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Influence of osmotic dehydration pre-treatment on oven drying and freeze drying performance

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ABSTRACT

Drying is largely used in food industry, since it allows prolonging the product shelf life by inhibiting microorganisms' growth and enzyme activity. Traditional drying techniques, such as air drying and freeze drying, suffer from several drawbacks, mainly long processing time, low rehydration capacity and change in food properties. Some pre-treatments, such as osmotic dehydration, can be applied prior to conventional techniques in order to produce an intermediate moisture product and, therefore, to improve the drying process. In this work, the influence of osmotic dehydration on oven drying and freeze drying performance was evaluated. Firstly, the effects of the main osmotic dehydration parameters were investigated in order to find the best conditions for water desorption. Secondly, experiments with oven drying, freeze drying and their combination with osmotic pre-treatment were carried out. Results of each technique in terms of final moisture content, water activity, rehydration ability, textural properties and microstructure were compared and discussed. It has been observed that the application of the pre-treatment allows reducing considerably the processing time and better retaining the food properties.

1. Introduction

Food market increasingly requires the development of techniques able to extend foodstuffs shelf-life, since consumers demand fresh-quality products without the use of preservatives (Maskan, 2001).

Fruits and vegetables are highly perishable foods, since they easily undergo degradation reactions by bacteria proliferation, because of their elevated moisture content (Dev & Raghavan, 2012). For this reason, several industrial processes have been developed for their preservation. Among them drying is the most common method, since water removal inhibits microorganisms' growth and enzyme activity and decreases the weight of the product, simplifying also its transport and storage (de Bruijn et al., 2016). For these purposes, dried foods should have water content lower than 25 g/100 g and water activity lower than 0.6 (de Bruijn et al., 2016; Stevenson et al., 2015). Water activity (a_w) is a measure of the quantity of water that is available for chemical and biological reactions, so it represents an indication of food stability with respect to microbial growth (Oliveira, Brandão, & Silva, 2016). On the other hand, downstream the drying process, it should be possible to recover the properties of the fresh food rehydrating the dried. Rehydration ability depends on the degree of cellular and structural disruption; therefore, it is considered as a measure of the damage caused by drying to the food structure (Vega-Gálvez et al., 2015).

Different drying processes have been proposed in literature. The most popular and ancient dehydration technique is air drying, in which moisture is removed by evaporation (Ratti, 2001). However, several authors reported that this process can cause several adverse effects on food attributes such as case hardening, shrinkage, poor rehydration ability and the alteration of the sensory features (Maskan, 2000). Another common technique is represented by freeze drying, which consists in the freezing of the product and then water removal by sublimation. This technique allows to retain food quality and structure better than other dehydration processes, but it suffers from some drawbacks, such as high energy costs and very long processing times, which restricts its applicability to high-value products (Karam, Petit, Zimmer, Baudelaire Djantou, & Scher, 2016).

In order to optimise moisture desorption, some pre-treatments have also been proposed, with the aim to produce an intermediate moisture product. Among them, osmotic dehydration has received much attention due to its low cost and complexity. This process consists of the immersion of the foodstuff in a hypertonic solution:

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in this way moisture diffuses from the food towards the solution thanks to the semi-permeability of the cell membrane and, in the opposite way, the solute used as osmotic dehydrator flows from the solution to the food, even if in minor extent (da Costa Ribeiro, Aguiar-Oliveira, & Maldonado, 2016). Different authors (Rastogi & Raghavarao, 1997; Tsotsas & Mujumdar, 2014) reported that this method allows reducing water content up to 50% weight. In order to complete the drying, other methods, as those mentioned above, need then to be applied.

In literature many papers are focused on osmotic dehydration and its application prior to microwave drying (Botha, Oliveira, & Ahrné, 2012; de Bruijn & Bórquez, 2014; Corrêa, Dev, Gariepy, & Raghavan, 2011; Prothon et al., 2001), but limited studies have been performed till date on osmotic dehydration + oven drying and osmotic dehydration + freeze drying. In these studies, the authors focused their attention on water desorption, but rarely on the effects of drying on water activity, rehydration capacity and food microstructure in order to have a comprehensive overview of the process. De Costa Ribeiro et al. (da Costa Ribeiro et al., 2016) observed that when osmotic dehydration was applied prior to conventional oven drying, a reduction of 41.8% of the drying time was possible to achieve a pear final moisture content of 0.25 kg/kg dry solids; however, they did not report the samples' final water activity and rehydration capacity. Patil et al. (Patil, Kalse, & Jain, 2012) also observed that the application of the pre-treatment to convective drying allowed to reduce onion drying time by approximately 40% but the effect on samples' water activity and microstructure was omitted. Ruiz-López at al. (Ruiz-López, Huerta-Mora, Vivar-Vera, Martínez-Sánchez, & Herman-Lara, 2010) pointed out that the osmotic dehydration pre-treatment led to a significant decrease in chayote moisture content, allowing to reduce air-drying time up to 65% depending on the used dehydrator; however, also in this case, information about water activity, rehydration ability and structural properties were missing.

In the present work, osmotic dehydration was applied prior to oven drying and freeze drying in order to improve their performances. The model food chosen for the experimentation was strawberry, since it is one of the most consumed fruits, thanks to its enjoyable organoleptic characteristics and its healthy properties. First, an optimisation of the pre-treatment operating conditions was carried out in order to identify the best conditions for the highest water desorption. Several experiments were then performed using oven drying, osmotic dehydration + oven drying, freeze drying and osmotic dehydration + freeze drying. The results in terms of samples' final moisture content, water activity, rehydration ability and quality retention were compared and discussed.

2. Materials and methods

2.1. Materials

Fructose (purity ≥ 99%), maltodextrin (purity ≥ 99.5%), maltose (purity ≥ 95%) and sucrose (purity ≥ 99.5%) were supplied by Sigma Aldrich (UK). All materials were used as received. Fresh strawberries (*Malling centenary*) were purchased by a local supermarket and stored in a refrigerator at 5 °C. After washing in tap water and draining with blotting paper, strawberries were cut into cubes of 1 cm^3.

2.2. Osmotic dehydration

Osmotic dehydration experiments were carried out by immersion of 10 g of strawberry cubes in the osmotic solution, at fixed temperature, under stirring at 250 rpm. The fruit to solution ratio (F:OS) was fixed at 1:10. At the end of each experiment, samples were taken and blotted with paper.

2.3. Oven drying

Conventional drying tests were carried out introducing strawberry cubes in an oven (Fistreem International Co. Ltd, Leicestershire, UK) with no flow air, at room pressure and fixed temperature.

2.4. Freeze drying

Fresh cubic samples were frozen at −20 °C and then lyophilised using a bench top Freeze Dryer (SCANVAC Coolsafe™, model 110-4, Lynge, Denmark), condenser temperature −110 °C, pressure 10 Pa.

2.5. Moisture content analysis

Moisture content (MC) analyses were carried out using a moisture analyser (model MB 25, OHAUS, Nanikon, Switzerland). Two grams of sample were placed within the aluminium pans and located over the pan support of moisture meter. Halogen element inside the moisture meter provides uniform infrared heating. It heats the sample at a set temperature of 120 °C until the sample weight becomes constant. Moisture percentage as a function of weight change is recorded and displayed. Strawberry initial moisture content was found to be equal to 86.4 g/100 g.

2.6. Water activity analysis

Water activity of fresh and dried samples was measured using an AquaLab® dew point water activity meter (model 4TE, Decagon Devices Inc., Pullman, WA, USA). The temperature controlled sample chamber was set to 25 °C. The water activity of the fresh samples was found to be equal to 0.988.

2.7. Soluble solids gain determination

Total solids content (SS) was determined by direct reading using an automatic refractometer (Model J357, Rudolph Research Analytical, Hackettstown, NJ, USA). The solids gain (SG %) was calculated using the following equation (Campos, Sato, Tonon, Hubinger, & Cunha, 2012):

$$SG\% = \frac{\left(SS_f \cdot w_f - SS_0 \cdot w_0\right)}{w_0} \quad (1)$$

where SS_f is the soluble solid content (° Bx) after osmotic dehydration; w_f is the sample weight after osmotic dehydration (g); SS_0 is the initial soluble solid content (° Bx); w_0 is the sample initial weight (g). Strawberry initial solid content (SS_0) in 10 g (w_0) of fruits was found to be equal to 2.05° Bx.

2.8. Rehydration

Rehydration experiments were performed by immersing a weighed amount of dried samples into distilled water at room temperature. The samples were removed at regular intervals, blotted with paper to eliminate the surface water and then reweighed.

Rehydration capacity (RC) was measured for all the samples using the following equation (de Bruijn & Bórquez, 2014):

$$RC = \frac{(w(t) - w_d)}{(w_0 - w_d)} 100 \quad (2)$$