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Determination of Suitable Drying Model for Combined Microwave-Fan Assisted Convection Drying of Strawberry

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Abstract

Strawberry slices with 100 (±0.04) g weights and 91.62% (±0.02) initial moisture content on wet basis were dried in microwave oven until moisture content fell down to 15.12% (±0.05) on wet basis. In this study, the effects of microwave drying (180, 360, 540, 720 and 900W); fan assisted convection (100, 150, 200ºC); combined fan assisted convection (100, 150, 200ºC) and microwave (180 and 360 W) on drying time, drying ratio of strawberry slices have been investigated. The drying data were applied to seven different mathematical models, namely, Newton, Page, Henderson and Pabis, Midilli-Kucuk, Wang and Singh, Two Term, Two Term Exponential 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 square (RSS), between the observed and predicted moisture ratios. The Midilli-Kucuk model showed a better fit to experimental drying data as compared to other models.

Key Words: Strawberry, Drying, Microwave, Modelling.

Çileğin Mikrodalga- Fan Destekli Konveksiyon Kombinasyonuyla Kurumasına Uygun Kuruma Modelinin Belirlenmesi

Özet

100 (±0.04) g ağırlığına ve yaş baza göre %91.62 (±0.02) ilk nem içeriğine sahip olan çilek dilimleri, yaş baza göre son nem içeriği %15.12 (±0.05) olana kadar mikrodalga fırında kurutulmuştur. Bu çalışmada, mikrodalga (180, 360, 540, 720 ve 900 W), fan destekli sıcak hava (100, 150, 200°C), mikrodalga (180 ve 360W) ve fan destekli sıcak hava (100, 150, 200°C) kombinasyon yöntemlerinin çilek dilimlerinin kuruma süresi ve nem oranı üzerine etkileri incelenmiştir. Newton, Page, Henderson ve Pabis, Midilli-Küçük, Wang ve Singh, İki terimli, İki terimli Üssel olmak üzere yedi 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, diğer model eşitliklerle karşılaştırıldığında Midilli- Küçük modeli en iyi tahmini vermiştir.

Anahtar Kelimeler: Çilek, Kurutma, Mikrodalga, Modelleme

Introduction

Strawberry is the most important berry fruit in all over the world. According to FAOSTAT data, production quantity of strawberry was about 5,416,810 Mt in 2012 in the word. Turkey produced about 353,173 Mt (Anonymous, 2014). Strawberry is one of the delicate and highly perishable fruits owing to respiration, weight loss and susceptibility to fungal contamination (Doymaz, 2008). Thus, it can be conserved by freezing and drying processes such as freeze, osmotic, microwave and air drying (Alibas, 2012; Doymaz I, 2008). Furthermore, it could use up fresh or in many other forms such as juice, concentrate jam and jelly and dried rehydrated with yoghurt and bakery products (Doymaz I,2008).

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). Drying of fruits is one of the most time and energy consuming processes in the food industry. New and innovative drying techniques that increase the drying rate and enhance product quality have achieved significant attention in the recent past. Microwave drying is one of them, obtaining popularity because of its natural advantages over traditional heating such as reducing the drying time of biological material without quality loss (Arslan and Özcan, 2010).

Several researchers investigated the drying kinetics of various agricultural products and developed different mathematical models for describing the microwave and hot-air drying characteristics such as banana (Maskan 2000), kiwifruit (Maskan 2001), organic apple (Sacılık and Elicin 2006), apple pomace (Wang et al. 2007).

The common objective of the present study was to compare the different developed mathematical models for drying of strawberry, to investigate the moisture ratio of strawberry slices dried by microwave and fan-assisted microwave drying as a function of the microwave power used and oven temperature and to determine the drying constant and estimate the effect of selected parameters.

Materials And Methods

Fresh strawberry samples from local market in Isparta, Turkey, were used in the drying experiments. All of the strawberry samples were stored at 4±0.5 ºC before experiments to slow down the respiration, physiological and chemical changes (Maskan, 2001).

100 g samples were dried in an oven and the initial moisture content of the strawberry samples was determined as 91.62% (±0.02) on 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.

A programmable domestic microwave oven (Arçelik MD-824, Turkey) with maximum output of 900 W at 2450 MHz was used in the experiments. 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).

Different microwave output powers were determined as 180, 360, 540, 720, 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 strawberry samples were used. The samples were uniformly spread on the turn-table inside the microwave cavity during treatment for an even absorption of microwave energy later 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). Strawberry samples were dried until equilibrium moisture content (no weight change) was reached.

Combined fan-assisted convection and microwave were performed as two-stage drying process at constant microwave powers of 180 W and 360 W. At the same time the drying was performed according to a preset power and time schedule Microwave oven temperatures were 100, 150 and 200ºC in both cases.

Different temperature (100, 150 and 200ºC) 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 electronic balance. When the samples reached a constant weight, equilibrium moisture content was assumed to be obtained.

Table 1. Mathematical models tested for the moisture ratio values of the strawberry

No	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	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	Two term exponential	$MR=a\exp(-kt)+(1-a)\exp(-kat)$	Sharaf-Elden *et al*. (1980)

Mathematical modelling of the drying curves

Drying curves were fitted with ten thin-layer drying models, enumerated in (Table 1). The moisture ratio of strawberry 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 and t is drying time (min).

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 microwave drying of strawberry slices under various microwave output power, combination and only fan assisted hot air; SEE, Standard error of estimate; R^2, coefficient of determination; RSS, residual sum of square.

Results

Fig. 1 present 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 and 720 W, respectively. It is quite clear from Fig. 1 that increasing the microwave power caused an important decrease in the drying time. With drying, the time taken to reduce the moisture content of strawberry slices was 41, 16, 9, 7 and 6 min at 180, 360, 540, 720 and 900W, respectively. The reducing in drying time with increase in drying microwave output power has been observed by Wang and Xi (2005) for carrot slices.

Fig. 2 suggest the variations of experimental and predicted moisture ratios by the Midilli-Kucuk drying model with drying time at the drying air temperatures of 100, 150 and 200ºC, respectively. With drying, the time taken to reduce the moisture content of strawberry slices was 66, 59 and 51 at 100, 150 and 200ºC, respectively.

It can be seen that combining microwave oven with fan assisted convection results in a higher moisture rate (Fig. 3). The total drying times to reach the final moisture content for the strawberry were 33, 28, 29, 16, 14 and 14 min at 180W-100ºC, 180W-150ºC, 180W-200ºC and 360W-100ºC, 360W-150ºC, 360W-200ºC respectively. It can also be seen that in combined drying systems, there is very important impact of microwave power at high moisture content levels. Plots of experimental and predicted by Midilli-Kucuk Model moisture ratio values with drying time are shown in Figures 1, 2 and 3.

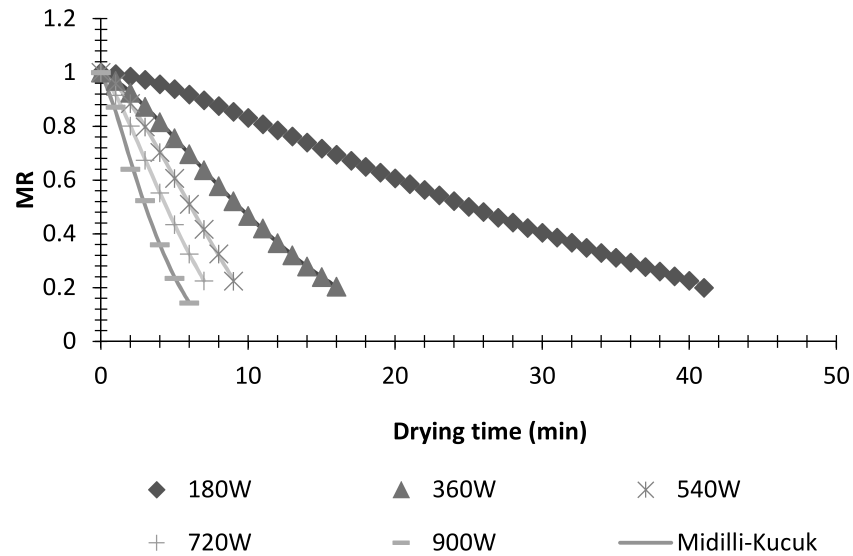

Figure 1. Variation of experimental and predicted moisture ratio by Midilli-Kucuk model with drying time at selected microwave output powers

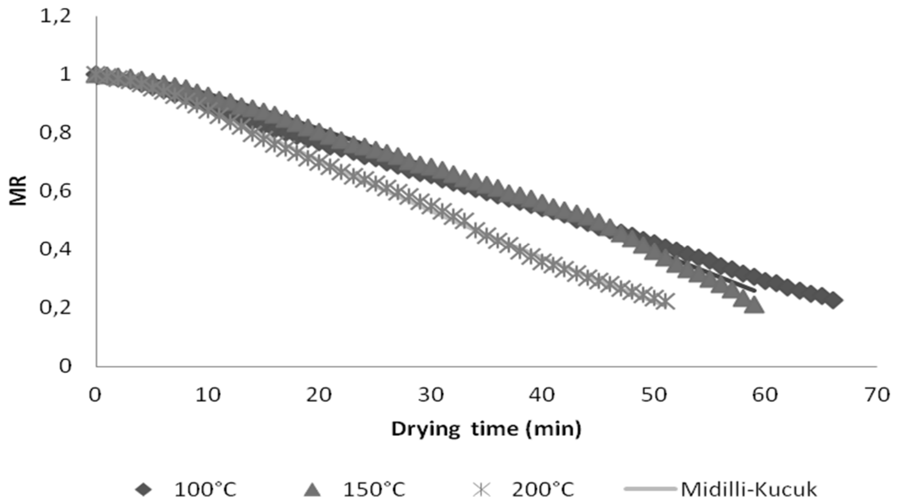

Figure 2. Variation of experimental and predicted moisture ratio by Midilli-Kucuk model with drying time at selected temperatures.

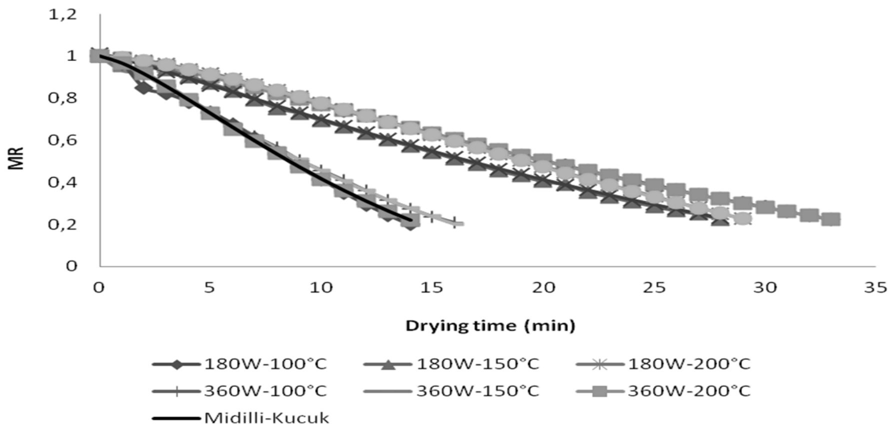

Figure 3. Variation of experimental and predicted moisture ratio by Midilli-Kucuk model with drying time at selected temperatures and 180W and 360 W microwave powers.

Mathematical modelling

The seven 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). Seven thin layer drying models were used as described by several researchers and were shown in Table 1.

The statistical analyses results applied to 7 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 and 360W are given in Tables 2, 3 and 4 for strawberry slices .

In this study, the thin layer drying model in which (R^2) 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. Based on the multiple regression analysis, the accepted model was as follows:

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

(2)

Tablo 2. Non-linear regression analysis results for microwave drying of strawberry under various microwave output power

	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	0.9454	0.0588	0.1416	0.9517	0.0585	0.0548	0.9224	0.0753	0.0511	0.9505	0.0623	0.0272	0.9648	0.0601	0.0217
2	0.9992	0.0071	0.0020	0.9997	0.0049	0.0004	0.9980	0.0128	0.0013	0.9989	0.0101	0.0006	0.9965	0.0208	0.0022
3	0.9728	0.0420	0.0704	0.9718	0.0462	0.0320	0.9470	0.0660	0.0349	0.9641	0.0573	0.0197	0.9726	0.0580	0.0168
4	**0.9998**	**0.0033**	**0.0004**	**1.0000**	**0.0014**	**0.0002**	**0.9998**	**0.0045**	**0.0001**	**1.0000**	**0.0011**	**0.0004**	**0.9971**	**0.0242**	**0.0018**
5	0.9959	0.0163	0.0106	0.9957	0.0180	0.0048	0.9973	0.0148	0.0018	0.9978	0.0143	0.0012	0.9948	0.0254	0.0032
6	0.9728	0.0430	0.0704	0.9718	0.0496	0.0320	0.9470	0.0763	0.0349	0.9641	0.0702	0.0197	0.9726	0.0749	0.0168
7	0.9454	0.0602	0.1416	0.9517	0.0626	0.0548	0.9224	0.0854	0.0511	0.9505	0.0738	0.0272	0.9648	0.0736	0.0217

SEE Standard error of estimate; R^2, coefficient of determination; RSS, residual sum of square

Tablo 3. Non-linear regression analysis results for microwave drying of strawberry under microwave power and fan combination

	180W									360W								
	100ºC			150ºC			200ºC			100ºC			150ºC			200ºC		
No	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS
1	0.9559	0.0518	0.0885	0.9638	0.0466	0.0607	0.9251	0.0684	0.1357	0.9645	0.0495	0.0393	0.8405	0.1000	0.1401	0.9506	0.0586	0.0480
2	0.9559	0.0518	0.0885	0.9923	0.0218	0.0129	0.9992	0.0073	0.0015	0.9995	0.0063	0.0006	0.8682	0.0944	0.1158	0.9995	0.0061	0.0005
3	0.9774	0.0377	0.0454	0.9790	0.0361	0.0352	0.9588	0.0516	0.0747	0.9791	0.0393	0.0231	0.8407	0.1038	0.1400	0.9707	0.0468	0.0285
4	**1.0000**	**0.0014**	**0.0005**	**0.9929**	**0.0218**	**0.0118**	**1.0000**	**0.0017**	**0.0007**	**0.9999**	**0.0025**	**0.0008**	**0.9998**	**0.0007**	**0.0009**	**0.9999**	**0.0036**	**0.0001**
5	0.9969	0.0140	0.0063	0.9910	0.0236	0.0151	0.9959	0.0164	0.0075	0.9974	0.0138	0.0028	0.8853	0.0881	0.1008	0.9959	0.0175	0.0040
	0.9774	0.0389	0.0454	0.9790	0.0375	0.0352	0.9588	0.0536	0.0747	0.9791	0.0422	0.0231	0.8407	0.1128	0.1400	0.9707	0.0509	0.0285
7	0.9559	0.0534	0.0885	0.9638	0.0483	0.0607	0.9251	0.0709	0.1357	0.9645	0.0530	0.0393	0.9475	0.0512	0.0752	0.9506	0.0632	0.0480

SEE Standard error of estimate; R^2, coefficient of determination; RSS, residual sum of square

Tablo 4. Non-linear regression analysis results for microwave drying of strawberry under fan air assisted hot air

	100ºC			150ºC			200ºC		
No	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS	R^2	SEE(±)	RSS
1	0.9556	0.0487	0.1565	0.9002	0.0732	0.3159	0.9411	0.0600	0.1834
2	0.9946	0.0171	0.0191	0.9888	0.0247	0.0355	0.9973	0.0130	0.0085
3	0.9732	0.0381	0.0946	0.9389	0.0578	0.1934	0.9682	0.0445	0.0989
4	**0.9995**	**0.0020**	**0.1110**	**0.9983**	**0.0015**	**0.0591**	**0.9988**	**0.0088**	**0.0037**
5	0.9994	0.0055	0.0019	0.9975	0.0117	0.0079	0.9963	0.0151	0.0114
6	0.9732	0.0387	0.0946	0.9389	0.0588	0.1934	0.9682	0.0454	0.0989
7	0.9556	0.0494	0.1565	0.9002	0.0744	0.3159	0.9411	0.0612	0.1834

SEE Standard error of estimate; R^2, coefficient of determination; RSS, residual sum of square

Conclusions

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

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

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