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Rehydration of air-dried Shiitake mushroom (*Lentinus edodes*) caps: Comparison of conventional and vacuum water immersion processes

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ABSTRACT

Air-dried Shiitake mushroom (*Lentinus edodes*) caps were rehydrated using conventional and vacuum techniques, at different temperatures (30, 40, 50 and 80 °C) and times (1, 2, 3, 6, 9, 12, 15, 18, 21, 120, 150 and 210 min). Three empirical models were used to model the rehydration process: 1st order kinetics, Peleg's model and the Weibull distribution function. To determine the effects of temperature and pressure on the mushroom caps, the texture of the rehydrated material was determined, evaluating peak shear force and microstructure using cold-stage scanning electron microscopy (cryo-SEM). The rehydration of the mushrooms was found to be temperature and pressure-dependant. The speed of vacuum rehydration was faster compared to conventional rehydration. When rehydrated at 80 °C, a loss in rehydration capacity was observed in both cases, which can be explained by the structural damage and cell shrinkage which occurred during air-drying. Also, the vacuum rehydrated samples had the lowest toughness values. It was concluded that vacuum rehydration of dried Shiitake mushroom caps could be a feasible alternative to the conventional rehydration process, resulting in a lower immersion time and in a desirable texture.

1. Introduction

Shiitake mushrooms (*Lentinus edodes)* have many uses in Chinese and Japanese cuisines. They are served in many steamed and simmered dishes. Shiitake is often dried and must be rehydrated before use. Many people prefer dried Shiitake to fresh, as the drying process draws out the superior umami flavour (the flavour common to savoury products such as meat, cheese, and mushrooms) by breaking down proteins into amino acids.

Today, Shiitake mushrooms are popular in many other countries as well. Russia produces and also consumes large amounts of them, mostly sold pickled; and the Shiitake is slowly making its way into western cuisine as well. There is a global industry in Shiitake production, with local farms in most western countries in addition to large scale importation from China, Japan and elsewhere. Shiitake production and importation are of great economic interest and present attractive market opportunities. The Spanish production of mushrooms, including Shiitake, in 2008 had an economic value of 141 million Euros (MAPA, 2008, chap. 20.6.21).

Drying methods to obtain Shiitake mushrooms (edible mushrooms in general) are hot-air, freezing and vacuum. The drying process removes water in foods up to a certain level (normally less than 10%), at which microbial spoilage is minimized, but pre-drying treatments and drying itself greatly affect the material, which undergoes some irreversible structural changes: cellular rupture and dislocation, resulting in loss of integrity and hence the hyphae of air-dried samples are flattened and collapsed, with reduced hydrophilic properties, as reflected by the inability to imbibe sufficient water to rehydrate fully (Krokida & Marinos-Kouris, 2003).Properties such as colour, texture, density, porosity and sorption characteristics of dehydrated materials are affected by the drying method (Krokida, Karathanos, & Maroulis, 2000).

Rehydration is a complex process aimed at the restoration of raw material properties when dried material comes into contact with water or water-vapour. Rehydration is composed of three simultaneous processes: water absorption, swelling and soluble leaching (Lewicki, 1998; McMinn & Magee, 1997). The rehydration is dependent on the degree of cellular and structural disruption. It is desirable to have as fast rehydration process as possible to maintain adequate structural and chemical characteristics and obtain better quality-reconstituted products (flavour, texture and nutritional quality) (Sanjuán, Cárcel, Clemente, & Mulet, 2001).

Several empirical equations must be used for the modelling of mass transfer kinetics during the rehydration process, which are useful for the optimization of the process itself. Most of the models used to describe the rehydration process are based on Fick's

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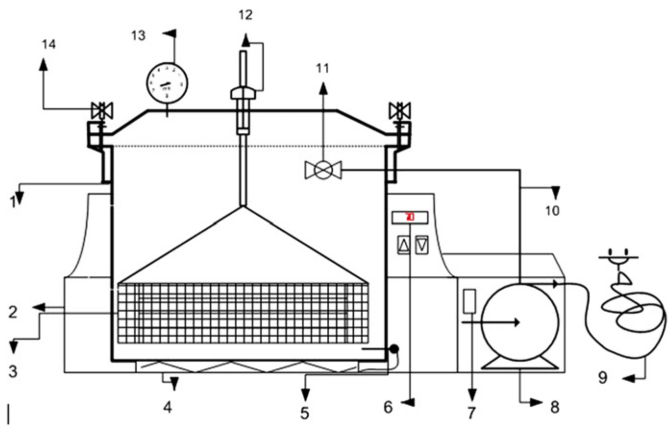

Fig. 1. Vacuum and atmospheric rehydration system. (1) Main body, (2) pan, (3) basket, (4) heating element, (5) temperature probe, (6) temperature selector, (7) switch, (8) vacuum pump, (9) electric supply, (10) vacuum connector, (11) valve, (12) elevator, (13) manometer, (14) hermetic closing.

diffusion model (Kaymak-Ertekin, 2002). Considering empirical equations, the model proposed by Peleg (1988) has an important calculation simplicity (it can be transformed into a linear relationship) compared to other equations. Another widely used equation in food engineering is Weibull's probabilistic model, due to its simplicity and flexibility in the estimation of its kinetic parameters (Vega-Gálvez, Notte-Cuello, Lemus-Mondaca, Zura, & Miranda, 2009).

Rehydration is influenced by several factors, grouped as intrinsic factors (product chemical composition, drying pre-treatments, product formulation, drying techniques and conditions, post-drying procedures, and so on), and extrinsic factors such as composition of the immersion media, temperature, and hydrodynamic conditions (pressure). Some of these factors induce changes in structure and composition of vegetal tissues such as loss of cell wall integrity or solute lixiviation, which result in impaired reconstitution properties (Debnath, Hemavathy, Bhat, & Rastogi, 2004; Taiwo, Angersbach, & Knorr, 2002).

The aim of this work is to study the effect of temperature and pressure conditions on the rehydration kinetics of air-dried Shiitake mushrooms. Texture and microstructure were evaluated in rehydrated material to elucidate the effect of the temperature and pressure on rehydration characteristics.

2. Materials and methods

2.1. Convective drying of Shiitake mushrooms

Fresh raw Shiitake mushrooms used for the experiments (*L. edodes*) were purchased in a local supermarket in Valencia, Spain, and kept refrigerated at 5 ± 0.5 °C.

The mushrooms were selected by visual inspection according to their homogeneity in size (4.5 ± 0.5 cm diameter), shape and ripeness, the stems were removed and only the caps were used. Convective drying of mushroom caps (gill side down) was performed in a Digitheat cabinet drier (Selecta, Barcelona, Spain) with through flow at 50 °C and 1 m s^{-1} (Hernando, Sanjuán, Pérez-Munuera, & Mulet, 2008). Moisture contents of the mushrooms were determined by drying a constant weight in an oven under vacuum conditions, at 70 °C for 24 h (AOAC, 1990).

2.2. Rehydration process

For rehydration treatments, equipment designed at the Universidad Politécnica of Valencia was used (Fig. 1) (Martínez-Monzó, Salvador-Andrés, Torres-Martínez, Sanjuán Pellicer, & García-Segovia, 2004, 8 p.).

In order to study the rehydration process, only the caps of the dehydrated mushrooms were immersed in distilled water (ratio 1:200 mushroom/water) for different times, temperatures and pressure processes. The temperatures analyzed were 30, 40, 50 and 80 °C in atmospheric pressure or under vacuum conditions (13 kPa s for 30, 40 and 50 °C; 40 kPa s for 80 °C, in all cases below boiling point). For each temperature, times investigated were 1, 2, 3, 6, 9, 12, 15, 18, 21, 120, 150 and 210 min. Three mushroom caps were rehydrated for each condition (time/temperature/pressure) 288 samples in total. For vacuum treatments, mushrooms (previously weighed) were placed into a basket, the lid closed, and the vessel evacuated. Then, the basket was submerged into the water for the desired rehydration time. Once the time was reached, the basket was lifted from the water and the vessel was pressurized to avoid vacuum impregnation of the samples. Next, the lid of the vessel was opened and the mushrooms were allowed to cool at room temperature, dried with paper and weighed again. For the atmospheric rehydration experiments, the same equipment and procedure was used but the vacuum pump was switched off.

2.3. Mathematical models

Of the various models thus far proposed, empirical models are the most commonly employed due to their mathematical simplicity and utility (Moreira, Chenlo, Chaguri, & Fernandes, 2008). Three empirical models were used in modelling the rehydration process. 1st order kinetics (Eq. (1)) (Krokida & Marinos-Kouris, 2003; Machado, Oliveira, Gekas, & Singh, 1998), Peleg's model (Eq. (2)) (Abu-Ghannam & McKenna, 1997; Hernando et al., 2008; Peleg, 1988; Machado et al., 1998; Maskan, 2002; Ruíz-Díaz, Martínez-Monzó, Fito, & Chiralt, 2003; Sacchetti, Pittia, Biserni, Pinnavaia, & Rosa, 2003;), and the Weibull distribution function (Eq. (5)) (Ruíz-Díaz et al., 2003; Sacchetti et al., 2003). The aim was to work with three empirical models with different approaches. The first model was based on the diffusion model of Fick's second law for different geometries (Kaymak-Ertekin, 2002). The second model, proposed by Peleg (1988), is not derived from any physical laws or diffusion theories and is therefore empirical, its application has been demonstrated for several cereals and legumes (Maskan, 2002). The third model (Weibull distribution function) is a widely used equation in food engineering to model the kinetics of chemical, enzymatic or microbiological degradation processes (Marabi, Livings, Jacobson, & Saguy, 2003; Marfil, Santos, & Telis, 2008)

The first order kinetic model used to fit the results of moisture increase is expressed in the following equation:

$$X_t = X_{eFok} - (X_{eFok} - X_0)\ e^{-k_r t} \quad (1)$$

where X_t is moisture content at time t ($kg_{water}/kg_{d.m.}$), X_{eFok} is the equilibrium moisture content of rehydrated Shiitake (kgwater/kgd.m.), X_0 the moisture content of the dry material (kgwater/kgd.m.), k_r is the rehydration rate (min^{-1}) determined as the slope of the falling rate rehydration curve, and t is the rehydration time (min).

The model proposed by Peleg (1988) (Eq. (2)) is a two parameter, non-exponential equation used to describe moisture sorption curves. The Peleg model has been applied to rehydration for different kinds of foods (García-Pascual, Sanjuán, Melis, & Mulet, 2006; Hernando et al., 2008; Moreira et al., 2008; Peleg, 1988; Sanjuán et al., 2001; Vega-Gálvez et al., 2009). Peleg's equation assumes the form (Peleg, 1988):

$$X_t = X_0 + (t/(A + B \cdot t)) \quad (2)$$