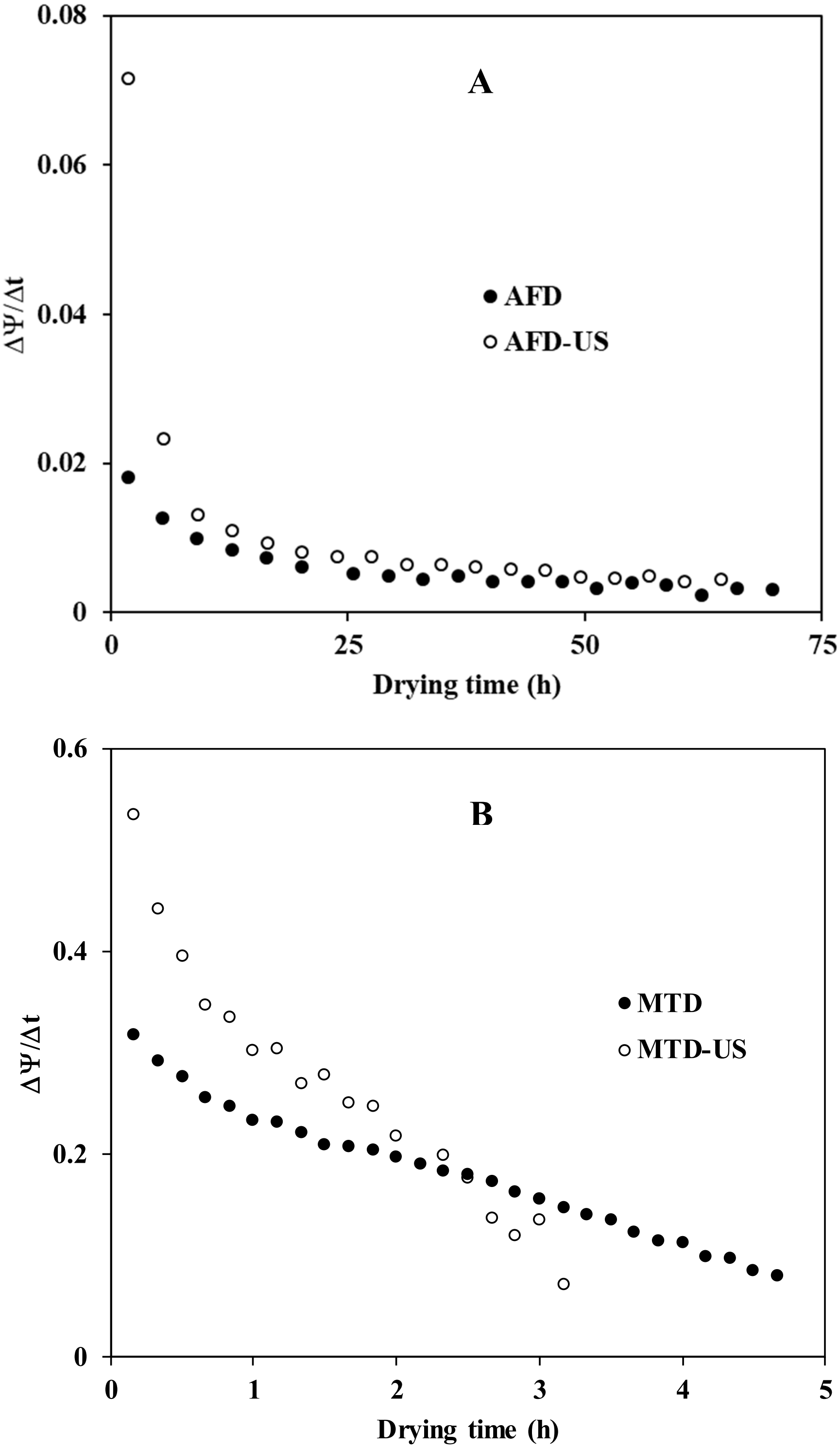

Figure 2. Evolution of drying rate during drying of orange peel at: (A) -10 °C without (AFD) and with ultrasound application (AFD-US); (B) 50 °C without (MTD) and with ultrasound application (MTD-US).

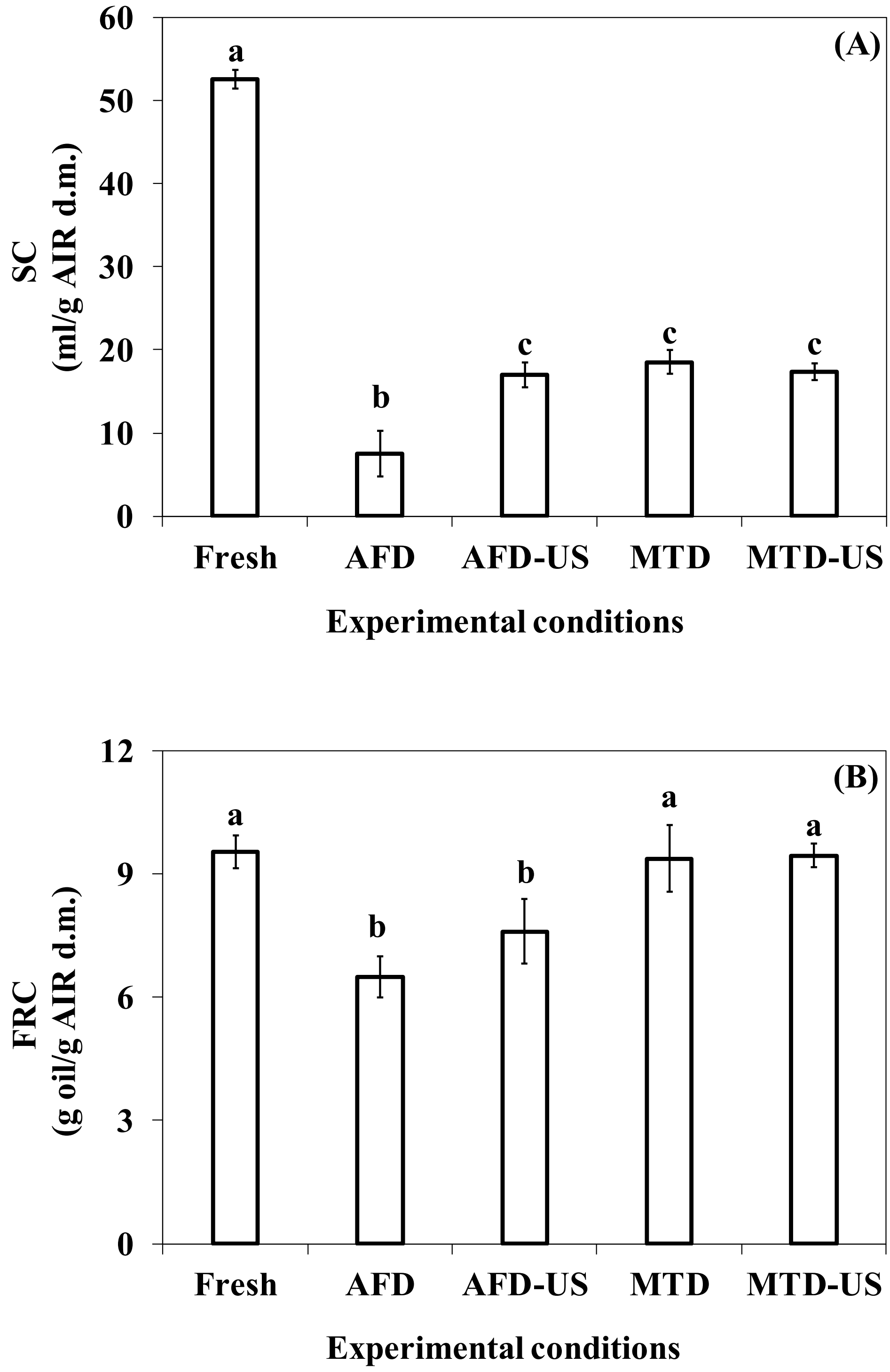

Figure 3. Functional properties of AIRs from fresh and dried orange peel. (A) SC – Swelling capacity; (B) FRC – Fat retention capacity. Same letter shows homogeneous groups determined by Least Significant Difference ($p<0.05$) intervals.

Table 1. Weibull model parameters (α and β) identified for the drying of orange peel (Valencia Late var.) at different temperatures, without and with ultrasound (20.50kW/m^3; 21.9 kHz) application.

Treatment	α	β (s^{-1})	VAR
AFD	0.63±0.02^a	395569±73199^a	99.73
AFD-US	0.60±0.06^a	244711±43912^b	99.64
MTD	1.14±0.08^b	9290±183^c	99.40
MTD-US	1.3±0.2^b	6398±531^d	99.16

AFD (atmospheric freeze-drying; -10 °C), AFD-US (ultrasound assisted atmospheric freeze-drying; -10 °C; 20.5kW/m^3), MTD (convective drying at moderate temperature; 50 °C) and MTD-US (ultrasound assisted convective drying at moderate temperature; 50 °C; 20.5kW/m^3). Letters in the same column show homogeneous groups determined by Least Significant Difference ($p<0.05$) intervals.