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Evaluation of high pressure pretreatment for enhancing the drying rates of carrot, apple, and green bean

Umut Yucel *, Hami Alpas, Alev Bayindirli

Department of Food Engineering, Middle East Technical University, Ankara, Turkey

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A B S T R A C T

Preservation of fresh produce by drying dates back to ancient times and is still an indispensible technique. Conventional drying of fruits and vegetables is often accompanied by changes in color, texture, and taste. Suitable pretreatments can improve the drying process by reducing the drying time, yielding higher-quality products, and energy savings. In this study, two varieties of apples, Amasya and red delicious, green beans and carrots were pretreated with high hydrostatic pressure (HHP) at different pressure–time–temperature combinations (100–300 MPa for 5–45 min at 20 and 35 °C) prior to drying. The drying experiments were carried out by using a hot-air tunnel dryer at different temperatures (27–85 °C) and air velocities of 0.4 and 0.8 m/s with constant external conditions. Improving the drying conditions by increasing the drying temperature generally masked the effect of HHP pretreatment on drying rate. Generally, pressures of more than 100 MPa caused cell permeabilization resulting in higher drying rates. Among 14 models, the modified Page model was found to best explain the drying behaviors and model constants were evaluated accordingly. The Tukey multiple comparison test was applied on characteristic drying times to evaluate the relative effects of different pretreatments and drying conditions.

1. Introduction

Fruits and vegetables are perishable due to their high moisture content. Drying, a process of moisture removal due to simultaneous heat and mass transfer, is one of the processes used for preservation; it also results in reduced transportation and storage costs. Many fruits and vegetables can be dried. One of the most important aspects of industrial drying is to predict the drying behavior to increase the efficiency of the process. The rate of drying, storage stability, rehydration characteristics, and quality changes depend on the type of the drier, processing parameters, and also pretreatment of the dried material.

Hot water or steam blanching is a general pretreatment method applied before drying. The primary purpose of blanching is to inactivate naturally occurring enzymes in addition to removal of gases from surfaces and intercellular spaces to prevent oxidation, discoloration, and off-flavor development as well as reducing the initial number of microorganisms (Rahman and Perera, 1999). Blanching is also applied prior to drying to increase the drying rates of fruits and vegetables, such as banana (Dandamrongrak et al., 2002), red paprika (Ade-Omowaye et al., 2001a), fig (Piga et al., 2004), potato (Al-Khuseibi et al., 2005; Eshtiaghi and Knorr, 1993; Severini et al., 2005), strawberries (Alvarez et al., 1995), and green beans, carrots and potatoes (Eshtiaghi et al., 1994).

Among nonthermal methods, HHP treatment, which subjects liquid and solid foods with or without packaging to pressures between 100 and 800 MPa, has been one of the most successful (Gould, 2001; Hoover, 1997; Knorr, 1999, 2002; Knorr et al., 2002; Rastogi et al., 2007). Akyol et al. (2006) showed that HHP and mild heat treatment combinations can be used for blanching purposes to inactivate vegetable enzymes.

When fruits and vegetables are pretreated with HHP, cell permeabilization may facilitate the diffusion and provide higher drying rates. In the case of osmotic dehydration, where the mass transfer rate is low, nonthermal treatments, such as HHP or pulsed electric field, can be used to improve the mass transfer rate during drying of fruits and vegetables such as red paprika, carrot, potato, green bean, pineapple, and apple (Ade-Omowaye et al., 2001a,b; Angersbach and Knorr, 1997; Eshtiaghi and Knorr, 1993; Eshtiaghi et al., 1994; Knorr, 1999, 2002; Knorr et al., 2002; Rastogi and Niranjan, 1998; Rastogi et al., 1999, 2000, 2002; Taiwo et al., 2002).

In the study by Rastogi and Niranjan (1998), HHP pretreatment (100–700 MPa for 5 min) was applied to enhance mass transfer rates during osmotic dehydration of pineapples at 40 °C and 50 °Brix. The diffusivity increased with treatment pressures up to 400 MPa above which it did not significantly change.

* Corresponding author. Address: Department of Food Science, The Pennsylvania State University, 338 Food Science Building, University Park, PA 16802, USA. Tel.: +1 814 863 2999.
E-mail address: uzy100@psu.edu (U. Yucel).

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Osmotic dehydration of HHP-treated (200 and 400 MPa for 10 min at 25 °C) potato samples was also shown to be faster than that of the untreated ones due to the combined effects of osmotic stress and high-pressure-induced cell permeabilization (Rastogi et al., 2000). There was a progressive increase in tissue softening as the osmotic dehydration proceeded. Tissue softening following HHP treatment may be due to destruction of cell membranes and partial liberation of cell substances.

The effects of water blanching and HHP on drying kinetics and quality of potato (i.e., rehydratability, texture, color, and apparent density) have been investigated in a recent study (Al-Khuseibi et al., 2005). The potato cubes in 1% citric acid solution as the immersion medium were pressure treated at 400 MPa for 15 min. Hot water blanching was done in boiling water for 3 min. HHP and thermally treated potato were dried by convective hot air in a cabinet air dryer for 8–9 h at 75 °C. Drying rates were found to be higher in the initial period of drying for the pressure-treated samples. HHP-treated samples had a similar rehydratability to thermally treated samples. It was found that pressure-treated samples had a hardness value close to that of fresh samples, whereas thermal treatment resulted in a softer texture. HHP pretreated dried samples were found to have higher apparent density than thermally treated samples.

Eshtiaghi et al. (1994) have studied the water blanching of carrots and green beans for 7 min and potatoes for 4 min in boiling water, high pressure (600 MPa for 15 min at 70 °C), and freezing (at −18 °C for 24 h) pretreatments before fluidized bed drying at 70 °C at air velocities of 4.0, 4.6, and 4.8 m/s during the first 60 min and 3.2, 4.6, and 3.7 m/s for the remainder of the drying process for green beans, carrots and potatoes, respectively. Pressure-treated samples had texture and color nearest that of the raw material as compared to other pretreatments. On the other hand, HHP treatment resulted in incomplete rehydration but improved on combination with freezing. Initial drying rates were highest for water-blanched and frozen, pressure-treated and frozen or just frozen samples, followed by hot-water-blanched and HHP-treated samples. The authors claimed that HHP treatment, in conjunction with subsequent freezing, can improve mass transfer in plant products and enhance product quality.

Although the application of high pressure generally results in membrane permeabilization of the cell structure and positively affects the mass transfer, the findings in the literature are not quite consistent with each other for drying of HHP-pretreated fruits and vegetables. The main reason for this is due to the different pressure–time–temperature combinations, drying conditions, and also the variety of the selected fruits and vegetables. In this study, apples, carrots, and green beans were selected, since they are harvested in large amounts in Turkey and are widely used for drying kinetics studies. The objective of this study was to evaluate the effectiveness of HHP pretreatment for enhancing the drying rate of Amasya apples, red delicious apples, green beans, and carrots in an attempt to decrease the drying time which would be desirable for product quality and also economical aspects.

2. Materials and methods

Amasya apples (moisture content = 87.1 ± 0.3%), red delicious apples (moisture content = 85.6 ± 0.3%), carrots (moisture content = 90.5 ± 0.3%), and green beans (moisture content = 90.8 ± 0.2%) were purchased from a local market. The initial moisture contents were determined by oven drying at 100 °C until constant weight was attained for each sample. The selected fruits and vegetables were stored at refrigeration temperature (4 °C) until used, and the change in the initial moisture content was verified to be within the limits of variability of the source. After washing, the samples were cut: green beans to 3 cm in length and apples and carrots to rectangular slabs of 1 × 1 × 4 cm.

2.1. HHP treatments

HHP treatments were performed in a specially designed and constructed lab-scale direct compression unit (capacity: 30 cm^3, maximum *P*: 500 MPa, Fig. 1). The rates of pressure increase and pressure release were approximately 5–10 s for the system. The equipment consists of a pressure chamber of cylindrical design, two end closures, a means for restraining the end closures, a pressure pump, and a hydraulic unit to generate high pressure, and also a temperature control device. The pressure vessel was made of hot galvanized carbon steel and the piston was hard chrome-plated and polished to mirror finish (steel type heat-treated special K) which was processed into the required sizes at the Electrical and Electronic Engineering Department of Middle East Technical University, Ankara, Turkey. The liquid was either heated by an electrical heating system or cooled by a water circulation system surrounding the chamber to the desired temperature prior to pressurization. Pressurization time reported in this study did not include the pressure increase and release times.

Before pressurization, the samples were wrapped with LDPE film. The samples were placed into the pressure vessel and kept for 5 min for temperature equilibration. The samples were pressurized at 100, 200, 250, and 300 MPa for 5, 15, 30, and 45 min at 20 and 35 °C before drying.

2.2. Drying

The drying experiments were conducted in a laboratory-scale tunnel dryer (model D.27412; Armfield Ltd., Hampshire, England). It consists of a rate-adjustable fan and an adjustable electrical heater with setting switches. The flow cross-section throughout the dryer is 22 × 22 cm^2. Air was circulated in the dryer by a motor-driven axial flow fan impeller.

After the HHP treatment, the samples, which were attached to thin wires of about 0.06 g in weight, were hanged onto the thin holder-wires, which were located 1.5 m away from the air inlet and suspended into the air-stream flowing through the tunnel. Thus, at the sample point, air flowed parallel to the surface of the sample, which was positioned horizontally with respect to the direction of air flow. For sample weight measurements, the thin wire was attached to the bottom of a Sartorius digital balance (model PT120, 0.01 g sensitivity).

Drying of the samples was carried out under constant external conditions at four different air temperatures: (27, 45, 65, and 85 °C) at constant relative humidity (RH) (35 ± 5%, 12 ± 2%, 5.0 ± 0.5%, and 2.5 ± 0.3%, respectively) by using two air velocities (0.4 and 0.8 m/s).

Dry bulb temperature of the air stream at the sample location was measured by means of a digital temperature indicator (model NR900, 0.1 °C sensitivity; Nel Electronic Equipments, Ankara, Turkey), having thermocouples and a digital display, and was kept constant throughout the process. Air velocity was measured by using a vane anemometer (in the range of 0–44.8 m/s; Davis Instruments, California, USA). The relative humidity of air was measured at flap places (i.e., without disturbing the drying process) before and after the sample point with a digital Testo humidity meter (model 610, 0–100% RH and −20 to 70 °C).

All experiments were performed in triplicate. The dimensionless moisture ratio (MR) was calculated as:

$$\mathrm{MR} = \frac{X_t - X_e}{X_0 - X_e} \tag{1}$$

where X_t is moisture content at a given time, X_e equilibrium moisture content, and X_0 is initial moisture content, on a dry basis. For