LWT - Food Science and Technology 84 (2017) 717–725

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Improving quality of dried fruits: A comparison between conductive multi-flash and traditional drying methods

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ARTICLE INFO

Article history:
Received 19 April 2017
Received in revised form
5 June 2017
Accepted 19 June 2017
Available online 20 June 2017

Keywords:
Mango
Multi-flash
Drying
Rehydration
Vacuum

ABSTRACT

Conductive multi-flash drying (KMFD) is an innovative drying process based on the application of multiple cycles of heating-vacuum pulse to a food to be dried. This method allows obtaining crispy-and-dried products with appealing characteristics. The objective of this study was to compare different drying methods (KMFD, air-drying, vacuum drying and freeze-drying) with respect to drying kinetics and physical properties of dried mangoes (porosity, microstructure, color, and mechanical properties). The influence of these drying methods on carotenoids concentration and rehydration were also investigated. Mango samples were dried from 5.30 g/g moisture (dry base) to 0.01 g/g (a_w = 0.293) in 2.25 h by the KMFD, which was much shorter than the drying times observed for freeze-drying (16 h), air-drying (12 h) and vacuum drying (8 h). Porosity and texture of samples dried by KMFD were similar to the observed for freeze-dried samples, despite the different microstructures. Carotenoids concentration of freeze-dried samples was 1.6 times higher than that from KMFD, which was in turn 1.27 times higher than that from air-dried samples. KMFD is a new and innovative drying process that allows the production of crispy mangoes in reduced drying times, with carotenoids contents and rehydration ability similar to freeze-dried samples.

1. Introduction

Innovative drying technologies have been developed to obtain high quality dried fruit and vegetables, reducing process time and operational costs. Drying processes such as HTST (high-temperature-short-time) (Hofsetz, Lopes, Hubinger, Mayor, & Sereno, 2007), explosion puffing (Zou, Teng, Huang, Daí, & Wei, 2013), instant controlled pressure drop (DIC) (Louka & Allaf, 2002; Louka, Juhel, & Allaf, 2004), convective multi-flash drying (CMFD) (Laurindo, Porciuncula, & Zotarelli, 2011; Zotarelli, Porciuncula, & Laurindo, 2012), conductive multi-flash drying (KMFD) (Laurindo et al., 2011; Porciuncula, Segura, & Laurindo, 2016) and microwave multi-flash drying (MWMFD) (Monteiro, Carciofi, & Laurindo, 2016) have been proposed as alternatives to conventional drying processes, to produce high-quality dried products.

In multi-flash drying processes (CMFD, KMFD and MWMFD), the product is heated at atmospheric pressure up to the desired temperature, and then a vacuum pulse is applied, leading to flash evaporation and, consequently, to cooling of the sample (Laurindo et al., 2011). This drying technology allows producing dried and crispy fruits and vegetables with high porosity, low moisture content and low water activity in reduced processing time. Moreover, this processes show low capital and operational costs and can be an alternative to freeze-drying in many situations (Laurindo et al., 2011; Porciuncula et al., 2016; Zotarelli et al., 2012).

The quality loss during drying can limit the market value and the demand for dried foods (Achanta & Okos, 2000). The assessment of parameters such as shape, color, texture, flavor and nutritional characteristics is very important in the investigation of dried fruit quality. One of the main reasons for traditionally dried fruits quality loss is the collapse of the product structure that can be evaluated through physical parameters such as volume, porosity, pore size distribution, and texture. Collapse can reduce the porosity of dried materials, influencing flavor retention, moisture distribution, rehydration capacity, resulting in undesirable hardening of the product (Yan, Sousa-Gallagher, & Oliveira, 2008). Besides, nutritional and sensory properties of products dried by traditional processes (i.e. solar drying, air-drying) can be damaged during drying, due to the heat sensitivity of pigments and nutrients of

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http://dx.doi.org/10.1016/j.lwt.2017.06.045
0023-6438/

most fruits and vegetables, causing significant loss of the original color and content of vitamins and other nutrients (Ochoa-Martínez, Quintero, Ayala, & Ortiz, 2012).

Rehydration capacity is another important quality parameter of dehydrated foods. When dehydrated products are immersed in water, complex phenomena take place, which influence the properties of the rehydrated product. In a perfect dehydration process, the material structural integrity is preserved and the dried product can absorb water until reaching the same moisture content of the fresh product and recover its original properties (Marques, Prado, & Freire, 2009). Actually, rehydration capacity is one of the most discussed quality attributes of dried fruits and vegetables. The effect of hot air drying, vacuum drying and freeze-drying on rehydration capacity was widely investigated in many products, i.e. strawberries (Meda & Ratti, 2005), mangoes and other tropical fruits (Marques et al., 2009), pumpkin (Seremet, Botez, Nistor, Andronoiu, & Mocanu, 2016), bananas (Khawas, Dash, Das, & Deka, 2016), and carrots (Doymaz, 2016). A few studies have been published on the rehydration properties of products dehydrated by alternative drying processes, e.g. puff drying applied to mangoes (Zou et al., 2013), and microwave-assisted drying of blueberries (Zielinska & Markowski, 2016). These studies demonstrated that innovative drying techniques improve both the physical properties (texture, microstructure and porosity) and the rehydration capacity of dried fruits and vegetables.

Thus, the aim of this study was to evaluate the drying kinetics, physical and microstructural properties of mango samples submitted to different drying methods (air-drying, vacuum drying, freeze-drying and KMFD) as well as the influence of these methods on the nutritional and rehydration properties of the dried fruit.

2. Materials and methods

2.1. Samples preparation

Mangoes (*Mangífera indica* L., Tommy Atkins) were purchased in a local market (Florianopolis, Brazil - 27°35′48″ S, 48°32′57″ W) and selected based on their state of ripeness, which was evaluated from visual appearance, soluble solids content - 14.5 ± 0.8 °Brix measured using a digital refractometer (AR200, Reichert, Depew, USA) and resistance to penetration - 3.9 ± 1.9 N measured by a penetrometer (FT 327, Ø = 8 mm, Effegi, Cavaion Veronese, Italy). Then, mangoes were washed, peeled and sliced in the direction parallel to their fibers to a thickness of 5 mm.

2.2. Drying experiments

After slicing, mangoes were submitted to different drying processes: air-drying (AD), freeze-drying (FD), vacuum drying (VD) and KMFD.

2.2.1. Air-drying

Approximately 100 g of mango samples were dried in a convection oven (TE 394/2, TECNAL, Ourinhos, Brazil) at 60 °C. The relative humidity (24.1 ± 1.9%) and air velocity (≈1 m/s) were measured with a hygrometer (ThermoHygrometer, TESTO 610, Lenzkirch, Germany) and a portable anemometer (Anemometer, TESTO 425, Lenzkirch, Germany) during the drying process. An on-line weight determination system was adapted to the oven to obtain the drying curves. This system consists of an aluminum plate connected to a single-point load cell (Alfa Instrumentos, model GL1, São Paulo, Brazil), with a capacity of 2 kg and accuracy of 0.1 g, sustained by a metallic support into the dryer. The load cell was connected to a computer by an electronic interface (Alfa Instrumentos, Model 3102, São Paulo, Brazil).

2.2.2. Freeze-drying

Freeze-drying was performed using a modified lab-scale freeze dryer (Liotop, Model - L101, São Carlos-SP, Brazil) adapted to allow the on-line monitoring of the drying curve during the process (Tribuzi & Laurindo, 2014). Samples were frozen at −60 ± 1 °C and dried at a pressure of 20 ± 5 Pa. Freeze-drying experiments were performed in triplicate with approximately 100 g of mango.

2.2.3. Vacuum drying

Samples were vacuum dried in a vacuum oven (440-DE, Ethik Technology, Vargem Grande Paulista, Brazil) connected to a vacuum pump (LC305, DVP Vacuum Technology, San Pietro in Casale, Italy) at 60 °C and 3.5 kPa. Approximately 400 g of mango slices were dried in each experiment. To perform the analysis, samples were removed from the dryer every 30 min for the first 2 h of drying, and every 60 min in the remaining drying time.

2.2.4. Conductive multi-flash drying

The experimental device used in the KMFD was described by Porciuncula et al. (2016). This device consists of a 100 L vacuum drying chamber (440-DE, Ethik Technology, Vargem Grande Paulista, Brazil) connected to a vacuum pump with a nominal capacity of 350 m^3/h. Samples were distributed on a Mylar® film (to avoid fruit from sticking to the metal plates) and placed on plates heated with electrical resistances (90 °C) controlled by a PID (proportional–integral–derivative) system. The pressure of the chamber was monitored with a digital manometer (IT-MN-DG, Velki, Itu, Brazil). The temperature of the mango slices was monitored with T-type thermocouples (TF-TX-A-TF-R30AWG, Iope, São Paulo, Brazil) inserted into the geometric center of five samples at different positions in the chamber, and connected to an acquisition data system (34970A, Agilent Technologies, Santa Clara USA).

Approximately 400 g of mango slices were used to determine drying kinetics and properties of mango samples. Samples were heated at atmospheric pressure up to 60 °C before applying a vacuum pulse (sudden decompression). The vacuum chamber pressure was maintained at 3.5 kPa for 5 min before recovering atmospheric pressure to start a new heating-vacuum pulse cycle. After four heating-vacuum pulse cycles, the samples were vacuum dried for 105 min at 3.5 kPa. The moisture content from KMFD process was determined after each heating-vacuum pulse and at each 30 min during the vacuum drying period (135 min). All the drying experiments were performed in triplicate.

2.3. Characterization of drying fruits

2.3.1. Analytical determinations

The moisture content of samples was determined by the gravimetric method using a vacuum oven (TE-395, TECNAL, Piracicaba, Brazil) at 70 °C (AOAC, 2005). Water activity (a_w) was measured with a dew-point hygrometer (Aqualab Series 3, Decagon Devices Inc., Pullman, USA). True volume (V_t) was measured with a gas pycnometer (Sereno, Silva, & Mayor, 2007). Bulk volume (V_b) was determined as described by Lozano, Rotstein, and Urbicain (1980). Bulk density (ρ_b) was calculated as the ratio between sample mass and bulk volume ($\rho_b = m/V_b$).

Accessible porosity (ε), defined as the ratio between the volume of the porous space filled with gas and the bulk volume, was calculated from the true volume and bulk volume:

$$\varepsilon[\%] = \left[1 - \frac{V_t}{V_b}\right] \cdot 100 \quad (1)$$

in which V_b is the bulk volume and V_t is the true volume.

Carotenoids content of fresh and dried samples was determined