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Ultrasonically assisted low-temperature drying of desalted codfish

J.V. Santacatalina, M.E. Guerrero, J.V. Garcia-Perez, A. Mulet, J.A. Cárcel*

Grupo ASPA, Departamento de Tecnología de Alimentos, Universitat Politècnica de València, Camí de Vera s/n, E46022, València, Spain

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Low-temperature drying (LTD) constitutes an interesting means of dehydrating foodstuffs, thus preserving the quality of the product. Power ultrasound (US) generates several mechanical effects that could help to shorten the long drying times associated with LTD. In this work, the feasibility of using US in LTD of desalted cod was assessed.

For this purpose, desalted cod slices (50 × 30 × 5 mm) were dried (2 m/s) at different temperatures (10, 0 and −10 °C) without (AIR) and with (AIR + US, 20.5 kW/m^3) US application. Afterwards, the dried samples were rehydrated in distilled water (25 °C). A diffusion model was used to describe both drying and rehydration kinetics. The color and hardness of both dried and rehydrated cod samples were also measured.

The application of US increased the drying rate at every temperature tested, shortening the drying time by 16% at 0 °C and up to 60% at −10 °C. The ultrasonically assisted dried samples presented a rehydration rate which was slightly lower than that of those that had been conventionally dried, but they were harder and whiter, which is more suited to consumer preferences. Therefore, power ultrasound could be considered an affordable technology with which to accelerate LTD of desalted cod, providing high quality dried products.

1. Introduction

Dried and salt-cured cod (*Gadus morhua*) is a highly-appreciated product due to its high nutritional value (high protein and low fat content) and its particular sensory properties. It is mainly produced in Norway and Iceland and primarily consumed in the Southern European countries, such as Spain and Portugal (Martínez-Álvarez & Gómez-Guillén, 2013; Oliveira, Pedro, Nunes, Costa, & Vaz-Pires, 2012). The high salt concentration of this product (approximately 20% w/w) prevents its degradation but limits its direct consumption; for this reason salted cod must be desalted (Ozuna, Puig, Garcia-Perez, & Cárcel, 2014a), a process that takes approximately 24 h. This slow salt diffusion constrains the consumption of salted cod for both domestic use and the catering industry. In addition, the desalting converts the cod into a highly perishable product (Fernández-Segovia, Escriche, Fuentes, & Serra, 2007) and, in fact, the fish must be either immediately consumed, chilled or frozen (Lauritzsen et al., 2004). Therefore, it could be interesting to explore alternative preservation methods, such as drying, that ensure both the desalted product's stability and the retention of the sensory attributes (Andrés, Rodríguez-Barona, & Barat, 2005). The desalted and dried cod may be used as an ingredient in prepared foods, such as instant meals or ready-to-use products, due to its low salt content and rehydration ability.

Convective drying constitutes a traditional dehydration method for foodstuffs (Garcia-Perez, Ozuna, Ortuño, Cárcel, & Mulet, 2011). The use of high air temperatures accelerates the drying kinetics, but causes chemical and physical changes that can affect the quality traits of the dried product (Soria et al., 2010). Consumer demand for high quality products has encouraged research into alternative techniques to minimize quality degradation during processing. In this sense, low temperature drying (LTD) could be an interesting method. However, the long drying times linked to LTD could limit its use on an industrial scale.

Power ultrasound (US) has been used to speed up the convective drying of several foodstuffs (Cárcel, Garcia-Perez, Riera, & Mulet, 2011; Gallego-Juárez et al., 2007; Garcia-Perez et al., 2011), mainly by introducing mechanical energy. The ultrasonic waves generate alternating expansions and contractions when travelling across a medium, which have a similar effect to that found in a sponge when

* Corresponding author.
E-mail address: jcarcel@tal.upv.es (J.A. Cárcel).

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it is repeatedly squeezed and released (Gallego-Juárez et al., 2007). This mechanical stress helps the water move from the inner parts of the product to the surface and could create microscopic channels that reduce the internal resistance to mass transfer (Gallego-Juárez, 2010). Moreover, in solid/gas systems, the application of US also produces oscillating velocities, micro-streaming and pressure variation at the interfaces, which reduce the boundary layer and, as a consequence, improve water movement from the solid surface to air. Therefore, US could help to reduce both the external and the internal mass transfer resistance without introducing a significant amount of thermal energy during drying (Cárcel et al., 2011). In this sense, the feasibility of US application during the LTD process of different products, such as apple (Garcia-Perez, Cárcel, Riera, Rosselló, & Mulet, 2012; Santacatalina et al., 2014), salted cod (Ozuna, Cárcel, Walde, & Garcia-Perez, 2014b), green peas (Bantle & Eikevik, 2011), carrot or eggplant (Garcia-Perez et al., 2012) has been proved. More research has been done on analyzing the effect of US on the drying kinetics than on the product quality (Pingret, Fabiano-Tixier, & Chemat, 2013). Therefore, the aim of this work was to evaluate the feasibility of using US in LTD of desalted cod, analyzing not only drying and rehydration kinetics but also quality parameters, such as color and texture.

2. Materials and methods

2.1. Raw material and sample preparation

A homogeneous batch of salted cod (*G. morhua*) was provided by a local supplier (Carmen Cambra S. L., Spain). The pieces of salted cod averaged 1.5 ± 0.25 kg. Parallelepiped-shaped samples (50 × 30 × 5 mm) were obtained from the central part of the cod loin using a sharp knife and, afterwards, were wrapped in plastic waterproof film and kept refrigerated at 2 ± 1 °C (maximum storage time 120 h) until the desalting process took place. For that purpose, the slices of salted cod were immersed in water (70 g cod/L water) of low mineral content (Cortes S.A., Spain) at 4 ± 1 °C for 24 h. After desalting, the surface water was removed with tissue paper. Then the samples were wrapped in plastic waterproof film and separated into three batches. Two of them were kept in refrigeration at 2 ± 1 °C (maximum storage time 4 h) until the drying experiments were conducted (samples dried at 0 and 10 °C). The third (samples dried at −10 °C) was frozen by placing samples at −18 ± 1 °C until processing (at least 72 h).

The moisture and the NaCl content of the cod samples were measured before and after desalting following standard methods 950.46 and 971.27, respectively (AOAC, 1997). Thus, the moisture content was obtained by the difference of weighting between salted or desalted cod samples and the same cod samples dried at 105 °C until they achieved constant weight (24 h approximately). For the NaCl measurement, approximately 0.5 g of ground sample was placed into 100 mL of distilled water and homogenised at 9500 r.p.m. for 5 min with an ultra-turrax mod. T25 provided with a dispersion tool mod. S25N-18G (IKA Labortechnik, Janke & Kunkel GMBH & Co, Staufen, Germany). The chloride content of the extract was determined in triplicate using a chloride meter (Ciba Corning, mod. 926. L; Halstead, Essex, United Kingdom). Thus, the average value of the moisture content of desalted cod was 4.42 ± 0.02 kg water/kg dry matter of desalted cod (dmdc) and the NaCl content was 0.023 ± 0.001 kg NaCl/kg dmdc.

2.2. Drying experiments

Drying experiments were carried out in a convective drier with air recirculation (Fig. 1), already described in the literature (Garcia-Perez et al., 2012). The system provides an automatic temperature and air velocity control. Moreover, an ultrasonically activated cylindrical radiator generates a high intensity ultrasonic field (155 dB) in the drying chamber. Drying experiments were conducted using a constant air velocity (2 m/s) at three different temperatures (10, 0 and −10 °C), without (AIR) and with (AIR+US, 20.5 kW/m^3) US application. Drying kinetics were obtained by weighing samples at preset times (interval of 15 min) and considering the initial moisture content. In every case, the initial mass load was of 138.7 ± 6.9 g (10 cod slices) and the relative humidity of drying air was maintained below 10 ± 3% during the whole drying process.

The drying experiments were replicated at least three times for each drying condition tested and extended until samples lost 65 ± 3% of the initial weight. After drying, the moisture content of the samples was also measured following standard method 950.46 (AOAC, 1997). Finally, the dried samples were vacuum-sealed and stored in refrigeration (0 ± 1 °C; maximum storage time 4 days) until the quality analyses (rehydration, color and texture) were carried out.

2.3. Modeling of drying kinetics

A diffusion model was used to describe the drying kinetics. The mass transport was considered to be one-dimensional due to the fact that sample thickness (5 mm) was 1/6 (30 mm) and 1/10 (50 mm) shorter than the other dimensions. Thus, the approach of considering the samples as infinite slabs can be considered as appropriate (Garau, Simal, Femenia, & Rosselló, 2006). Assuming the effective moisture diffusivity as constant and the solid to be isotropic and homogeneous, the diffusion equation (equation (1)) is written as follows:

$$\frac{\partial W_p(x,t)}{\partial t} = D_{ed}\left(\frac{\partial^2 W_p(x,t)}{\partial x^2}\right) \quad (1)$$

where W_p is the local moisture (kg water/kg dmdc), t is the time (s), D_{ed} is the effective moisture diffusivity (m^2/s) during drying and x represents the characteristic mass transport direction in the slab geometry (m).

In order to solve equation (1), the following assumptions were considered: solid symmetry, uniform initial moisture content and temperature, constant shape during drying and negligible external resistance to mass transfer. The analytical solution of the diffusion equation, expressed in terms of the average moisture content, is shown in equation (2) (Crank, 1975).

$$W(t) = W_e + (W_0 - W_e)\left[2\sum_{n=0}^{\infty}\frac{1}{\lambda_n^2 L^2}e^{-D_{ed}\lambda_n^2 t}\right] \quad (2)$$

where, λ_n are the eigenvalues calculated as $\lambda_n L = (2n+1)\pi/2$, W is the average moisture content (kg water/kg dmdc), L the half-thickness of the sample (m) and subscripts 0 and e represent the initial and equilibrium state, respectively.

The diffusion model was fitted to the experimental drying kinetics in order to identify the effective moisture diffusivity. The identification was carried out by minimizing the sum of the squared differences between the experimental and the calculated average moisture content. For that purpose, the Generalized Reduced Gradient (GRG) optimization method, available in Microsoft Excel™ spreadsheet (Microsoft Corporation, Seattle, WA, USA) was used. The goodness of the fit was determined by calculating the percentage of explained variance (VAR, equation (3)).