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DRYING CHARACTERISTICS OF SULTANA GRAPE FRUIT IN MICROWAVE DRYER

Sevil Karaaslan, Kamil Ekinci, Davut Akbolat
[1]*University of Suleyman Demirel, Isparta. Turkey*

Abstract

Drying of sultana grape fruits was studied using a microwave dryer under the laboratory environment at the Department of Agricultural Machinery and Technologies Engineering at Suleyman Demirel University. In this study, the effects of microwave drying and fan assisted microwave drying on drying time, drying ratio of grape samples were examined. Sultana grape fruits were dried by using microwave, microwave-convective combination and convective drying, respectively. The effects of microwave drying (180, 540 and 720 W); combined convective and microwave drying (180W-100ºC, 360W-100ºC and 540 W-100ºC), convective drying (100, 150, 200ºC) on drying time, drying rate of grape samples have been investigated. The drying data were applied to four different mathematical models, namely, Midilli-Kucuk, Weibull distribution, logistic and Alıbas Equation Models. The performances of these models were compared according to the coefficient of determination (R2), standard error of estimate (SEE) and residual sum of squares (RSS), between the observed and predicted moisture ratios. The drying characteristic curves were estimated against four mathematical models and the Weibull distribution was found to be the best descriptive model for all the drying experiments of thin layer grape fruit samples except for 540W-100ºC. Alıbas model equation was also found to be the best descriptive model for combined microwave and convective drying (540W-100ºC).

Key words: Drying characteristics, grape fruits, microwave dryer, mathematical modeling

INTRODUCTION

Grapes (*Vitis vinifera*) produced for wine, as raisins, as table grapes, and for other uses are among the world's most important and widely grown fruit crops (74.4 million tons) (Faostat, 2014). The world raisin production is about 25 million tons annually with the most important raisin producers being the United States, Turkey, Iran, and China. In countries where grapes are grown, drying grapes into raisins is a major and profitable business (Faostat, 2014).

Drying is one of the safe and widely used conserving methods. sun and solar drying can be considered as the most common drying methods in tropical and subtropical countries because of cheap process when compared to others (Santos and Silva, 2008). Hot air drying is also another very common method in the drying of fruits and vegetables. Although hot air is traditional drying method in drying of fruits and vegetables, it frequently damaged product quality. Losses of volatile compound, worsening of the food colors, surface of food hardening and nutritional content can also occur during dehydration, because fruits and vegetables are exposed to high temperatures for a long process. Thus, alternative methods of drying are required for manufacturing better products (Yongsawatdigul and Gunasekaran, 1996).

The use of microwave in the drying of foods has the specific advantage of rapid and uniform heating due to the penetration of microwaves into the body of the products and a homogeneous energy distribution on the products (Ozkan *et al.,* 2007). The rapid absorption of energy by water molecules causes quick evaporation of water, resulting in high drying rates of the fruits and vegetables (Kouchakzadeh and Shafeei, 2010). This method significantly decreases drying time. Nevertheless, when internal heating extracts moisture to the surface, the existence of a convective flow can remove it from the surface quickly. So, the combined microwave-convective method could be more useful (Sadeghi *et al.* 2013).

Many authors studied the drying characteristics in fruits and vegetables during microwave and combination with air-drying methods. Air drying methods have demonstrated to be effective for several different fruits and vegetables such as garlic (Cui *et al.,* 2003), eggplant (Ertekin and Yaldız, 2004). Microwave drying methods have proved to be effective for many fruits and vegetables such as potato (Bouraout *et al.,* 1994), apple (Bilbao-Sainz *et al.,* 2006). Many fruits and vegetables were dried successfully with microwave-air drying methods. Fruits and vegetables such as apple and mushroom (Funebo and Ohlsson, 1998), carrot (Prabhanjan *et al.,* 1995) were dried effectively using microwave-air drying methods.

This study aimed to investigate the efficiency of microwave, air and combined microwave-air drying methods for different grape samples, to compare the experimental data found during all drying methods with the predicted values obtained by using some drying models.

MATERIAL AND METHODS

Homogeneously sized grape samples were used in this study as experimental material. Fresh grape samples (*Morus alba L*) were purchased from the supermarket to use in the experiment.

A domestic microwave dryer constructed at Department of Agricultural Machinery and Technologies Engineering at Suleyman Demirel University was used in this study (Figure 1).

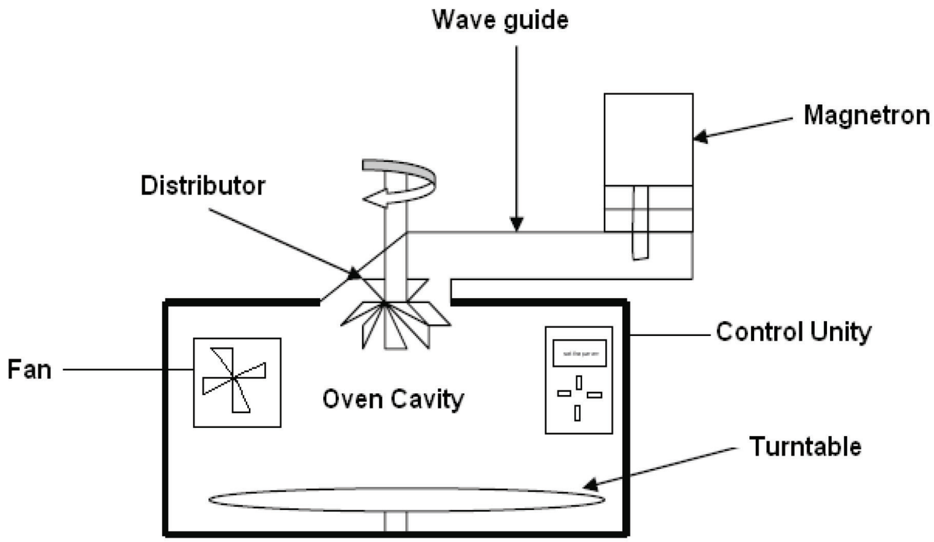

Figure 1. Schematic diagram of the microwave oven

100 g grape samples were dried in an oven and the initial moisture content of the grape samples was indicated as 81,6 % on w.b. using a standard method by the drying oven at 105º C for 24 h (Soysal, 2004). This drying process was replicated three times. Drying treatment was performed a programmable domestic microwave oven (Arçelik ARMD 594, Turkey) with maximum output of 900W at 2450 MHz. The dimensions of the microwave cavity were 230 by 350 by 330 mm. The microwave oven has a glass turn-table (325 mm diameter). The microwave oven has the standard capability of operating at five different microwave power levels, being 180, 360, 540, 720 and 900W and it has different temperatures between 100 and 250°C. For the mass determination, a digital

weight of 0.01 g accuracy (Sartorius GP3202, Germany) was used. Depending on the drying methods, moisture loss was recorded at 1 min interval during drying at the end of power-on time by detracting the turntable from the microwave, and placing this, along with sample on the digital weight periodically (Soysal *et al,* 2006).

The moisture ratio (MR) was calculated based on moisture content as a function of time (t) (M(t)), initial moisture content of samples (M_0), and equilibrium moisture content of samples (M_e).

$$MR = \frac{M(t) - M_e}{M_0 - M_e} \tag{1}$$

All moisture contents were reported as wet basis (%, w.b). Simplification of MR in Eq. (1) as M/Mo was suggested by Diamente and Munro (1993); Elicin and Sacılık (2005) due to the continuous fluctuation of relative humidity of drying air under solar tunnel dryer conditions. Therefore, the drying rate as $g_{water.}h^{-1}$ (DR) of the sultana grape fruits was determined by Eq. (2)

$$DR = \frac{M_{t+dt} - M_t}{dt} \tag{2}$$

where M_{t+dt} is the moisture content at t+dt ($g_{water}/g_{dry\ matter}$).

A non-linear regression analysis (Sigma Plot 12.00) was applied to experimentally obtained MR as a function of time using drying models given in Table 1. The constants (a, n, b, c, m, k, and g) of models tested in Table 1 were determined based on the non-linear regression analysis. The performance of models was evaluated by coefficient of determination (R^2), the standard error of estimate (SEE), and residual sum of square (RSS).

Table 1. Mathematical models tested for the moisture ratio values of the sultana grape fruits

No	Model name	Model Equation	References
1	Midilli *et al*.	MR=a exp(-kt^m)+b t	Midilli *et al*. (2002)
2	Weibull distribution	MR=a-bexp(-(kt^n))	Babalis *et al*. (2006)
3	Logistic	MR=a0/(1+aexp(kt))	Alibas (2012)
4	Alibas	MR=aexp((-kt^n)+(bt))+g	Alibas (2012)

RESULTS

The initial moisture of sultana grape fruit was 81% (w.b). The moisture ratio of sultana grape fruits as a function of drying time is showed in Fig. 2, Fig. 3, and Fig. 4.

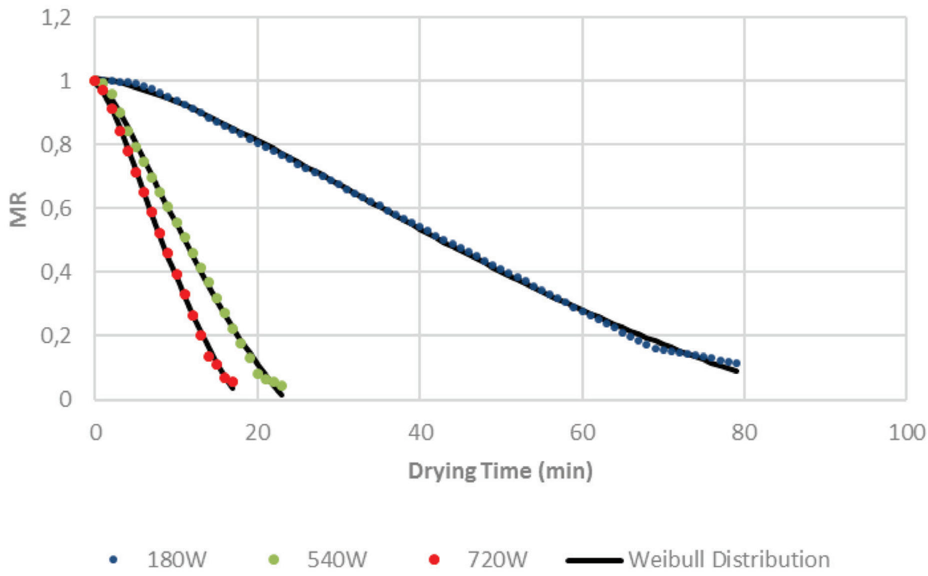

Figure 2. Variation of experimental and predicted moisture ratio by Weibull Distribution model with drying time at selected microwave output powers

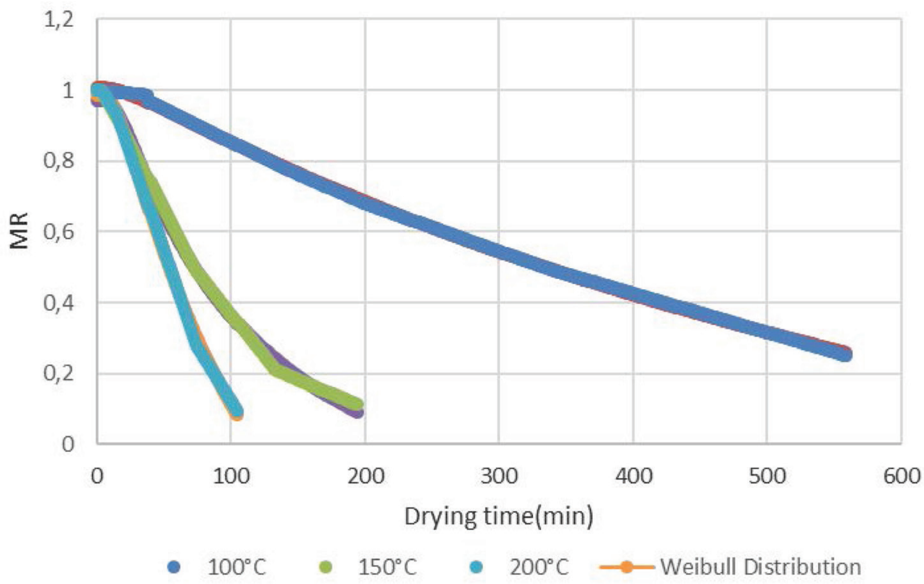

Figure 3. Variation of experimental and predicted moisture ratio by Weibull Distribution model with drying time at selected temperatures

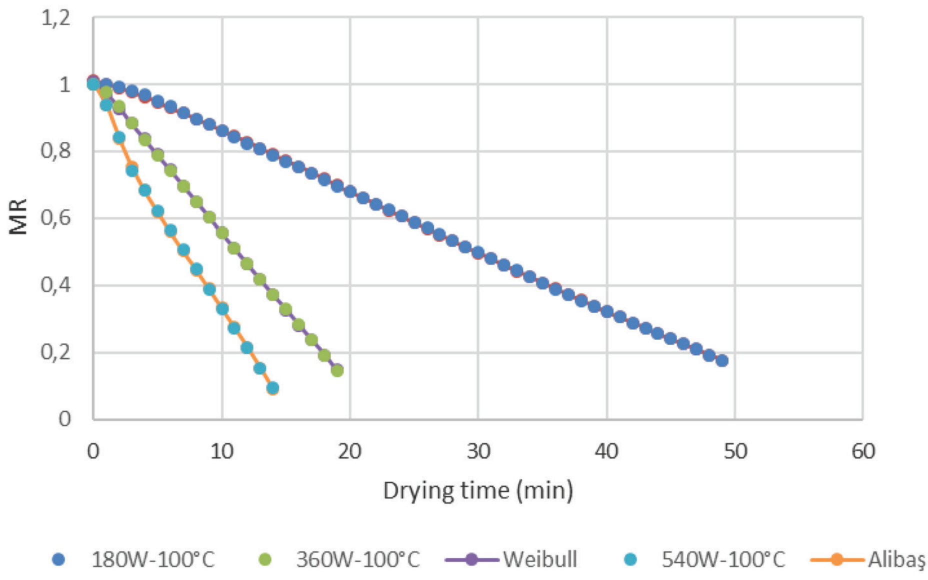

Figure 4. Variation of experimental and predicted moisture ratio by Weibull distribution and Alibas models with drying time at selected temperatures and 180W, 360W and 540 W microwave powers

The results show that applying microwave power decreased drying time considerably. The total drying times to reach the final moisture content for the sultana grape fruits were 79, 23 and 17 min at 180, 540 and 720 W, respectively. The same results have been reported for several agricultural products such as banana (Maskan,2000), orange slices (Diaz *et al.,* 2003), and grape Tulasidas *et al.*,1993). Plots of experimental and predicted by Weibull Distribution Model moisture ratio values with drying time are shown in Fig. 2.

The effect of changing the temperature in the microwave oven on the moisture ratio curve of sultana grape fruits is shown in Fig. 3. The total drying times to reach the final moisture content for the sultana grape fruits were 559, 194 and 105 min at 100, 150 and 200 ºC, respectively.

Combining microwave with convective drying results was showed in a higher moisture ratio (Fig. 4). The total drying times to reach the final moisture content for the sultana grape fruits were 49, 19 and 14 minutes respectively at 180, 360 and 540 W at a drying temperature of 100ºC.

Drying rate have two stages, first the moisture content rapidly decreased and then slowly reduced with increase in drying time. During the first stage, the surface of sultana grape fruit behaves as a surface of free water. The rate of moisture content exclusion from the surface is dependent on situation of places that drying is happened, but in second period the moisture movement from the inter layers of sultana grape fruits to surface, this stage is dependent on the rate diffusion of moisture from within the product to the surface and moisture removal from the surface. In the two-main rate regime, both the external factors and the internal mechanism controlling the drying process are important in defining the whole drying rate of agricultural products (Ekechukwu, 1999).

Four different moisture ratio models were used to predict the moisture content as a function of drying time (Table1). The statistical values, obtained under different drying conditions for these mathematical models are shown in Table 2, Table 3 and Table 4, respectively.

The best model describing drying of sultana grape fruits in given conditions was determined based on R^2 with the lower value of SEE and RSS, which are evaluation criteria used to compare the statistical validity of the fit. The results showed that the R^2, SEE, and RSS values of nonlinear regression analysis ranged from 0.8406 to 0.9991, from 0.0092 to 0.0943, and from 0.0022 to 0.1562, respectively for microwave drying. (Table 2). According to the microwave drying, Weibull model yielded the highest R^2 for sultana grape fruits, with the lowest SEE and RSS values (Table 2).

Table 2. Results of nonlinear regression analysis of fitting the four drying models to the experimental data for microwave drying of sultana grape fruits

	Microwave power levels								
	180W			540W			720W		
Models	R^2	SEE(±)	RSS(±)	R	SEE(±)	RSS(±)	R	SEE(±)	RSS(±)
Midill-Kucuk	0,8406	0,1190	1,0762	0,9887	0,0368	0,0270	0,9809	0,0491	0,0338
Weibull D.	0,9991	0,0092	0,0064	0,9983	0,0143	0,0041	0,9987	0,0126	0,0022
Logistic	0,9982	0,0125	0,0121	0,9944	0,0253	0,0135	0,9968	0,0196	0,0057
Alibas	0,9966	0,0174	0,0228	0,9349	0,0907	0,1562	0,9347	0,0943	0,1156

The results showed that the R^2, SEE, and RSS values of nonlinear regression analysis ranged from 0.9896 to 0.9997, from 0.0036 to 0.0240, and from 0.0042 to 0.2913, respectively for convective drying (Table 2). According to the convective drying, Weibull model yielded the highest R^2 for sultana grape fruits, with the lowest SEE and RSS values (Table 3).

The outcomes showed that the R^2, SEE, and RSS values of nonlinear regression analysis ranged from 0.9549 to 0.9999, from 0.0027 to 0.0635, and from 0.0003 to 0.1465, respectively for combined microwave and convective drying (Table 4). According to the combined microwave and convective drying, Weibull model yielded the highest R^2 for sultana grape fruits, with the lowest

SEE and RSS values (Table 4). However, Alıbas model equation was also found to be the best descriptive model for combined microwave and convective drying (540W-100ºC).

Table 3. Results of nonlinear regression analysis of fitting the four drying models to the experimental data for convective drying of sultana grape fruits

	Temperature								
	100°C			150°C			200°C		
Models	R^2	SEE(±)	RSS(±)	R^2	SEE(±)	RSS(±)	R^2	SEE(±)	RSS(±)
Midill-Kucuk	0,9896	0,0229	0,2913	0,9958	0,0183	0,0640	0,9937	0,0240	0,0586
Weibull D.	0,9997	0,0036	0,0073	0,9987	0,0136	0,0353	0,9995	0,0101	0,0105
Logistic	0,9990	0,0070	0,0272	0,9977	0,0103	0,0203	0,9989	0,0064	0,0042
Alibas	0,9992	0,0062	0,0213	0,9961	0,0176	0,0589	0,9939	0,0237	0,0568

Table 4. Results of nonlinear regression analysis of fitting the four drying models to the experimental data for combined microwave and convective drying of sultana grape fruits

	Microwave power levels and temperature								
	180W-100°C			360W-100°C			540W-100°C		
Models	R^2	SEE(±)	RSS(±)	R^2	SEE(±)	RSS(±)	R^2	SEE(±)	RSS(±)
Midill-Kucuk	0,9962	0,0164	0,0124	0,9915	0,0274	0,0120	0,9986	0,0122	0,0016
Weibull D.	0,9999	0,0027	0,0003	0,9998	0,0041	0,0003	0,9985	0,0122	0,0016
Logistic	0,9989	0,0086	0,0035	0,9970	0,0157	0,0042	0,9923	0,0269	0,0087
Alibas	0,9549	0,0571	0,1465	0,9569	0,0635	0,0605	0,9997	0,0057	0,0003

To take into account the effect of the drying variables on the Weibull Distribution and Alibas model constants a, b, k, n and g were regressed against those of drying air temperatures using multiple regression analysis. Based on the multiple regression analysis, the accepted model was as follows described in formulas No. 3 and 4:

$$MR(a,b,k,n) = \frac{M - M_e}{M_0 - M_e} = \mathrm{a - bexp(-(kt^n))} \quad (3)$$

$$MR(a,k,n,b,g) = \frac{M - M_e}{M_0 - M_e} = \mathrm{aexp((-kt^n) + (bt)) + g} \quad (4)$$

CONCLUSIONS

In this study, an experiment of microwave and convective drying sultana grape fruits are presented. Based on the experimental results reported, following conclusions can be made:

1. Drying time decreased considerably with increased microwave power and temperature.
2. Two stage drying process was occurred as an increasing rate period at the very beginning and the falling rate period lasted till end of the drying.
3. Different mathematical models, namely, Midilli-Kucuk, Weibull Distribution, Logistic, Alıbas used to describe the drying kinetics of sultana grape fruits. The Weibull distribution model gave excellent fit for all data points with higher R^2 values and lower SEE and RSS values except for 540W-100°C. Alıbas model equation was also found to be the best descriptive model for combined microwave and convective drying (540W-100ºC).

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Corresponding author: Assis. Prof. Dr. Sevil KARAASLAN
Prof. Dr. Kamil EKİNCİ
Prof. Dr. Davut AKBOLAT
Suleyman Demirel University,
Faculty of Agriculture,
Department of Agricultural Machinery and Technologies Engineering,

32260, Isparta-Turkey
e-mail: sevilkaraaslan@sdu.edu.tr

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