TÜRK
TARIM ve DOĞA BİLİMLERİ
DERGİSİ

TURKISH
JOURNAL of AGRICULTURAL
and NATURAL SCIENCES

www.turkjans.com

Mathematical Modelling of Orange Slices during Microwave, Convection, Combined Microwave and Convection Drying

[a]Sevil KARAASLAN*, [b]Tunahan ERDEM

[a] Suleyman Demirel University, Faculty of Agriculture, Department of Agricultural Machinery, 32260 Isparta, Turkey
[b] Cukurova University, Faculty of Agriculture, Department of Agricultural Machinery, 01330 Adana, Turkey
*Corresponding author: sevilkaraaslan@sdu.edu.tr

Received: 06.01.2014 Received in revised form: 29.01.2014 Accepted: 30.01.2014

Abstract

In this work, the microwave (180, 360, 540, 720 and 900 W), convective (100, 150, 200 ºC), combined microwave (180, 360 and 540 W) and convective drying (100, 150, 200 ºC) behaviours on drying time, moisture ratio of orange slices were investigated. The drying data were applied to nine different mathematical models, namely Page, Henderson and Pabis, Logarithmic, Wang and Singh, Diffusion Approach, Verma, Two Term, Two Term Exponential, Midilli-Kucuk Equation Models. The performances of these models were compared according to the coefficient of determination (R^2), standard error of estimate (SEE) and residual sum of squares (RSS), between the observed and predicted moisture ratios. Results showed that the Midilli-Kucuk equation gave the best prediction to the drying kinetics evidenced by coefficient of determination, R^2 ranging from 0.9964 – 0.9999.

Keywords: Orange, drying, microwave, convection

Mikrodalga, Sıcak Hava ve Mikrodalga-Sıcak Hava Kombinasyonu ile Kurutulan Portakal Dilimlerinin Matematiksel Modellemesi

Özet

Bu çalışmada, mikrodalga (180, 360, 540, 720 ve 900 W), sıcak hava (100, 150, 200 °C), mikrodalga (180, 360 ve 540 W) ve sıcak hava (100, 150, 200 °C) kombinasyon yöntemlerinin, portakal dilimlerinin kuruma süresi ve nem oranı üzerine etkileri incelenmiştir. Page, Henderson ve Pabis, Logaritmik, Wang ve Singh, Difüzyon Yaklaşımı, Verma, İki terimli, İki terimli Üssel, Midilli-Küçük olmak üzere dokuz farklı matematiksel modeller birbirleri ile karşılaştırılmıştır. Bu modellerin performansları gözlemlenen ve tahmini nem oranları arasında belirtme katsayısı değeri (R^2), tahmini standart hatası (SEE) ve kalanların kareleri toplamına (RSS) göre karşılaştırılmıştır. Sonuçlar göstermiştir ki R^2'si 0.9964-0.9999 aralığında olan Midilli- Küçük modeli en iyi tahmini vermiştir.

Anahtar kelimeler: Portakal, kurutma, mikrodalga, sıcak hava

Introduction

Fruit and vegetable have protective effects against cancer and cardiovascular diseases. The advantage ascribed to fruit and vegetable based diets is due to the intake of diverse antioxidant compounds such as vitamin C and the main dietary carotenoids and polyphenols (Mrad et al., 2012). standards, contamination problems, long drying times (Soysal, 2004). Microwave drying compared The oranges are interesting for their wealth of vitamin C. The studies showed that oranges lower the cholesterol level in the blood. Drying is one of the used methods of fruits and vegetables preservation. However, traditional drying has many disadvantages due to inability to handle the large quantities and to achieve consistent quality with traditional drying is an alternative method as its uniform energy and high thermal conductivity to the inner sides of the material, space utilization, sanitation, energy saving, precise process control, fast start-up and shut-down conditions. It also reduces the drying time and prevents food from decomposing (Soysal, 2004; Maskan, 2000).

Materials and Methods

Experimental material and method

Orange slices used in this study were purchased from a local market. The orange samples were stored at 4±0.5 ºC before experiments to slow down the respiration, physiological and chemical changes (Maskan, 2001). Before the drying, material samples were taken out of storage and orange slices were peeled off and sliced 4 mm thickness with a knife. 100g samples were dried in an oven and the initial moisture content of the orange samples was determined as 84.84% (w.b.) using a standard methods by the drying oven at 105 ºC for 24 h. This drying procedure was replicated three times.

A programmable domestic microwave oven (Arcelik MD-824, Turkey) with maximum output of 900 W at 2450 MHz. was used in the experiments. The dimensions of the microwave cavity were 230 mm by 350 mm by 330 mm. 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. Depending on 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 samples on the digital balance periodically (Soysal et al., 2006).

Drying procedure

Different microwave output powers were determined as 180, 360, 540, 720 and 900 W 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. In all the drying experiments, 100 g of orange slices were used. The samples were uniformly spread on the turn-table inside the microwave cavity during treatment for an even absorption of microwave energy afterwards the drying experiment started. Moisture loss was recorded with 1 min intervals during drying for determination of drying curves by an electronic balance (Maskan, 2001). Orange slices were dried until equilibrium moisture content (no weight change) was reached.

Combined convection and microwave were performed as three stage drying process at constant microwave powers of 180 W, 360 and 540 W. At the same time the drying was performed according to a first power and time schedule.

Microwave oven temperatures were 100, 150 and 200 ºC in both cases. Different temperature intensities (100, 150 and 200 ºC) were investigated in fan assisted convection at constant sample loading density of 100 g. Moisture loss was recorded at 1 min intervals during drying by taking out and weighing the dish on a electronic balance. When the samples reached to a constant weight, equilibrium moisture content was assumed to be obtained.

Mathematical modelling of the drying curves

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

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

where, *MR*, M, M_0, M_e, are the moisture ratio, moisture content at any time, initial moisture content, equilibrium moisture content, respectively (Maskan, 2000; Ertekin and Yaldız, 2004).

Statistical analysis

Statistical analysis was conducted using the sigma plot (scientific graph system, version 9.00, jardel). Non-linear regression analysis was performed using Sigma-Plot (SPSS Inc., version 9.00) to estimate the parameters of equations. Regression results include the microwave drying of orange slices under various microwave output power, combination and hot air and microwave drying with thickness of sample, microwave drying with mass load of sample; SEE, Standard error of estimate; R^2, coefficient of determination; RSS, residual sum of square.

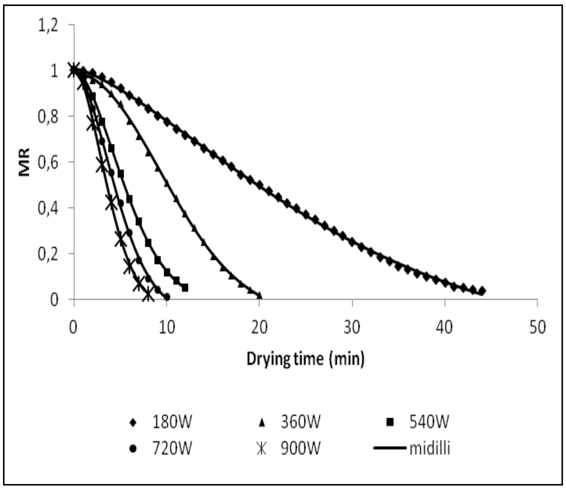

Figure 1. Variation of experimental and predicted moisture ratio by Midilli model with drying time at selected microwave output powers

Results and Discussion

Microwave drying experiments were conducted at the microwave powers values of 180, 360, 540, 720 and 900 W. Figure 1 shows a reduction in drying time occurred with the increase in microwave power level (Alıbas, 2012). The drying stages of oranges slices from initial moisture content of 84.84% on wet basis to a moisture content of 16.95% wet basis were 44, 20, 12, 10, 8 min in microwave powers of 180, 360, 540, 720 and 900 W, respectively. The drying time at the 900 W microwave power was 5.5 times shorter than that of 180 W. The drying time at the 360, 540 and 720 W microwave powers was increased by 2.5, 1.5, 1.25 times when the orange slices were dried compared with the drying process at 900 W of microwave power. A marked reduction in drying time with increase in drying microwave power has been observed by (Soysal, 2004) for parsley, (Wang and Xi, 2005) for carrot slices, (Alibas et al., 2007), (Karaaslan and Tuncer, 2008) for spinach, (Alibas, 2012) for strawberry.

Value of moisture ratio depending on time of orange slices dried with 180 W-100 ºC, 180 W-150 ºC, 180 W-200 ºC ;360 W-100 ºC, 360 W-150 ºC, 360 W-200 ºC; 540 W-100 ºC, 540 W-150 ºC, 540 W-200 ºC microwave- convective drying levels were given in Figure 2. According to Figure 2, a reduction in drying time resulted in the increasing microwave power and temperature. The total drying times to reach the final moisture content for the orange slices were 44, 31, 28; 17, 17, 13; 12, 11 and 11 min at 180 W-150 ºC, 180 W-200 ºC ;360 W-100 ºC, 360 W-150 ºC, 360 W-200 ºC; 540 W-100 ºC, 540 W-150 ºC, 540 W-200 ºC respectively. As expected, a strong effect of microwave power and temperature on moisture ratio was observed, as reported in the literature (Maskan, 2001; Karaaslan and Tuncer, 2008; Bouraouı et al., 1994; Sharma and Prasad, 2001).

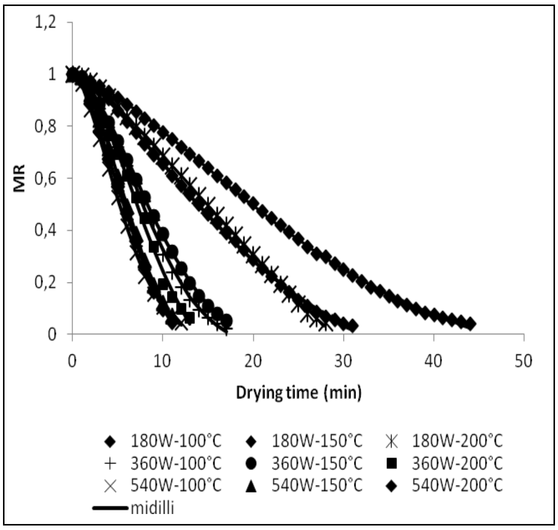

Figure 2. Variation of experimental and predicted moisture ratio by Midilli model with drying time at selected temperatures and 180 W, 360 W and 540 W microwave powers

Table 1. Mathematical models used to predict the moisture ratio values of the orange slices

No	Model name	Model equation	References
1	$MR=exp(-kt^n)$	Page	(Agrawal and Singh, 1977)
2	$MR=a\ exp(-kt)$	Henderson and Pabis	(Akpınar et al., 2006)
3	$MR=a\ exp(-kt)+c$	Logarithmic	(Yaldız et al., 2001)
4	$MR=1+at+bt^2$	Wang and Singh	(Wang and Singh, 1978)
5	$MR=a\ exp(-kt)+(1-a)exp(-kbt)$	Diffusion Approach	(Toğrul and Pehlivan, 2003)
6	$MR=a\ exp(-kt)+(1-a)exp(-gt)$	Verma	(Verma et al., 1985)
7	$MR=a\ exp(-kt)+bexp(-k_1t)$	Two Term	(Alibas, 2012)
8	$MR=a\ exp(-kt)+(1-a)exp(-kat)$	Two Term Exponential	(Sharaf et al., 1980)
9	$MR=a\ exp(-k(t^m)+bt$	Midilli and Kucuk	(Sacılık and Elicin, 2006)

Convective drying experiments were conducted at the temperature values of 100, 150, and 200 °C. The effect of changing the temperature in the microwave oven on the moisture ratio curve of orange samples is shown in Fig 3. The total drying times to reach the final moisture content of the orange slices at the temperatures of 100, 150 and 200 °C were 184, 98 and 68 min, respectively. It is clearly shown that the air temperature had a importantly effect on the drying time. From the range analysis of the experiments, it can be found that the drying time is longest at 100 °C, and shortest at 200 °C. Similar findings were reported by (Alıbas, 2006) for chard leaves, (Vega-Galvez et al., 2008) for apple samples.

Mathematical modelling of drying curves

The nine thin layer drying models were compared in terms of the statistical parameters R^2 (Coefficient of determination), SEE (Standard error of estimate), RSS (residual sum of square) Nine thin layer drying models were used as described by several researchers and were shown in Table 1.

The statistical analyses results applied to 9 drying models at drying process at 180, 360, 540, 720 and 900 W microwave output powers; 100, 150, 200 ºC drying air temperatures; 100, 150 and 200 ºC drying air temperatures at constant microwave powers of 180 W, 360 W and 540 W are given in Tables 2, 3, 4 and 5 for orange slices.

In this work, the thin layer drying model in which (R) value was closest 1.0000 and smallest SEE and RSS values were chosen to be the most optimum model. To take into account the effect of the drying variables on the Midilli–Kucuk model constants a, k, m and b were regressed against those of drying air temperatures using multiple regression analysis (Ertekin and Yaldız, 2004). Based on the multiple regression analysis, the accepted model was as follows:

$$MR(a,k,m,b) = \frac{M - M_e}{M_0 - M_e} = a.\exp(-kt^m) + bt \quad (2)$$

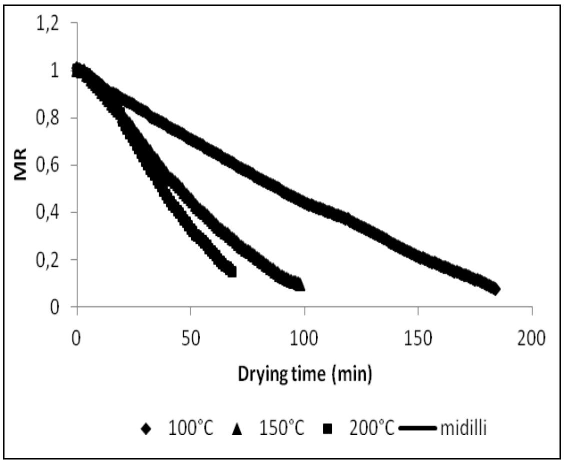

Figure 3. Variation of experimental and predicted moisture ratio by Midilli model with drying time at selected temperatures

Table 2. Non-linear regression analysis results for microwave drying of orange slices under microwave power

Microwave power	Statistics	No 1	2	3	4	5	6	7	8	9
180W	R^2	0.9969	0.9559	0.9971	0.9928	0.9237	0.9237	0.9559	0.9237	0.9996
	SEE(±)	0.0180	0.0675	0.0176	0.0273	0.0899	0.0899	0.0691	0.0899	0.0064
	RSS	0.0140	0.1960	0.0131	0.0320	0.3393	0.3393	0.1960	3393	0.0017
360W	R^2	0.9984	0.9081	0.9886	0.9810	0.8640	0.8640	0.9081	0.8640	0.9996
	SEE(±)	0.0144	0.1086	0.0408	0.0494	0.1358	0.1358	0.1148	0.1358	0.0074
	RSS	0.0040	0.2241	0.0166	0.0465	0.3317	0.3317	0.2241	0.3317	0.0009
540W	R^2	0.9997	0.9452	0.9886	0.9822	0.9162	0.9162	0.9452	0.9162	0.9998
	SEE(±)	0.0064	0.0853	0.0408	0.0486	0.1106	0.1106	0.0943	0.1106	0.0059
	RSS	0.0005	0.0800	0.0166	0.0260	0.1224	0.1224	0.0800	0.1224	0.0003
720W	R^2	0.9983	0.9326	0.9874	0.9821	0.9066	0.9066	0.9326	0.9066	0.9994
	SEE(±)	0.0159	0.1013	0.0465	0.0523	0.1265	0.1265	0.1149	0.1265	0.0110
	RSS	0.0023	0.0924	0.0173	0.0246	0.1279	0.1279	0.0924	0.1279	0.0008
900W	R^2	0.9991	0.9330	0.9856	0.9804	0.9098	0.9098	0.9330	0.9098	0.9995
	SEE(±)	0.0121	0.1040	0.0521	0.0562	0.1303	0.1303	0.1230	0.1303	0.0106
	RSS	0.0010	0.0757	0.0163	0.0221	0.1019	0.1019	0.0757	0.1019	0.0006

SEE: Standard error of estimate; R^2: Coefficient of determination; RSS: residual sum of square

Drying time decreased substantially with increased microwave power and temperature. Different mathematical models, namely Page, Henderson and Pabis, Logarithmic, Wang and Singh, Diffusion Approach, Verma, Two Term, Two Term Exponential, Midilli-Kucuk Equation Models used to describe the drying kinetics of orange slices. The Midilli-Kucuk model gave excellent fit for all data points with higher R^2 values and lower SEE and RSS values.

Conclusions

In this study, an experiment of microwave and convective drying orange slices are presented. The effects of different microwave power and temperature levels on the drying of orange slices were considered based on the drying parameters such as the drying time and moisture ratio.

Table 3. Non-linear regression analysis results for microwave drying of orange slices under microwave power-air temperature

	180 W								
	100 ºC			150 ºC			200 ºC		
No	R^2	SEE (±)	RSS	R^2	SEE (±)	RSS	R^2	SEE (±)	RSS
1	0.9970	0.0174	0.0130	0.9964	0.0195	0.0115	0.9929	0.0268	0.0193
2	0.9535	0.0689	0.2042	0.9533	0.0708	0.1503	0.9357	0.0806	0.1756
3	0.9962	0.0200	0.0167	0.9967	0.0190	0.0105	0.9983	0.0454	0.0203
4	0.9930	0.0267	0.0305	0.9932	0.0269	0.0217	0.9963	0.0192	0.0100
5	0.9243	0.0890	0.3324	0.9239	0.0919	0.2448	0.9006	0.1022	0.2717
6	0.9242	0.0890	0.3325	0.9235	0.0921	0.2462	0.9002	0.1024	0.2727
7	0.9535	0.0706	0.2042	0.9533	0.0733	0.1503	0.9357	0.0838	0.1756
8	0.9243	0.0890	0.3324	0.9239	0.0919	0.2448	0.9006	0.1022	0.2717
9	0.9996	0.0062	0.0016	0.9996	0.0070	0.0014	0.9996	0.0062	0.0010
	360 W								
	100 ºC			150 ºC			200 ºC		
No	R^2	SEE (±)	RSS	R^2	SEE (±)	RSS	R^2	SEE (±)	RSS
1	0.9963	0.0221	0.0078	0.9987	0.0122	0.0024	0.9933	0.0288	0.0099
2	0.9280	0.0974	0.1517	0.9403	0.0841	0.1132	0.9114	0.1047	0.1314
3	0.9870	0.0427	0.0274	0.9929	0.0300	0.0135	0.9888	0.0164	0.0016
4	0.9808	0.0503	0.0404	0.9871	0.0391	0.0245	0.9871	0.0400	0.0192
5	0.8939	0.1221	0.2236	0.9051	0.1095	0.1799	0.8749	0.1299	0.1855
6	0.8904	0.1241	0.2309	0.9022	0.1111	0.1853	0.9864	0.0201	0.0928
7	0.9280	0.1041	0.1517	0.9403	0.0899	0.1132	0.9114	0.1146	0.1314
8	0.8939	0.1221	0.2236	0.9051	0.1095	0.1799	0.8749	0.1299	0.1855
9	0.9976	0.0189	0.0050	0.9997	0.0062	0.0005	0.9964	0.0232	0.0054

SEE: Standard error of estimate; R^2: Coefficient of determination; RSS: residual sum of square

Table 4. Non-linear regression analysis results for microwave drying of orange slices under microwave power-air temperature

	540 W								
	100 ºC			150 ºC			200 ºC		
No	R^2	SEE (±)	RSS	R^2	SEE (±)	RSS	R^2	SEE (±)	RSS
1	0.9995	0.0078	0.0007	0.9992	0.0104	0.0011	0.9973	0.0185	0.0034
2	0.9497	0.0816	0.0732	0.9207	0.1011	0.1023	0.9311	0.0943	0.0889
3	0.9898	0.0385	0.0148	0.9902	0.0375	0.0127	0.9940	0.0294	0.0078
4	0.9854	0.0439	0.0212	0.9846	0.0446	0.0199	0.9902	0.0356	0.0127
5	0.9256	0.1040	0.1082	0.8821	0.1300	0.1520	0.9009	0.1191	0.1277
6	0.9256	0.1040	0.1082	0.9906	0.0120	0.0385	0.8962	0.1219	0.1338
7	0.9497	0.0902	0.0732	0.9207	0.1131	0.1023	0.9311	0.1054	0.0889
8	0.9256	0.1040	0.1082	0.8821	0.1300	0.1520	0.9009	0.1191	0.1277
9	0.9997	0.0064	0.0004	0.9997	0.0064	0.0003	0.9996	0.0076	0.0005

SEE: Standard error of estimate; R^2: Coefficient of determination; RSS: residual sum of square

Table 5. Non-linear regression analysis results for microwave drying of orange slices under air temperature; SEE Standard error of estimate; R^2, coefficient of determination; RSS, residual sum of square

	100 ºC			150 ºC			200 ºC		
No	R^2	SEE (±)	RSS	R^2	SEE (±)	RSS	R^2	SEE (±)	RSS
1	0.9926	0.0232	0.0981	0.9991	0.0087	0.0073	0.9997	00052	0.0018
2	0.9727	0.0445	0.3620	0.9754	0.0451	0.1977	0.9616	0.0551	0.2035
3	0.9997	0.0046	0.0038	0.9981	0.0124	0.0148	0.9943	0.0213	0.0300
4	0.9997	0.0049	0.0043	0.9951	0.0202	0.0394	0.9878	0.0311	0.0647
5	0.9595	0.0544	0.5376	0.9504	0.0644	0.3982	0.9207	0.0798	0.4201
6	0.9595	0.0544	0.5376	0.9504	0.0644	0.3982	0.9207	0.0798	0.4201
7	0.9727	0.0447	0.3620	0.9754	0.0456	0.1977	0.9616	0.0559	0.2035
8	0.9595	0.0544	0.5376	0.9504	0.0644	0.3982	0.9207	0.0798	0.4201
9	0.9997	0.0044	0.0035	0.9999	0.0035	0.0012	0.9997	0.0051	0.0017

SEE: Standard error of estimate; R^2: Coefficient of determination; RSS: residual sum of square

References

Agrawal, Y.C., Singh, R.P., 1977. Thin layer drying studies on short grain rough rice. *ASAE*.. Paper No 3531. St. Joseph MI:ASAE.

Akpınar, E.K., Bicer, Y., Cetinkaya, F., 2006. Modeling of thin layer drying of parsley leaves in a convective dryer and under open sun. *Journal of Food Engineering* 75, ,p.308-315.

Alibas-Ozkan, I., Akbudak, B., Akbudak, N., 2007. Microwave drying characteristics of spinach. *Journal of Food Engineering* 78,(2), 577-583.

Alibas, I., 2012. Microwave drying of strawberry slices and the determination of the some quality parameters. *Journal of Agricultural Machinery Science* 8 (2), 161-170.

Alibas, I., 2006. Characteristics of chard leaves during microwave, convective, and combined microwave-convective drying. *Drying Technology: An International journal* 24, (11), 1425-1435.

Bouraouı, M., Richard, P., Durance, T., 1994. Microwave and convective drying of potato slices. *Journal of Food Process Engineering* 17, (3), 353-363.

Ertekin,C., Yaldız, O., 2004. Drying of Eggplant and Selection of a Suitable Thin Layer Drying Model. *Journal of Food Engineering* 63: 349-359.

Karaaslan, SN., Tunçer, I.K., 2008. Development of a drying model for combined microwave–fan-assisted convection drying of spinach. *Biosystems Engineering* 100,(1): 44-52.

Maskan, M., 2000. Microwave /air and microwave finish drying of banana. *Journal of Food Engineering* 44, 71-78.

Maskan, M., 2001. Drying, shrinkage and rehydration characteristics of kiwifruits during hot air and microwave drying. *Journal of Food Engineering* 48, 177-182.

Mrad, N.D., Boudhrioua, N., Kechaou, N., Courtois,F., Bonazzi, C., 2012. Influence of air drying temperature on kinetics, physicochemical properties, total phenolic content and ascorbic acid of pears. *Food and Bioproducts Processing* 90 (3), 433-441.

Sacılık, K., Elicin, A.K., 2006. The thin layer drying characteristics of organic apple slices. *Journal of Food Engineering* 73, 281-289.

Sharaf-Elden, Y.I., Blaisdell, J.L., Hamdy, M.Y., 1980. A model for ear corn drying. *Transactions of the ASAE* 5, 1261-1265.

Sharma, G.P., Prasad, S., 2001. Drying of garlic (*Allium sativum*) cloves by microwave-hot air combination. *Journal of Food Engineering* 50, 99-105.

Soysal, Y., 2004. Microwave drying Characteristics of Parsley. *Biosystems Engineering* 89, 167-173.

Soysal, Y., Oztekin, S., Eren, O., 2006. Microwave drying of parsley: Modelling, kinetics, and energy aspects. *Biosystems Engineering* 93(4), 403-413.

Toğrul, I.T., Pehlivan, D., 2003. Modeling of drying kinetics of single apricot. *Journal of Food Engineering* 58, 23-32.

Wang, C.Y., Singh, R.P., 1978. A single layer drying equation for rough rice. ASAE Paper No:78-3001, *ASAE*, St. Joseph, MI.

Wang, J., Xi, Y.S., 2005. Drying characteristics and drying quality of carrot using a two- stage microwave process. *Journal of Food Engineering* 68, 505-511.

Vega-Galvez, A., Mıranda, M., Bılbao-Saınz, C., Uribe, E., Lemus-Mondaca, R., 2008. Empirical modelling of drying process for apple (*Cv. Granny Smith*) slices at different air temperatures, *Journal of Food Processing and Preservation* 32(6), 972-986.

Verma, L.R., Bucklin, R.A., Endan, J.B., Wratten, F.T., 1985. Effects of drying air parameters on rice drying models. *Transactions of the ASAE* 28, 296-301.

Yaldiz, O., Ertekin, C., Uzun, H.I., 2001. Mathematical modelling of thin layer solar drying of Sultana grapes. *Energy* 26, 457-465.