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Microwave Drying of Orange Peels and Its Mathematical Models

Tunahan Erdem[1], Sevil Karaaslan[2] Serdar Öztekin[1], Zeynep Şahan[3] , Harun Çiftçi[4]

[1]Cukurova University Dept. of Agricultural Machinery in Adana, 01330 Balcali, Turkey,
[2]Suleyman Demirel University, Fac. of Agriculture, Dept. of Agricultural Machinery, Isparta, Turkey.
[3]Adıyaman University Dept. of Zoology, Turkey
[4]Cukurova University Dept. of Zoology in Adana, 01330 Balcali, Turkey
terdem@cu.edu.tr

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ABSTRACT: Turkey is one of the orange producing countries which are located at north border of orange growing region. Because of the climatic conditions many products are waste material. Annually 12% of citrus production is scrapped among 3.6 million productions in Turkey. In addition to this citrus peels are by-products of the juice extraction industry. Therefore the study aims to search the possible way to valorise orange peel use as feedstock. In the study, orange (Valencia) peel was dried in microwave oven and drying parameters and its mathematical models were investigated. The selected microwave power levels were (180, 360, 540, 720 and 900 W) and behaviour's on drying time, drying rate of orange peels were investigated. The drying data were applied to nine different mathematical models, namely, Newton, Page, Modified Page, Henderson and Pabis, Logarithmic, Wang and Singh, Diffusion Approach, Verma, Two Term Exponential, Midilli-Kucuk 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. It was found that the Midilli-Kucuk model described the drying curve best in all drying methods (R2 =0.9995-1.0000, SEE=0.0033-0.0173, RSS=0.0001-0.0060).

Key words: Orange peel, drying, microwave, modelling.

INTRODUCTION

Citrus fruits are consumed by humans as fresh fruit or processed juice or nowadays dried slices. Juice extraction methods remain a residue such as comprised of peel (flavedo and albedo), pulp (juice sac residue), rag (membranes and cores) and seeds. These components are in use of BPF either individually or in various combinations (Sinclair, 1984; Ensminger et al.,1990). The global orange production reached an about 51.73 million tons in 2013 (USDA 2014). In the World market, 40% of the orange production is used in orange juice processing, which generates an average mass of waste of 0.5 kg/kg of raw orange that may be considered an environmental issue in terms of disposal (Garcia-Perez, Ortuno et al. (2012). Although Citrus sinensis peels are a valuable source of compounds such as essential oils, flavonoids, and antioxidants (Senevirathne, Jeon et al. 2009), Tasirin, Puspasari et al. (2014). In addition to these orange peels contains the 10-12 percent of essential oil which contains the D-limonene and pectin that is used in organic farm, food and medicinal, in cleaning agents and aromatic therapy area. On the other hand Şahan (2012) evaluated use of essential oil of orange peel as an ingredient of feed additive in vitro condition. Orange peel essential oil improved the digestion of DM, OM, NDF (dry material, organic material and neutral detergent fiber) respectively.

Turkey is the 9 th rank in the world in orange producer countries (Table 1). In addition 12% of citrus production is scrapped among 3.6 million productions per year in Turkey. Due to the fact that the possible utilization of the orange peel as an alternative feedstock and use in other sectors by obtain the essential oil could valorize the waste product. The main idea of the this research is to evaluate the use of dried orange peels as BPF before and after extraction of essential oil.

Table 1. Orange production by country (USDA, 2014)

	Area	Production (MT)
1	Brazil	18012560
2	United States of America	8166480
3	China, mainland	6500000
4	India	5000000
5	Mexico	3666790
6	Spain	2933800
7	Egypt	2786397
8	Italy	1770503
9	Turkey	1662000
10	South Africa	1612828
11	Indonesia	1611784

Earlier studies have been reported by some researcher on citrus peel drying. Some of examples are; citrus peel drying kinetics in a fluidized bed with inert material were investigated (Tasirin, Puspasari et al. 2014), different drying temperatures (50, 60, 70, 80, 90 and 100 degrees C) on changes in the flavonoid, phenolic acid and antioxidative activities of citrus fruit (Citrus sinensis (L.) Osbeck) peels (Chen, Yang et al. 2011), Ultrasound application and hot air drying were applied to identify the ultrasound effect on dried orange peels (Garcia-Perez, Ortuno et al. 2012) and microwave drying of orange peels (Miller and Braddock 1982).

Drying is one of the oldest methods in food preservation and it is a difficult food processing operation due to undesirable changes in the quality of the dried product (Maskan 2000). Microwaves are electromagnetic waves within the range of radio frequencies from 300 MHz to 300 GHz. Electromagnetic energy at 915 and 2450 MHz can be absorbed by water- containing materials or by other “lossy” substances, such as carbon and some organics, and it is converted to heat energy (Maskan 2000). Microwave heating results in a rapid and uniform drying process. The uniformity of microwave drying, shorter drying times and reduction of both microorganisms and nutritive value of the food are caused by the thermal effect rather than microwave energy (Tsami, Krokida et al. 1998).

Several researchers evaluated the drying kinetics of various agricultural products and developed different mathematical models for describing the microwave and hot-air drying characteristics such as for banana (Maskan 2000), for kiwifruit (Maskan 2001), for olive pomace (Gogus and Maskan 2001), for garlic (Sharma and Prasad 2001), for mushroom (Torringa, Esveld et al. 2001), for eggplant (Ertekin and Yaldiz 2004), for parsley (Soysal 2004), for potato (Wang, Xiong et al. 2004), for aromatic plants (Akpinar 2006), for parsley (Akpinar, Bicer et al. 2006), for mint leaves (Doymaz 2006), for organic apple (Sacilik and Elicin 2006), for apple pomace (Wang, Sun et al. 2007), for pumpkin (Wang, Wang et al. 2007), for purslane (Karaaslan, Erdem et al. 2013) .

In this part of the study the drying parameters of orange peels on the microwave drying and its mathematical modelling were evaluated. In the future the study will go on evaluation of different drying application and its effect on animal feeding, orange peels essential oil composition and nutritional values.

MATERIAL and METODS

Oranges (Citrus sinensis (L.) Osbeck) were used in this study and were purchased from a local market. The whole samples were stored at 4±0.5 ºC before experiments in order to slow down some, physiological and chemical changes. Prior to drying, samples were taken out of storage and orange peels were hand-peeled and sliced 10x10 mm sizes.

Drying equipment

A programmable domestic microwave oven (Arçelik ARMD 594, Turkey) with maximum output of 900 W at 2450 MHz was used in the experiments (Fig 1). The dimensions of the microwave cavity were 230 mm by 350 mm by 330 mm. The microwave oven was fitted with a glass turntable (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 sample on the digital balance periodically (Soysal et al., 2006).

Table 2. Evaluated different drying mathematical models

	Model name	Model equation	References
1	Page	$MR=\exp(-kt^n)$	Agrawal ve Singh (1977)
2	Henderson and pabis	$MR=a\exp(-kt)$	Akpınar *et al.* (2006)
3	Logarithmic	$MR=a\exp(-kt)+c$	Yaldız *et al.* (2001)
4	Midilli-Kucuk	$MR=a\exp(-k(t^n))+bt$	Sacilik and Elicin (2006)
5	Wang and Singh	$MR=1+at+bt^2$	Wang ve Singh, (1978)
6	Two Term	$MR=a\exp(-kt)+b\exp(-k_1t)$	Soysal *et al.*(2006)
7	Verma	$MR=a\exp(-kt)+(1-a)\exp(-gt)$	Verma *et al.*(1985)
8	Two term exponential	$MR=a\exp(-kt)+(1-a)\exp(-kat)$	Sharaf-Elden *et al.* (1980)
9	Diffusion Approach	$MR=a\exp(-kt)+(1-a)\exp(-kbt)$	Toğrul and Pehlivan (2003)

Drying procedure

Different microwave output powers were determined as 180, 360, 540, 720W 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 peel 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. Moisture losses was recorded at 1 min intervals during drying for determination of drying curves by an electronic balance (Sartorius, presicion: 0.01 g, maximum weighing capacity: 2000 g) (Maskan, 2001). Orange peel slices were dried under the 10 % of wt basis moisture content of itself.

Mathematical modelling of the drying curves

Drying curves were fitted with ten thin-layer drying models, numbered in (Table 1). The moisture ratio and drying rate of orange peel slices were calculated using the following equations:

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

$$\text{Drying rate} = \frac{M_{t+dt} - M_t}{dt} \qquad (2)$$

where *MR*, *M*, M_0, M_e, M_t and M_{t+dt} are the moisture ratio, moisture content at any time, initial moisture content, equilibrium moisture content, moisture content at *t* and moisture content at *t*+d*t* (kg [H_2O] kg^{-1} dry matter), respectively and t is drying time (min).

RESULTS and DISCUSSION

The mostly given parameters such as Moisture Content, Drying Rate and MR are illustrated in Figure 1 to 3.

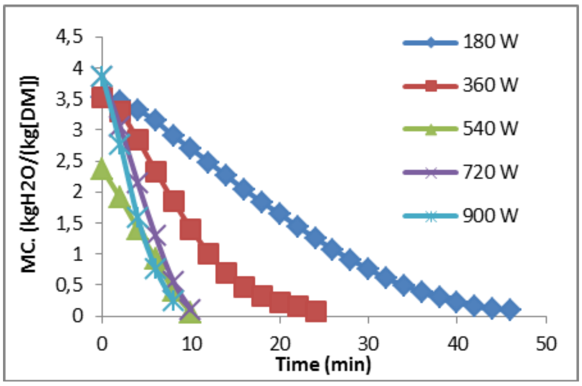

Figure 1. Orange peels of moisture content versus drying time.

Microwave drying of orange peel shows similar findings with the study of garlic cloves and slices dried in a vacuum oven as reported by Figiel (Figiel 2009) who claims that after period of increasing drying rate, decreasing drying rate period were observed.

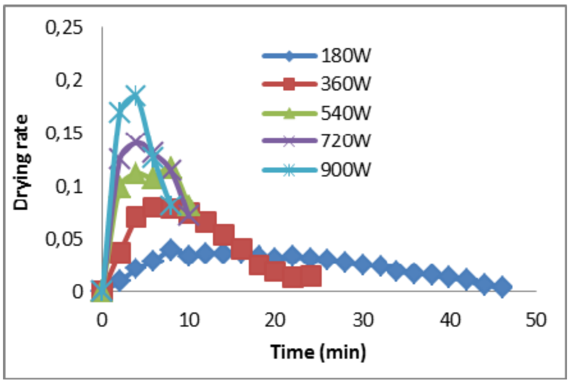

Figure 2. Orange peels of drying rate versus drying time.

Same drying conditions were reported also by Karaaslan as well (Karaaslan, Erdem et al. 2013). In addition to these results the higher output power resulted the lower drying time. The moisture content data at the different drying conditions were converted to the more useful moisture ratio (MR) expression and then curve fitting computations with the drying time were carried on the 9 drying models evaluated by the previous researchers.

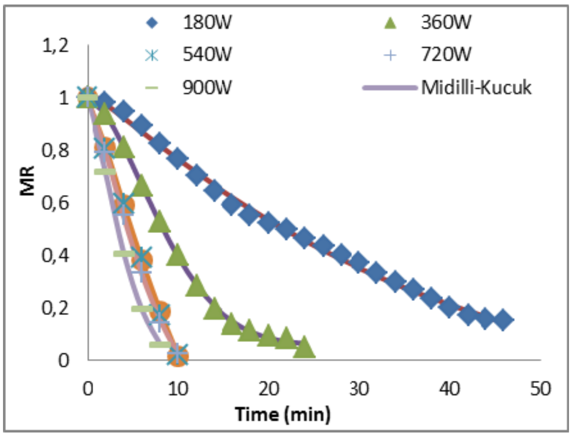

Figure 3. Variation of experimental and predicted moisture ratio of Orange peels in microwave conditions.

Non-linear regression analysis was performed using the Sigma Plot computer program. Coefficient of determination (R^2) is one of the important factors for selecting the best model to define the drying curves of orange peels. In addition to this, various statistical parameters such as Standard error of estimate SEE and residual sum of square RSS were also used to evaluate the fit of the models. The validity of fit was determined by the lower the SEE and RSS values and the higher the R2 values. 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 3 for orange peel samples. The models were evaluated based on R^2, SEE and RSS. The Midilli-Küçük model gives the highest values of R^2 and the lowest values of SEE and RSS.

CONCLUSIONS

The effects of three different drying methods on the drying of orange peels were evaluated based on the drying parameters such as moisture content, moisture ratio analysis.

The drying kinetics of orange peels were evaluated in a laboratory scale microwave dryer; at a microwave power range of 180; 360; 540; 720 and900 W. Microwave power and temperature are the most important factor in drying of orange peels. High microwave power and temperature resulted in a shorter drying time.

In this present study experimental data for orange peels 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. Relations between the model parameters and the drying conditions for the computation of the moisture ratio in relation to drying time were determined and reported.

Table 3. Non-linear regression analysis results for microwave drying of orange peels

	180W			360W			540W			720W			900W		
No	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS
1	0,9956	0,0186	0,0076	0,9975	0,0178	0,0035	0,9899	0,0421	0,0071	0,9951	0,0297	0,0035	0,9994	0,0111	0,0004
2	0,9872	0,0318	0,0223	0,9702	0,0619	0,0422	0,9365	0,1056	0,0446	0,9511	0,0933	0,0349	0,9706	0,0759	0,0173
3	0,9961	0,0180	0,0068	0,9837	0,0481	0,0231	0,9987	0,0175	0,0009	0,9975	0,0246	0,0018	0,9967	0,0313	0,0020
4	**0,9966**	**0,0173**	**0,0060**	**0,9995**	**0,0092**	**0,0008**	**0,9995**	**0,0128**	**0,0003**	**0,9997**	**0,0099**	**0,0002**	**1,0000**	**0,0033**	**0,0005**
5	0,9943	0,0213	0,0100	0,9844	0,0448	0,0220	0,9986	0,0159	0,0010	0,9975	0,0212	0,0018	0,9974	0,0227	0,0015
6	0,9872	0,0334	0,0223	0,9702	0,0685	0,0422	0,9365	0,1494	0,0446	0,9511	0,1320	0,0349	0,9706	0,1315	0,0173
7	0,9748	0,0458	0,0440	0,9550	0,0798	0,0636	0,9200	0,1369	0,0562	0,9806	0,0680	0,0139	0,9664	0,0993	0,0197
8	0,9748	0,0457	0,0439	0,9550	0,0798	0,0636	0,9280	0,1298	0,0505	0,9443	0,1151	0,0397	0,9673	0,0981	0,0192
9	0,9748	0,0457	0,0439	0,9550	0,0798	0,0636	0,9280	0,1298	0,0505	0,9443	0,1151	0,0397	0,9673	0,0981	0,0192

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