Süleyman Demirel Üniversitesi Ziraat Fakültesi Dergisi 11 (1):27-33, 2016
ISSN 1304-9984, *Araştırma Makalesi*

Microwave Drying of Quince Slices

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Geliş tarihi: 01.12.2016, Yayına kabul tarihi: 12.04.2016

Abstract: In this research, microwave drying characteristics on moisture ratio, drying rate of quince slices were reported. Quince slices were dehydrated in a fan assisted microwave oven dryer. The effects of microwave drying (180, 360, 540, 720 and 900W) on drying time, drying rate of quince slices have been investigated. Quince slices were dried from 3.75 g water/g dry matter initial moisture content to 0.12 g water/g dry matter final moisture content. In the microwave drying system, quinces sliced into 5 mm thickness were dried at 180, 360, 540, 720 and 900W microwave drying powers. During microwave drying experiments, slices were weighted and data recorded manually per 1 minute. The drying data were applied to nine different mathematical models, namely, Newton, Page, Henderson and Pabis, Logarithmic, Midilli-Kucuk, Wang and Singh, Two Term, Verma, Two Term Exponential, Diffusion Approach Equation Models. It was found that the Midilli-Kucuk model described the drying curve satisfactorily in all drying methods.

Key words: Quince, microwave, modelling

Ayva Dilimlerinin Mikrodalga ile Kurutulması

Özet: Bu çalışmada, ayva dilimlerinin nem oranı, kuruma hızı ile mikrodalga kuruma karakteristikleri rapor edilmiştir. Ayva dilimleri fan destekli mikrodalga kurutucuda kurutulmuşlardır. Ayva dilimlerinin kuruma süresi ve kurutma hızı üzerinde mikrodalga kurutmanın (180, 360, 540, 720 and 900W) etkileri araştırılmıştır. Ayva dilimleri 3,75 g su/g kuru madde ilk nem içeriğinden 0,12 g su/g kuru madde son nem içeriğine kadar kurutulmuşlardır. Mikrodalga kurutma sistemi içerisinde, 5 mm kalınlıkta dilimlenen ayva dilimleri 180, 360, 540, 720 ve 900 W mikrodalga güç seviyelerinde kurutulmuştur. Mikrodalga kurutma denemeleri süresince, dilimler tartılmış ve her 1 dakikada elle ölçümler kaydedilmiştir. Kurutma verileri, 10 farklı matematiksel modellere (Newton, Page, Henderson ve Pabis, Logaritmik, Midilli-Kucuk, Wang ve Singh, iki terimli, Verma, iki terimli üssel, difüzyon yaklaşımı) uygulanmıştır. Tüm kuruma modelleri içerisinde, en uygun kuruma modeli, Midilli-Kucuk model eşitliği bulunmuştur.

Anahtar kelimeler: Ayva, mikrodalga, modelleme

Introduction

Quince fruit is known for its characteristics; pleasant smell and distinctive taste. The fruit is a member of pomes fruit family; 83.8% water and 15.3% carbohydrates (wet basis) are the main constituents of quince. Minor ingredients of quince are proteins (0.4%, wet basis) and fats (0.1%, wet basis). It is presumed to be a good source of fiber, potassium, and vitamin C (Noshad et al., 2012). The dried fruit is consumed as ingredients in the other food and cips as well. However, like other fruits, they are perishable; therefore drying is fairly advantageous, reducing water activity of the material, thus diminishing the microbiological activity to a level preventing deterioration. Even though the drying is one of the most common methods used to improve. Drying is one of the possibilities of processing the vegetables and fruits. Drying plays an important role in extending the shelf life of fleshy agricultural products. Also, it brings about substantial reduction in weight and volume, minimising packaging, storage and transportation costs. Hot air drying is a simple, common method for drying vegetables and fruits. Numerous investigators have examined the hot air drying. Microwave drying is usually done by incorporating microwave radiation for heating and evaporation of moisture instead of heating by conduction and convection. The major advantages of microwave drying over conventional drying methods are fast operation, energy savings, precise process control and faster start-up and shutdown operation. The objective of this study was study the thin layer microwave drying behaviour of quince samples. The effects of microwave output power level on drying characteristics for quince drying were studied. The experimental drying data was fitted to some selected thin layer models and suitable model was suggested.

Material and Methods

Material

Fresh quinces were bought from a local market in Isparta, Turkey. The whole samples were stored at 4±0.5 ºC before experiments in order to slow down the respiration, physiological and chemical changes (Maskan, 2001). Prior to drying, material samples were taken out of storage. The quinces were hand peeled, cut into slices of about 5.0±0.1 mm thickness with a sharp stainless steel knife. 100 g samples were dried in an oven and the initial moisture content of the quince samples was determined as 86% (w.b.) using a standard methods by the drying oven at 105º C for 24 h (Soysal, 2004). This drying procedure was replicated three times.

Methods

Drying of the quince slices

In this study, a programmable domestic microwave oven (Arçelik, MD-824, Turkey) with maximum output of 900 W at 2450 MHz. was used in the experiments (Fig 1). The dimensions of the microwave cavity were 210 mm by 340 mm the microwave oven had the capability of operating at five different microwave output power levels: 180, 360, 540, 720 and 900W.

The microwave oven was fitted with a glass turn-table (325 mm diameter) and was operated by a control terminal, which was able to control both microwave power level and emission time. For the mass determination, a digital balance of 0.01 g accuracy (Sartorius GP3202, Germany) was used and at interval of 1 min during the drying experiment (Maskan, 2001). Depending upon the drying conditions, moisture loss was recorded at 1 min interval during drying at the end of power-on time by removing the turntable from the microwave, and placing this, along with the sample on the digital balance periodically (Soysal *et al*,2006).

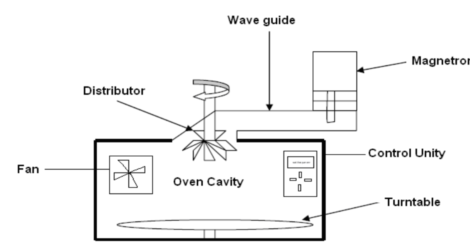

Figure 1. Schematic diagram of the microwave oven
Şekil 1. Mikrodalga fırının şematik diyagramı

Drying procedure

Different microwave output powers were determined as 180, 360, 540, 720 and 900W in drying experiments at constant sample loading density. A Teflon dish, containing the sample, was placed at the centre of the oven turn-table in the microwave cavity. About 100g of quince slices after weighing were uniformly spread in a oven turntable inside the microwave cavity during application for an even absorption of microwave energy thereafter the drying experiment started. Quince slices were dried until equilibrium moisture content (no weight change) was reached.

Mathematical modelling of the drying curves

Drying curves were fitted with ten thin layer drying models, namely, Newton, Page, Henderson and Pabis, Logarithmic, Midilli-Kucuk, Wang and Singh, Two Term, Verma, Two Term Exponential, Diffusion Approach Equation Models (Table 1). The moisture ratio and drying rate of quince slices were calculated using the following equation:

$$(\mathrm{MR}) = \frac{M - M_e}{M_0 - M_e} \quad (1)$$

where, MR, M, M_0 and M_e, are the moisture ratio, moisture content at any time, initial and equilibrium moisture content, respectively.

Mathematical models that describe drying mechanisms of grain and food provide the required temperature and moisture information (Doymaz, 2006). The thin-layer drying models, describing the drying process, can be distinguished in three main categories, namely the theoretical, the semi-theoretical and the fully empirical ones (Babalis et al, 2006). Newton model has been used to describe the thin layer drying characteristics of food crops (Ayensu, 1997).

$$MR = \exp(-k.t) \quad (2)$$

The common Semi-empirical Page's equation was used to describe the thin-layer drying kinetics of nettle leaves (Alibaş, 2007):

$$MR = \exp(-(kt)^n) \quad (3)$$

where, k and n are constants of model and t is time. Among semi-theoretical thin layer drying models, namely the Henderson and Pabis model, the Lewis model and the Page model are used widely. These models are generally derived by simplifying general series solution of Fick's second law. The Henderson and Pabis model is the first term of a general series solution of Fick's second law. This model was used successfully to model drying of okra (Doymaz, 2005a) and black tea (Panchariya et al, 2002). The model is given as:

$$MR = a.\exp(-kt) \quad (4)$$

where, a and k are constants of model and t is time.

Logarithmic model has been used to describe the thin layer drying characteristics of organic apple slices (Sacilik & Konuralp Eliçin, 2006), single apricot (Tuğrul & Pehlivan, 2003) and mint leaves (Doymaz, 2006).

$$MR = a.\exp(-k.t) + c \quad (5)$$

where, a, k and c are constants of model.

Midilli-Kucuk Model has been used to describe the thin layer drying characteristics of eggplant (Ertekin & Yaldız, 2004) and some vegetables and fruits (Akpınar, 2006). The model is given as:

$$MR = a.\exp(-k(t^n) + bt \quad (6)$$

where, a, b, n and k are constants of model and t is time.

Wang and Singh model has been used to describe the thin layer drying characteristics of rough rice (Wang & Singh,1978).

$$MR = 1 + a.t + b.t^2 \quad (7)$$

Two term model has been used to describe the performance evaluation of rosemary leaves dried by three different drying methods (Arslan and Ozcan, 2008).

$$MR = a.\exp(-k_0 t) + b\exp(-k_1 t) \quad (8)$$

where, a, b and k are constants of model and t is time. Verma model has been used to describe the sun drying characteristics of figs (Doymaz, 2005b)

$$MR = a.\exp(-kt) + (1-a)\exp(-gt) \quad (9)$$

where, a, k and g are constants which depend on the model.

Two term exponential model is the first two terms of general series solution to the analytical solution of Fick's second law, and has been used to describe drying agricultural products (Doymaz, 2006). The model is written as:

$$MR = a.\exp(-kt) + (1-a)\exp(-kat) \quad (10)$$

where, a and k are constants of model and t is time. Diffusion Approach model has been used to describe the performance evaluation of blanched carrots dried by three different driers (Prakash et al, 2004).

$$MR = a.\exp(-kt) + (1-a)\exp(-kbt) \quad (11)$$

where, a, b and k are constants which depend on the model. Table 1. summarizes the above mentioned drying models used in the data fit analysis of this work.

Table 1. Mathematical models applied to the drying curves
Tablo 1. Kuruma eğrilerine uygulanan matematiksel modeller

	Model name	Model equation	References
1	Newton	MR=exp(-kt)	Ayensu (1997)
2	Page	MR=exp(-kt^n)	Agrawal ve Singh (1977)
3	Henderson and pabis	MR=a exp(-kt)	Akpınar *et al.* (2006)
4	Logarithmic	MR=a exp(-kt)+c	Yaldız *et al.* (2001)
5	Midilli-Kucuk	MR=a exp(-k(t^n)+bt	Sacilik and Elicin (2006)
6	Wang and Singh	MR=1+at+bt^2	Wang ve Singh, (1978)
7	Two Term	MR=a exp(-kt)+bexp(-k$_1$t)	Soysal *et al.*(2006)
8	Verma	MR=a exp(-kt)+(1-a)exp(-gt)	Verma *et al.*(1985)
9	Two term exponential	MR=a exp(-kt)+(1-a)exp(-kat)	Sharaf-Elden *et al.* (1980)
10	Diffusion Approach	MR=a exp(-kt)+(1-a)exp(-kbt)	Toğrul and Pehlivan (2003)

Statistical analysis

Statistical analysis was conducted using the sigma plot (scientific graph system, version 12.00, jardel). Non-linear regression analysis was performed using Sigma-Plot (SPSS Inc., version 12.00) to estimate the parameters of equations. Regression results include the for microwave drying of quince slices under various microwave output power; SEE, Standard error of estimate; R^2, coefficient of determination; RSS, residual sum of square.

Results and Discussion

Drying characteristics of quince slices

Fig. 2 suggest the variations of experimental and predicted moisture ratios by the Midilli-Kucuk drying model with drying time at the drying microwave powers of 180, 360, 540, 720 and 900 W for slices thickness of 5 mm, respectively. All the drying in case of quince takes place in the falling rate period. It is obvious from Fig. 2 that increasing the microwave power caused an important increase in the drying rate, thus the drying time is decreased. The time required to reduce the moisture ratio to any given level was dependent upon the drying condition, being highest at 180 W and lowest at 720 W. With drying, the time taken to reduce the moisture content of quince slices from 3.75 g water/g dry matter initial moisture content to 0.12 g water/g dry matter final moisture content was 104, 39, 24, 22 and 12 min at 180, 360, 540, 720 and 900 W, respectively. The effect of drying microwave power was most impressive with moisture ratio decreasing rapidly with increased microwave power. The decrease in drying time with increase in drying microwave power has been observed by Soysal (2004) for parsley, Wang and Xi (2005) for carrot slices.

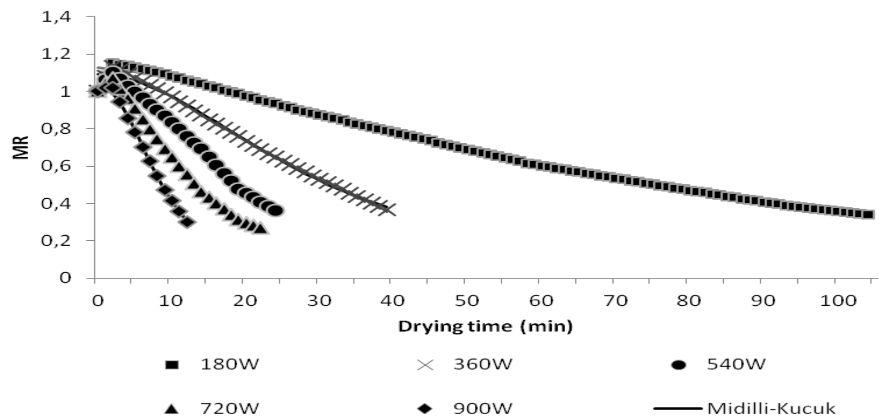

Figure 2. Variation of experimental and predicted moisture ratio by Midilli-Kucuk model with drying time at selected microwave output powers

Şekil 2. Seçilen mikrodalga güç seviyelerinde kuruma süresinin Midilli-Kucuk modeli ile deneysel ve tahmin edilen ayrılabilir nem oranının değişimi

Evaluation of the models

The moisture content data at the different drying conditions were converted to the more useful moisture ratio expression and then curve fitting computations with the drying time were carried on the 10 drying models evaluated by the previous researchers (Table 1).

Non-linear regression analysis was performed using the Sigma Plot computer program. Coefficient of determination (R^2) was one of the important factors for selecting the best model to define the drying curves of quince slices. However, various statistical parameters such as Standard error of estimate SEE and residual sum of square RSS were also used to evaluate the goodness of fit of the models. The quality of fit was determined by the lower the SEE and RSS values and the higher the R^2 values (Karaaslan, 2008).

The statistical analyses results applied to these models in the drying process at 180, 360, 540, 720 and 900 W microwave powers are given in Table 2 for quince samples. The models were evaluated based on R^2, SEE and RSS. According the Midilli-Küçük model highest values of R^2 and the lowest values of SEE and RSS were 0,9976; 0,0149; 0,0020 for 900 W MWD, respectively.

Table 2. Non-linear regression analysis results for microwave drying of quince

Tablo 2. Ayvanın mikrodalga kurutulmasına ilişkin non lineer regresyon analiz sonuçları

Microwave power	Statistics	No									
		1	2	3	4	5	6	7	8	9	10
180W	R^2	0,8753	0,9628	0,9877	0,9722	**0,9963**	0,9392	0,9877	0,8753	0,8753	0,8753
	SEE	0,0876	0,0481	0,0276	0,0211	**0,0154**	0,0615	0,0279	0,0885	0,0885	0,0885
	RSS	0,7984	0,2380	0,0785	0,0230	**0,0240**	0,3892	0,0785	0,7984	0,7984	0,7984
360W	R^2	0,8250	0,9621	0,9602	0,9825	**0,9934**	0,9420	0,9602	0,8250	0,8250	0,8250
	SEE	0,1004	0,0474	0,0485	0,0243	**0,0203**	0,0586	0,0498	0,1031	0,1031	0,1031
	RSS	0,3931	0,0852	0,0893	0,247	**0,0148**	0,1304	0,0893	0,3931	0,3931	0,3931
540W	R^2	0,8274	0,9773	0,9392	0,9826	**0,9945**	0,9582	0,9392	0,8261	0,8274	0,8274
	SEE	0,1017	0,0376	0,0617	0,0337	**0,0195**	0,0511	0,0645	0,1066	0,1062	0,1062
	RSS	0,2481	0,0326	0,0874	0,0250	**0,0079**	0,0601	0,0874	0,2500	0,2481	0,2481
720W	R^2	0,9042	0,9833	0,9663	0,9845	**0,9967**	0,9572	0,9663	0,9042	0,9042	0,9042
	SEE	0,0856	0,0366	0,0520	0,0230	**0,0172**	0,0586	0,0547	0,0898	0,0898	0,0898
	RSS	0,1613	0,0282	0,0568	0,0223	**0,0056**	0,0721	0,0568	0,1613	0,1613	0,1613
900W	R^2	0,8741	0,9925	0,9348	0,9835	**0,9976**	0,9740	0,9348	0,8741	0,8741	0,8741
	SEE	0,0929	0,0237	0,0698	0,0368	**0,0149**	0,0441	0,0772	0,1018	0,1018	0,1018
	RSS	0,1035	0,0062	0,0536	0,0136	**0,0020**	0,0214	0,0536	0,1035	0,1035	0,1035

Conclusions

The effects of different drying methods on the drying of quince slices were evaluated based on the drying parameters, such as the moisture ratio and drying time.

The increase in microwave power significantly reduced the drying time of quince slices. Drying curves of quince slices did not show a constant rate-drying period under the experimental employed and showed only a falling rate-drying period. In the present research experimental data for quince slices are used in order to evaluate several thin-layer drying models available in the literature. Among these models, in each of five applications, the Midilli–Kucuk model gave the best results. The relationships between the model parameters and the drying conditions for the computation of the moisture ratio in relation to drying time were determined and reported.

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