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FULL LENGTH ARTICLE

Study of the drying kinetics of pepper

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Abstract The present study investigated the influence of microwave power on the drying kinetics, energy consumption and drying efficiency of green pepper during microwave drying at 180, 240, 300, 360, 420, 480 and 540 W. Seven mathematical models for describing the thin-layer drying behaviour of pepper samples were investigated. The models were compared based on their R^2, RMSE and χ^2 values between experimental and predicted moisture ratios. By increasing the microwave output powers (180–540 W), the drying time decreased from 9 to 2.5 min. The drying process took place in the falling rate period. The results show that the Midilli model is the most appropriate model for drying behaviour of thin layer pepper samples. A third order polynomial relationship was found to correlate the effective moisture diffusivity with moisture content. The effective moisture diffusivity increased with decrease in moisture content of pepper samples. The average effective diffusivity varied from 8.315×10^{-8} to 2.363×10^{-7} m^2/s, over the microwave power range studied, with an energy activation of 14.19 W/g. Energy efficiency increased with increase in microwave power and moisture content. The least specific energy consumption (4.99 MJ/kg water) was at the microwave power of 240 W and the highest (6.80 MJ/kg water) was at 180 W.

1. Introduction

Dehydration is an important preservation process which reduces water activity through the decrease of water content, avoiding potential deterioration and contamination during long storage periods. Other important objectives of food dehydration are weight and volume reduction, intended to decrease transportation and storage costs (Celma et al., 2009; Sarimeseli, 2011; Figiel, 2010; Vega et al., 2007; Wang et al., 2007).

Fresh peppers may be stored for up to 3 weeks in cool, moist conditions (45–50 °F and 85–90 percent relative humidity) (ISU, 2009). Peppers are commonly dried for spice production. The dried spice is used in food mixtures, salad dressings, instant soups, frozen pizzas and many other convenience foods. Peppers are also a source of minerals such

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as calcium, phosphorous, potassium and iron (Faustino et al., 2007).

According to local producers, sun dehydration of pepper requires about seven consecutive days, and the fruits suffer undesirable fermentation, with consequent reduction in the sales (Soysal et al., 2009). This process is slow, requires a deal of care, and thus is not feasible once the actual quality of product is not competitive.

Hot-air drying has been to date the most common drying method employed for pepper (Vega et al., 2007; Ade-Omowaye et al., 2002; Tunde-Akintunde et al., 2005). But air drying has drawbacks of both long drying time required and poor quality (Chou and Chua, 2001; Soysal et al., 2006; Therdthai and Zhou, 2009). The desire to eliminate this problem, to prevent significant quality deterioration, as well as to achieve fast and effective thermal processing has resulted in the increasing use of microwaves for pepper drying. Microwave drying is more rapid, more uniform and more highly energy efficient compared to conventional hot air drying and infrared drying (Sarimeseli, 2011; Soysal et al., 2006; Duan et al., 2003; Al-Harahsheh et al., 2009). In a microwave drying system, the microwave energy has an internal heat generative capacity and can easily penetrate the interior layers to directly absorb the moisture in the sample. The quick energy absorption causes rapid evaporation of water, creating an outward flux of rapidly escaping vapour, thus, both thermal gradient and moisture gradient are in the same direction (Dadali et al., 2007; Soysal et al., 2006; Wang et al., 2007).

Various mathematical models describing the drying mechanism have been suggested for the optimisation of the process and the design of effective dryers. Also, the prediction of drying rates for thin layer drying and moisture diffusion parameters of vegetables and fruits are important components of microwave drying simulation models and are essential for an efficient moisture transfer analysis (Da Silva et al., 2009; Vega et al., 2007; Sharma and Prasad, 2004; Sharma et al., 2005).

Therefore, the aim of this research was the study and the modelling of the drying kinetics of mass transfer, energy consumption and drying efficiency during the microwave drying process of pepper, and the analysis of the influence of microwave power on the kinetic constants of the proposed models.

2. Materials and methods

2.1. Materials

Fresh green peppers were harvested from a green house in the Ilam province of Iran, in September 2009 and were stored in the refrigerator at temperature of 4 °C until the experiments were carried out. Before the experiments, the samples were removed from the refrigerator and allowed to reach room temperature (about 18 °C). The green peppers (average dimensions of 0.7 ± 0.1 cm diameter and 6 ± 1 cm length) were washed and halved. After removing the seed samples, they were cut to the length of 2 cm. The green pepper had an initial moisture content of 73.33% (wet basis), which was determined by drying in a convective oven at 103 ± 1 °C until the weight did not change any more (Kashani Nejad et al., 2002).

2.2. Drying equipment and method

Drying treatment was performed in a domestic digital microwave oven (model MG-607 900 W, LG, Korea) with technical features of 230 V, 50 Hz and 2650 W, at the frequency of 2450 MHz. The microwave power was regulated by a control terminal which could control both microwave power level and emission time. Drying trial was carried out at seven different microwave generation powers: 180, 240, 300, 360, 420, 480 and 540 W. The area on which microwave drying is carried out was 530 × 500 × 322 mm in size, and consisted of a rotating glass plate with 300 mm diameter at the base of the oven. The adjustment of microwave output power and processing time was done with the aid of a digital control facility located on the microwave oven. During drying experiments, each sample was put on the rotating glass of microwave and placed at the centre of the oven. Moisture loss was periodically measured by taking out the rotating glass and weighing on the digital balance with a precision of 0.01 g. Three replications of each experiment were performed according to a preset microwave output power and time schedule, and the data given were an average of these results. The microwave power was applied until the weight of the sample reduced to a level corresponding to moisture content of about 0.1 kg water/kg dry base. All weighing processes were completed in less than 10 s during the drying process.

2.3. Mathematical modelling

For the investigation of drying characteristics of green pepper, it is important to model the drying behaviour effectively. In this study, the experimental drying data of green pepper at different microwave powers were fitted into seven commonly used thin-layer drying models, listed in Table 1.

Moisture ratio of samples during drying is generally calculated by the following equation:

$$\mathrm{MR} = \frac{M_t - M_e}{M_0 - M_e} \tag{1}$$

where M_t, M_0 and M_e are moisture content at any time of drying (kg water/kg dm), initial moisture content (kg water/kg dm) and equilibrium moisture content (kg water/kg dm), respectively. The values of M_e are relatively small compared to M_t and M_0 for long drying times and accordingly one can write (Evin, 2011; Soysal et al., 2006):

$$\mathrm{MR} = \frac{M_t}{M_0} \tag{2}$$

2.4. Correlation coefficients and error analysis

The ability of the tested mathematical model to represent the experimental data was evaluated through the correlation coefficient (R^2), the reduced (χ^2) and the root mean square error (RMSE) parameters. The higher the R^2 and lower the χ^2 and RMSE values, the better is the fitting procedure (Wang et al., 2007; Ozbek and Dadali, 2007). These parameters are defined as follows:

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(\mathrm{MR}_{\mathrm{pre},i} - \mathrm{MR}_{\mathrm{exp},i}\right)^2}{N - z} \tag{3}$$