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RESEARCH ARTICLE

MOISTURE AND COLOR CHANGE OF THE PEAR (DEVECI) DRIED IN THE CONVEYOR BELT MICROWAVE DRYER

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ABSTRACT

In the present work, the effect of drying on properties of pear samples (Deveci) was analyzed by microwave energy drying at microwave powers of 2000W and 2800W. The drying was carried out using a microwave belt dryer at a rate of 0.175 m/min, 0.210 m/min and 0.245 m/min using pears with a slice thickness of 5 mm until the moisture content reduced at a rate of 10.1 ± 0.5 (w.b.). The energy consumed during drying was calculated, and the optimum results were obtained at 2800 W microwave power and at a drying rate of 0.175 m/min. From the color quality standpoint, the best results for pear slices were determined at a belt speed of 0.175 m/min at 2800W microwave power. Moreover, in estimating the removable moisture content, constant coefficients in Newton, Page, Henderson and Pabis, Geometric, Wang and Singh drying models were investigated by multiple regression method. As a result of the analyses it was determined that the model that predicts the best kinetics of drying in all experimental conditions is "Page" model. In addition, the energy consumed during drying and the color parameters of the dried product were also determined.

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INTRODUCTION

Pear is a common name for edible fruit of some of these species, with tree-qualified plant species belonging to the genus Pyrus classified in the Maloideae subfamily of the Rosaceae family. Pear is a species that can grow easily in all regions of Turkey. The number of pear species in the world is over 5000 and it is reported that in our country with many different ecological conditions, there are 640 kinds of pear grown in accordance with every region. Pears are a fruit that is preferred by consumers due to its unique taste, brittleness, smell and aroma.Deveci pear, has a very large, flat shape, thin crustaceous, juicy, less sweet and a long storage life. They are regarded as fresh fruit in the form of fruit juice and syrup, as cube for fruit salad, in canned form and as dried fruit. The pears that are produced in our country are generally consumed in fresh and very little in dried ones (Özayadın and Özçelik, 2016). The dried pear can be used for many purposes, such as in bakery products, gravies, compotes and for consumption of the dry fruit; it is also suitable to be consumed by diabetics, aged people and babies (Amiripour *et al*., 2015). In order to keep the agricultural products which are abundantly available during certain periods of the year within the period of consumption until they are consumed, they are stored in cold storage, freezing, processing with chemicals, irradiation, drying, etc. The oldest and most common application known in these processes is drying. Drying is defined as the removal of water from the product and the drying of the water in the product is reduced to a degree that does not allow its deterioration so that a definite storage is possible (Cemeroğlu and Acar, 1986). The method that finds the widest application area in self-contained food is dried and there are many purposes of drying. Drying has been widely used to preserve food products, and fruits in particular, since the reduction of their water content to certain levels inhibits microbial growth and enzymatic modifications. Additionally, food drying presents other advantages like avoiding the need of using expensive cooling systems for preservation, or facilitating transport and storage due to the reduction in size. On the other hand, it allows the diversification of available food products, with different flavors and textures (Guine *et al*., 2007).

Microwave heating has several unique features related to selective and volumetric heating compared to the traditional approaches. Firstly, microwave can selectively couple with materials having high loss factors like water, and therefore particles with higher moisture tend to absorb more microwave energy. In addition, a more uniform temperature distribution and a better energy transfer can be achieved in volumetric

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heating resulting from the direct microwave-material interactions. Moreover, the significant internal evaporation generated by internal heating will lead to a substantial increase of moisture transport and noticeably increase the drying rate, especially at the falling rate drying period. Moreover, the microwave energy transfer will decrease as the evaporation approaches completion, which will result in automatic moisture leveling;therefore, it may be possible to minimizeoverheating of the surface of the samples, which usually occurs in traditional drying. With regard to the above features of microwave, in recent years, microwave technology has been widely researched and it has been applied in the drying of food as well as in the wood and mining industry as an efficient and clean source of heat (Song *et al*., 2016).

Better energy efficiency and dried product quality can be obtained by microwave drying which provides a higher drying rate than hot air drying (Reyes *et al*., 2007). Microwave energy can be directly absorbed by moisturein drying material and lead to heat generation within material by two mechanisms, i.e. dipolarrotation and ionic conduction, caused by altering the electro magneticfield. The high heating rate of microwaves raisesthe product temperature rapidly, causing high vapour pressureto develop inside the product (Nahimana and Zhang, 2011), resulting in a very rapid transfer of water to the surface ofthe product. This phenomenon causes a moreporous structure to develop inside the dried product and leads to lower shrinkage, increased crispiness and lower energy consump-tion (Paengkanya *et al*., 2015). The aim of this study was to dehydrate pears (cv. Deveci) at 2000W and 2800W, andevaluate properties such as moisture, color and total energy comsumption along the drying process. In addition, a suitable model was determined by testing some of the drying models for the time-dependent change of the moisture content of the pear.

MATERIALS AND METHODS

Materials

Fresh pears from a local market (Tekirdağ/Turkey) were selected. The drying chamber with a maximum output of 3000W at 2450 MHz has a section area of 0.2 m^2 and a length of 3.5 m, and is schematically represented in Fig. 1. During the drying process, the conveyor speed was to regulate and could be set at the potentiometer of control unit. Periodically the samples were removed from each oven in order to measure their average weight with a Presica XB 620 M (Precisa Instruments AG, Dietikon, Switzerland), (Kuş, 2016).

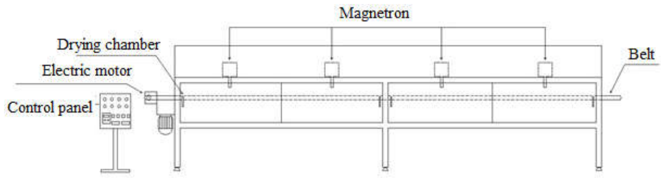

Figure 1. A schematic diagram of microwave conveyor dryer

Drying procedure

In order to determine the initial water content of the pears dried in an oven at 105 C for 24 h. The average initial moisture content of the material was measured 86%±0.8. The commercially dried pears were also supplied from the same location for comparison of quality parameters. Each drying experiment was independent, and the pears used for all were from the same supplier and had the same average initial moisture content. Prior to the drying experiment, the pears were washed with tap water, and cut into slices with thickness of 5 mm. Usual practice was applied in commercial pears production namely removal of fruit stems by hand, washing, cutting into slice and drying in a commercial continuous belt dryer at microwave power of 2000W and 2800W, at conveyor belt speed of 0.175 m/min, 0.210 m/min and 0.245 m/min. The moisture losses of samples were recorded at 3min intervals during the drying process by a digital balance with an accuracy of ±0.01 g. All measurements were carried out in triplicate (Kuş, 2016).

Modeling of drying kinetics

The moisture content of the samples and the dimensionless moisture ratio (MR) during the drying processes were found applying the following equations:

$$MR = \frac{m - m_e}{m_0 - m_e} \tag{1}$$

where m is the moisture content at any moment t (g.water/g.dry matter), mo, me are initial and equilibrium moisture content (g.water/g.wet matter) respectively. me is quite small compared with mo and m and in the MR definition may be ignored (Çelen *et al*., 2016).

Table 1. Drying models used in the comparison of experimental results (Kamil and Cihan, 2007)

Model	Model equation
Newton	$MR = \exp(-kt)$
Page	$MR = \exp(-kt^n)$
Henderson and Pabis	$MR = a\exp(-kt)$
Geometric	$MR = at^{-n}$
Wang and Singh	$MR = 1 + at + bt^2$

The experimental data were fitted in five models in Table 1. In order to determine each constant for the tested model, non-linear regression was used. The effectiveness of each model fit was evaluated via statistical criteria such as coefficient of determination (R^2), reduced chi-square ($\chi 2$) and root mean square error (e$_s$) between the experimental and the predicted moisture ratio values. The best model describing the thin-layer drying characteristics of pear slices was chosen based on the higher R^2 value and the lower $\chi 2$ and e$_s$ values.

$$R = \frac{n_o \sum_{i=1}^{n_o} MR_{pre,i} MR_{\exp,i} - \sum_{i=1}^{n_o} MR_{pre,i} \sum_{i=1}^{n_o} MR_{\exp,i}}{\sqrt{n_o \sum_{i=1}^{n_o} (MR_{pre,i})^2 - \left(\sum_{i=1}^{n_o} MR_{pre,i}\right)^2} \sqrt{n_o \sum_{i=1}^{n_o} (MR_{\exp,i})^2 - \left(\sum_{i=1}^{n_o} MR_{\exp,i}\right)^2}} \tag{2}$$

$$e_s = \sqrt{\frac{\sum_{i=1}^{n_o} (MR_{pre,i} - MR_{\exp,i})^2}{n_o}} \tag{3}$$

$$\chi^2 = \frac{\sum_{i=1}^{n_o} (MR_{pre,i} - MR_{\exp,i})^2}{n_o - n_c} \tag{4}$$

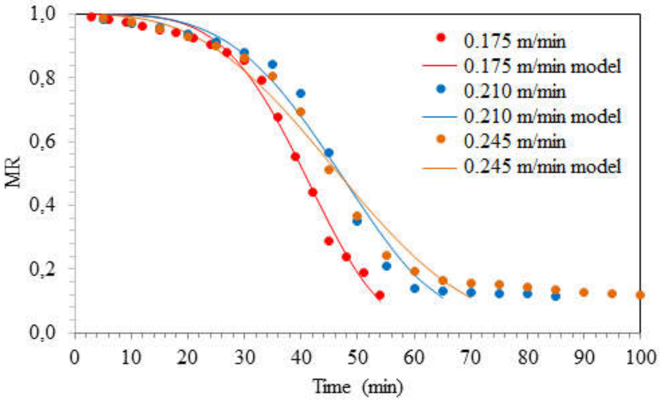

Figure 4. Drying curves based on Page model for 5 mm slice thickness and 2000 W drying power

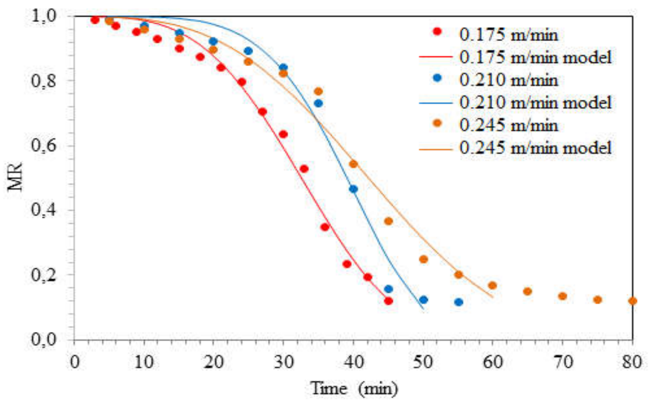

Figure 5. Drying curves based on Page model for 5 mm slice thickness and 2800 W drying power

Table 2. Analysis results of the models for 2000 W

Model	Bant Hızı	Sabitler	R	e_s	χ^2
Henderson and Pabis	0.175 m/min	a=1.2585 / k=0.0220	0.7518	0.1623	0.0263
	0.210 m/min	a= 1.35197 / k= 0.02344	0.8342	0.1622	0.0263
	0.245 m/min	a=1.325202 / k= 0.02271	0.861	0.139	0.0193
Geometric	0.175 m/min	a=1.7459 / n=0.29801	0.4715	0.2352	0.0553
	0.210 m/min	a= 2.74904 / n=0.46626	0.5747	0.2578	0.0665
	0.245 m/min	a=2.609683 / n=0.44383	0.6022	0.2331	0.0544
Wang and Singh	0.175 m/min	a=0.00544 / b= -0.00042	0.9778	0.0485	0.0024
	0.210 m/min	a=-0.006369/ b=-0.00007	0.8857	0.1355	0.0184
	0.245 m/min	a=-0.005633/ b= -0.00008	0.917	0.1082	0.0117
Newton	0.175 m/min	k= 0.01507	0.7896	0.1885	0.0355
	0.210 m/min	k= 0.01672	0.867	0.1974	0.039
	0.245 m/min	k= 0.01618	0.8917	0.1755	0.0308
Page	0.175 m/min	k=0.0000 / n=4.22905	0.9935	0.0293	0.0009
	0.210 m/min	k= 0.0000 / n=3.65857	0.9794	0.0671	0.0045
	0.245 m/min	k= 0.0000 / n= 2.87666	0.9782	0.0564	0.0032

Table 3. Analysis results of the models for 2800 W

Model	Bant Hızı	Sabitler	R	e_s	χ^2
Henderson and Pabis	0.175 m/min	a= 1.25213 / k= 0.02852	0.8055	0.1427	0.0204
	0.210 m/min	a= 1.33917 /k= 0.02625	0.744	0.1966	0.0387
	0.245 m/min	a=1.299376 / k= 0.024085	0.8378	0.1436	0.0206
Geometric	0.175 m/min	a= 1.77396 / n= 0.33898	0.5402	0.2177	0.0474
	0.210 m/min	a= 2.309734/ n= 0.40642	0.5074	0.2709	0.0734
	0.245 m/min	a= 2.36763 / n= 0.415570	0.5922	0.2263	0.0512
Wang and Singh	0.175 m/min	a= 0.001754/ b= - 0.00050	0.9856	0.0385	0.0015
	0.210 m/min	a= 0.004260/ b= -0.00042	0.939	0.0946	0.0089
	0.245 m/min	a=-0.002884/ b= -0.000188	0.9436	0.0838	0.007
Newton	0.175 m/min	k= 0.020124	0.8399	0.1685	0.0284
	0.210 m/min	k= 0.017405	0.7884	0.225	0.0506
	0.245 m/min	k= 0.017003	0.8714	0.1747	0.0305
Page	0.175 m/min	k=0.0000 / n=3.41648	0.9908	0.0353	0.0012
	0.210 m/min	k= 0.0000 / n=4.96248	0.9827	0.0566	0.0032
	0.245 m/min	k=0.0000 / n=3.04653	0.9801	0.0513	0.0026

Where $MR_{pre,i}$ is the *ith* predicted moisture ratio, $MR_{exp,i}$ is the *ith* experimental moisture ratio, n_o is the number of observations and n_c is the number of coefficients in the drying model.

Colour measurement

The colour analysis of the product was conducted by a Spec HP-200 (Jiangsu, China) colorimeter. The colour measurement of the pears was expressed in terms of *L** (lightness/darkness), *a** (redness/greenness) and *b**(yellowness/blueness). The colorimeter was calibrated witha standard black and white plate before measurement. Average color values of five dried pears were recorded in each experiment.

Determination of Energy Consumption

Energy consumption was measured with an electric counter (Köhler AEL.MF.03 brand, Turkey). Energy consumption values of microwave conveyor belt dryer were recorded using this device.

RESULTS

Drying characteristics of sliced pear samples of different sizes were given in Figures 2 and 3.As can be seen, the drying time is affected by the microwave power and, depending on the increase of the drying power the loss of moisture accelerates and the drying time shortens.At the same time, the decrease in belt speed and the decrease in slice thickness also change the drying time. This is due to the fact that the moisture in the product is not homogeneous, the heat energy is formed more in the interior, and the interaction of the microwave energy with the product originating from the belt speed varies in drying times. It is not exactly possible to establish a relationship between belt speed and drying times. For the 2000 W microwave power, drying was carried out at 54, 85 and 100 minutes respectively and at 28, 55 and 100 minutes respectively for 2800 W microwave power, respectively. Curve fitting computations was carried out on the five drying models relating the drying time and moisture ratio. The results are given in Table 2-3. The acceptability of the drying model is based on a value for the correlation coefficient R which should be close to one, and low values for the standard error e_s and the mean squared deviation χ^2. The results show that the most appropriate model in describing drying curves of pear is the Page model with R in the range of 0.9782–0.9935, and with e_s in the range of -0.0293–0.0671 and with χ^2 in the range of 0.0009–0.0045. Additionally the drying curves based on the *Page Model* are illustrated along with the experimental moisture ratios in Figure 4-5.

Five different color measurements were made before and after drying in each experiment to determine the color changes in fresh products and products dried in the dryer. The arithmetic average of the obtained values was evaluated. The color parameters of 5 mm thick slices dried in the microwave dryer were compared with the color parameters of the fresh product and color losses were determined.In microwave drying, the maximum losses for brightness (ΔL) were at 2000 W and a belt speed of 0.245 m/min. Overheating causes burns in the product, so there are blackouts. This is an unwelcome situation. The energy consumption of the drying stage in the microwave was recorded at the beginning and end of the test thanks to the counter located on the control panel.Energy consumption was measured between 1.370-3.059 kWh.As the microwave power for pear fruit decreases, the energy consumed also increases. The reason for this can be explained as follows. Because there is little heat generated by low microwave power, more time is required for transfer of the produced heat into the biological material and heat transfer to the environment from the product. Thus, the time required for the water in the product to reach the evaporation temperature is prolonged and the energy consumed for evaporation is reduced. In this case it prevents effective drying. Similarly, when drying times are taken into consideration, it is observed that the drying times are shortened at high microwave powers, while those at low powers are increasing. If a comparison is made in terms of the effect of belt speed on drying time, it is measured that the drying time increases at high belt speeds and decreases at low speeds. Although the differences are not great, the difference in time is due to the fact that the microwave energy density in the oven is the highest value below the microwave power units, and at high beltspeeds, the microwave energy of the product quickly passes through the intensified regions, where the energy is less exposed.

Conclusion

In the study, when the time required for drying 5 mm thick pear slices to 10.1 ± 0.5 (w.b.) moisture content and the optimum electrical energy consumption of the system are considered, the best results have been obtained for 2800 W microwave power and 0.175 m/minbelt speed. Increasing the microwave power reduced drying times and energy consumption. When the effects of belt speed change on the drying process were observed, increasing belt speed values generally increased drying time. Although the increase in microwave power caused a decrease in electricity consumption and drying time, there was no decisive effect on quality values.

When dried pear slices are examined by color, it is observed that the color factors of working conditions with the total microwave power of 2800 W for pear slices at the same belt speed usually give the closest results of the fresh product. The increase in microwave power has generally improved the color quality. From the point of view of color quality, the best result for pear slices of 5 mm thickness is seen at 0.175 m/min belt speed and 2800 W microwave power. In terms of color quality, the best result were obtained at a belt speed of 0.175 m/min. Estimation of the removable moisture ratio has yielded up to three models with estimates of the coefficients of the drying models with the highest R value depending on the microwave power and the belt speed. As a result of the analyses, the model that best predicts the drying kinetics was selected as the "Page" model in all experimental conditions.

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