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Influence of the temperature and ultrasound application in drying kinetics of apple skin

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Abstract

The great amount of waste produced by food industry contains interesting bioactive compounds. The extraction of these compounds requires the by-products previous stabilization being the convective drying one of most used techniques to this end. Drying conditions can affect both drying kinetics and final quality of products. The apple skin, byproduct of apple juice or cider industries, is rich in functional compounds such as polyphenols or vitamin C. The main goal of this contribution was to quantify the influence of temperature and ultrasound application in drying kinetics of apple skin. For this purpose, drying experiments at different temperatures (-10, 30, 50 and 70 ºC) and with (20.5 kW/m^3) and without application of ultrasound were carried out. Drying kinetics were modelled by using a diffusion based model. As can be expected, the higher the temperature the faster the drying. Ultrasound application accelerated the process at every temperature tested being the influence slightly lower than found from the literature for other products. This can be attributed at the physical structure of the apple skin, less porous than the pulp. In any case, the application of ultrasound significantly reduced the drying time.

Keywords: *by-products; dehydration;diffusivity; mass transfer.*

1. Introduction

The food industry generates a great amount of waste that produces an important environmental impact. However, these by-products could be considered as a source of interesting bioactive compounds.[1] Apple is one of the most consumed fruits in the world.[2, 3, 4] The main by-product generated by juices and cider industries is the apple skin. This by-product presents a very important antioxidant activity [5] containing flavonoids such as cyanidin glycosides and quercetin glycosides which are not present in the pulp.[6, 7] Therefore, it can be used as a source of these compounds or directly as a functional ingredient.[7, 8]

Convective hot air drying is one of the most applied methods to estabilize products and by-products [9] facilitating their management, storage and transport. However, drying can induce significant changes in product quality.[4, 9, 10] Thus, the influence of drying process on antioxidant capacity of apples [11, 12, 13] and apple skin [4] has been already studied. The drying processes at low temperature emerges as an excellent way to preserve the thermal-sensitive compounds.[14] However, at these conditions, the low rate of drying must be intensified to avoid log processing times. [15] In this sense, ultrasound application comes up as an efficient alternative to intensify drying process.[16]

The aim of this work was to assess the influence of the drying temperature and ultrasound application on drying kinetics of apple skin.

2. Materials and Methods

2.1 Sample preparation

Apple fruits (Royal Gala var.) were selected with a similar maturation degree, washed and peeled. Apple skin was blanched in boiling water for 30 s to inactivate the enzyme polyphenol oxidase.[17] Moisture content was determined by differential weighing between fresh and dried samples in an vacuum oven at 60ºC.[18]

2.2 Drying

The drying processes were carried out by an atmospheric freeze-drying and a hot air drying process.

2.2.1 Atmospheric freeze-drying experiments

Samples were placed in a sample-holder, frozen in a blast freezer (HIBER, mod. ABB BF051, Italy) at -35 ± 1ºC and placed in an ultrasonically-assisted convective drier.[15] Drying process was carried out at -10ºC, 2 m/s, without (AIR-10) and with (US-10) ultrasound application (electrical input of 50 W) by triplicate. The process finished when samples lost 85% of its initial weight.

2.2.2 Hot air drying experiments

These experiments were carried out at 30, 50 and 70ºC with (US30, US50, US70) and without (AIR30, AIR50, AIR70) the ultrasound application (electrical input of 50 W).[19] All the runs were performed by triplicate at 2 m/s and until samples lost 85% of initial weight.

2.3 Modelling

An unidimensional diffusion-based model was considered for modelling the experimental drying kinetics (Eq. 1).

$$\frac{\partial W(x,t)}{\partial t} = D_e \frac{\partial^2 W(x,t)}{\partial x^2} \tag{1}$$

Where W is the local moisture content of sample (kg water/kg dry matter, d.m.); D_e is the effective moisture diffusivity (m^2/s); x is the direction of the moisture transport (m); t is the drying time (s). Effective moisture diffusivity was considered constant during the process and it was assumed isotropic and uniform samples. Althougth, at atmospheric freeze-drying conditions, this fact is far from the reality, the model allowed to quantify the influce of the estudied process variables and to compare the drying kinetics.[11] The external layer of apple peel was considered a waterproof surface. The external resistance to mass transport was included in the model by means of Eq. 2.

$$-D_e \rho_{ss} \frac{\partial W_p(L,t)}{\partial x} = k(a_w(L,t) - \varphi_{air}) \tag{2}$$

where a_w is the water activity of samples, ρ_{ss} is the density of the dry solid (kg d.m./m^3), L is the experimental average thickness of the apple peel samples, φ_{air} is the relative humidity of the drying air and k is the mass transfer coefficient (kg water/m^2s). An implicit finite difference method was chosen to estimate the model parameters, D_e and k, using Matlab 2011B® (The Mathworks, Inc, Natick, USA).

The percentage of explained was used to measure the goodness of the model fitting.

$$\%\,VAR = \left(1 - \frac{S_{xy}^2}{S_y^2}\right) \cdot 100 \tag{3}$$

S^2_{xy} and S^2_y are the calculated moisture content of apple peel the variance of the experimental, respectively.

3. Results and Discussion

3.1 Experimental drying kinetics

The initial moisture content of apple skin was 4.99 ± 0.07 (kg water/kg d.m.). Only the falling rate of moisture content was considered in drying kinetics.

As expected, temperature significantly affected the process kinetics; the higher the temperature the faster the drying (Table 1). Thus, the average time needed to reach a moisture content of 1 kg of water/ kg of dry matter at 30ºC was 4.6 times greater than those needed at 70 ºC. The atmospheric freeze-drying experiments were the slowest processes due to the low level of energy available for moisture transport at these conditions.

Ultrasound application significantly shorten the drying processes (Fig. 1). The influence in time process reduction was higher as lower the drying temperature. Thus, the drying at atmospheric freeze-drying conditions (-10 ºC) assisted by ultrasound was 3.2 times faster than without ultrasound. At 30 º C, ultrasound application produced a 2.4 times shortening of drying process.

Table 1. Drying time needed to achieve a moisture content of 1 kg water/kg dry matter during drying of apple peel at different temperatures without ultrasound application.

Treatment	**Drying time (h)**
AIR-10	68.1 ± 23.4
AIR30	4.1 ± 0,92
AIR50	1.3 ± 0,29
AIR70	0.9 ± 0,10

3.2 Drying kinetics modeling

Taking into account the limitation of the model used, the modelling permitted to quantify the influence of the process variables on drying kinetics. The figure of the explained variance obtained showed the goodness of the model fit to the experimental data (Table 2).

Temperature significantly affected the values of D_e identified. Thus, the higher the temperature the greater the D_e figure. It can be highlithed the fact that the value of D_e found at atmospheric freeze-drying conditions (-10 ºC) was one order of magnitude smaller than those identified at temperatures above freezing point (Table 2). As a general rule, the identified D_e were in the range than those found by others authors drying apple flesh at similar temperatures.[11, 12, 13]

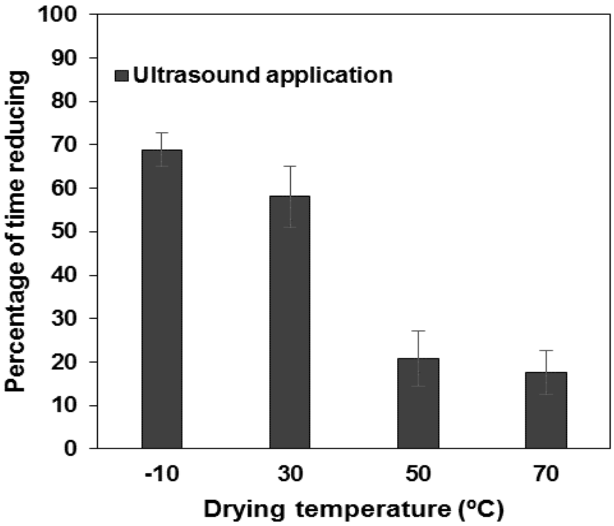

Figure 1. Percentage of time reduction by the application of ultrasound (50 W) during apple skin drying at different temperatures.

The relationship between D_e and temperature was modeled using an Arrhenius type equation (Eq. 4).

$$D_e = D_0 exp\left(\frac{E_a}{RT}\right) \tag{6}$$

Where D_0 is a pre-exponential factor (m^2/s), E_a is the activation energy (kJ/mol), R is the universal gas constant (kJ/mol K) and T the absolute temperature (K). The fit for AIR experiments was adequate ($r^2>0.99$) and the E_a obtained, 32.51 kJ/mol, was in the range of products such as passion fruit peel [20].

Ultrasound application increased the identified D_e value being this increase higher as lower was the drying temperature. Thus, at -10 ºC, ultrasound application increased 74% the D_e while this increase was only 10 % at 70 ºC. This fact has been preoviously observed in other products such as apple flesh [12] or passion fruit peel [20]. The D_e observed in the US experiments at at -10, 30 and 50 ºC also followed an Arrhenius type relationship (r2>0.99). The E_a obtained for these experiments was lightly lower than those found for AIR experiments (25.86 kJ/mol for US vs 32.51 kJ/mol for AIR) that would indicate that the US assisted drying will could be a less temperature dependent process than the AIR experiments. This fact means that the ultrasound application can make possible the lowering of the drying temperature. The pre-exponential factor was also lower for US ($1.6\cdot10^{-5}$ m^2/s) than for AIR experiments ($8.6\cdot10^{-5}$ m^2/s).

As for the mass transfer coefficient (k) neither temperature nor ultrasound application significantly affected the figures identified (Table 2). However other authors have found significant influence of these variables on k [11, 12]. This fact could indicate that, at the drying conditions tested, the influence of external resistanced compared with the internal one was negligible. Therefore, the effect of studied variables on internal resistence could mask the effect on external one and then, the model can not identify any influence on k.

Table 2. Effective diffusivity and mass transfer coefficient identified by using a diffusion model. Percentage of variance explained by the model. Letters in the same column show homogenous groups determined for Least Significance Difference ($p<0.05$) intervals.

Treatment	**D_e (x 10^{-10} m^2/s)**	**k (x 10^{-3} kg water/m^{2}s)**	**% var**
AIR-10	0.3 ± 0.1^{a}	1.9 ± 0.4^{a}	98.7
AIR30	1.7 ± 0.6^{b}	0.8 ± 0.2^{b}	99.1
AIR50	5 ± 3^{c}	1.9 ± 0.5^{a}	99.6
AIR70	9 ± 2^{d}	2.3 ± 0.2^{a}	99.9
US-10	1.16 ± 0.02^{b}	2.0 ± 0.4^{a}	98.4
US30	5.49 ± 0.02^{c}	1.8 ± 0.3^{a}	99.4
US50	10 ± 2^{d}	2.0 ± 0.3^{a}	99.8
US70	10 ± 1^{d}	2.4 ± 0.7^{a}	99.8

In view of the results obtained, the ultrasound application can be considered as an interesting means of intensify drying processes at moderate temperatures.

4. Conclusion

Temperature and ultrasound application are able to significantly affect the apple skin drying. The higher the temperature the faster the process. The ultrasound application can also reduce the drying process time being this reduction more significant as lower the temperature. The atmospheric freeze-drying of apple peel was a very time consuming process even when was intensified by an ultrasound application.

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