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Quality assessment of electrohydrodynamic and hot-air drying of quince slice

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ABSTRACT

In this study, quince slices with 2 mm in thickness, with three replications were dried by an electrohydrodynamic setup at a constant temperature of 70 °C using three voltage levels of 5, 7, and 9 kV. Drying experiments were conducted at air temperatures of 50, 60 and 70 °C with an air velocity of 1 ms^{-1}. In order to evaluate the effect of two drying methods on dried quince slices properties, remaining moisture content, shrinkage, water absorption capacity, shear strength, and color of dried quince were measured. The results showed that there were significant differences between electrohydrodynamic drying and hot-air drying methods There were significant differences between the shrinkage, color but no significant difference was observed in the shear strength and water absorption capacity of the dried quince slices. In addition, increased voltage caused increased water absorption capacity and decreased shear strength of the dried quince slices.

1. Introduction

Quince (Cydonia Oblonga Miller) belongs to one of the oldest species of plants (Silva et al., 2008). It is an important source of vitamins A, B, C, organic acids, sugar, crude fiber and pectin, minerals such as potassium, phosphorus, and calcium (Rop et al., 2011). The benefits of eating quince can reduce the risk of osteoporosis in women, lower blood sugar and blood cholesterol, balance the nervous system, relieve depression, and be anti-inflammatory, anti-cancer, anti-allergic, wound healing and also improve heart and brain function (Pacifico et al., 2012). Drying is a part of an engineering strategy with aims to apply unit operations, to increase the shelf life, to respond to market needs rapidly, to reduce costs, and to increase efficiency and quality (Doymaz, 2014). In general, vegetables and dried fruits are important in the global market. Among all materials processing, perhaps drying has the most applications in food industry (Tzempelikos et al., 2014). For this reason, the mechanisms of drying materials and designing drying devices are exploited to an industrial scale. Electro-hydrodynamic (EHD) drying is one of the new methods of drying agricultural products. This method relies on the production of a lot of ions in the gas environment between two electrodes (Bajgai and Hashinaga, 2001). In this way, by applying a high voltage electric field between the plate electrodes and the point electrode, the airflow is ionized between two electrodes creating a volumetric flow. This phenomenon is called ion wind or corona wind (Dalvand et al., 2013). Ionic wind hits the surface of the wet material and the boundary layer is disturbed causing the latent heat of vaporization to be reduced and the transfer of water to speed up; as a result, the drying process is accelerated (Alemrajabi et al., 2012). At present, there are only a few reports on drying agricultural products using EHD drying system. In this paper, the effects of EHD drying and hot-air drying on quince quality in terms of remaining moisture content, shrinkage, shear strength, water absorption capacity and color, are to be studied.

2. Material and methods

2.1. Sample preparation

Fresh quinces were obtained from a local market, were transferred to Isfahan University of Technology during November 2015 and were saved in the refrigerator at 4 °C before the drying experiments. The quinces were cleaned and sliced to the thickness of 2 mm with an electric slicer (Model SOFRACA®, Morangis, France). The initial moisture content of the quince was measured on ASAE standard (Bentini et al., 2009) and achieved as 3.7 g/g dry weight. No pretreatment was applied to the fresh slices.

2.2. Drying experiments

In the present study, around 36 gr of quince slices with 2 mm in thickness, were placed as a thin layer on a metal tray and was dried by EHD drying and hot-air drying method. All the experiments were

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performed at the laboratory temperature (25 °C) with a relative humidity of around 10%. During the experiments, the relative humidity of the air was measured and controlled by the humidity meter (Model HT-3003, lutron, Taiwan). In addition, the weight of quince slices was measured with the scale at certain time intervals, and when the quince slices reached a constant weight, the drying process was stopped.

2.3. Hot-air drying method

In the case of hot-air drying method, drying experiments were conducted at air temperatures of 50, 60, 70 °C with an air velocity of 1 m s.$^{-1}$. In hot-air drying method, the wind tunnel is opened so that the humid air exits. To measure the speed of the air flow in the hot air, the anemometer (Model AM-4201, lutron, Taiwan) was used. This device is capable of measuring the air flow rate up to 20 m per second. Then, using the appropriate dimmer in the blower of the drying machine, the airflow rate was set to the desired level (1 m s.$^{-1}$).

2.4. HVEF experimental apparatus

The experimental equipment for EHD at constant temperature of 70 °C drying system is shown in Fig. 1. Quince slices with 2 mm in thickness, with three replications were dried by an electro-hydrodynamic setup at a constant temperature of 70 °C using three voltage levels of 5, 7, and 9 kV (the electric field strength levels: 2.5, 3.5, and 4.5 $\frac{kV}{cm}$). The distance between the two electrodes (gap) was 2 cm to achieve a powerful electrostatic field between the plate and the needle. In order to generate the corona discharge electrostatic field, a high voltage power supply was used with a maximum output current of 5 mA (LS50kV–5 mA, China). The range of voltage can be adjusted from −50 to +50 kV by a controller. The range of voltage and gap were selected based on creating sparks and disorder in the electro-hydrodynamic system. The gap less than 1.5 cm and the voltage higher than 10 kV led to a spark in the system, It is important to note that using Electric field power higher than 6$\frac{kV}{cm}$ causes the phenomenon of electric field to fail and spark. So, the electric field strength levels varied between 2.5 and 4.5 $\frac{kV}{cm}$. Electro-hydrodynamic drying results from the conversion of electrical to mechanical energy and it has a convective nature. The wind speed of the corona in wind electric field was calculated from Eq. (1).

$$V = E^* \sqrt{\frac{\varepsilon_0}{\rho}} \tag{1}$$

V is the speed of the air flow (corona wind) (m/s), E is the electric field strength (V/m), ε_0 is the dielectric constant vacuum (F/m), ρ is air density (kg/m^3) (Hashinaga et al., 1999). In this study, a rectangular plate with 32 sewing needles (0.4 mm in diameter) was connected to a direct current high-voltage power source that supplied a positive high voltage. Studies show that the positive corona discharge is more effective and consumes less energy than its negative counterpart does. The described EHD system was placed in a chamber (Model BD-115, Binder, Germany) to provide constant temperature (70 °C) and relative humidity (around 10%). The chamber has an air vent for the evacuation of wet air.

2.5. Determination of moisture content

The moisture content of the quince slices was determined by the oven method. The dried quince slices were taken out and dried in the oven (Memmert, Schwabach, Germany) for 7–8 h at 105 °C in defined relative humidity until constant weight was achieved. A digital balance (Model Radwag, AS 220/C02, Radom, Poland) was used for weighing, and then moisture content (w.b.) was calculated. The tests were performed in duplex (El-Sebaii and Shalaby, 2013).

2.6. Shrinkage

Shrinkage, which represents the amount of structural damage during the drying process, was measured by using toluene method based on the reduced sample volume during the drying process. At first, the samples were weighed and then placed in a pycnometer, which was filled with toluene, and then it was measured by the digital scale. Finally, the shrinkage was calculated using the following equation:

$$V = W_s - (W_a - W_b) \tag{2}$$

$$S = \left(1 - \left({}^{Vt}\!/_{V0}\right)\right)^{*}100 \tag{3}$$

Where V is the volume of the sample (m^3), W_s is the weight of the sample (kg), W_a is the weight of the pycnometer containing the sample and toluene (kg), W_b is the weight of the pycnometer containing the sample (kg), S is the shrinkage of the quince slices (%), and V_0 and V_t are initial and final volumes (m^3) of samples in the time interval, respectively (Nieto et al., 2004).

2.7. Shear strength

Puncture test was performed on sample to evaluate texture of quince slices by using a Texture Analyzer (Model STM 20, Iran). Equipment of Texture Analyzer consists of a needle probe with a

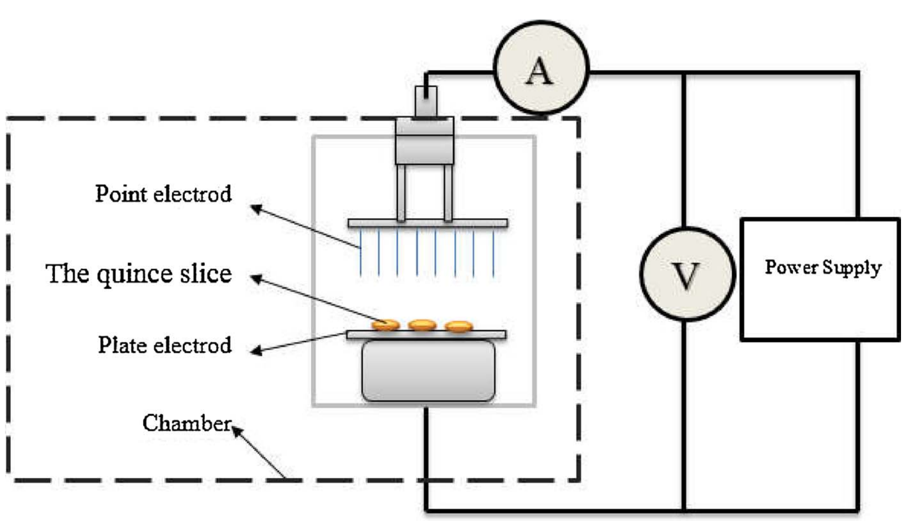

Fig. 1. Scheme of the EHD set-up.

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