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Drying Properties and Quality Parameters of Dill Dried with Intermittent and Continuous Microwave-convective Air Treatments

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ABSTRACT

In this study, influence of various microwave-convective air drying applications on drying kinetics, color and sensory quality of dill leaves (*Anethum graveolens* L.) were investigated. In general, increasing the drying air temperature decreased the drying time, and increased the drying rate. Increasing microwave pulse ratio increased the drying time. Page, Logarithmic, Midilli et al, Wang & Singh and Logistic models were fitted to drying data and the Page model was found to satisfactorily describe the microwave-convective air drying curves of dill leaves. Comparing to the fresh dill, lightness (L^*), greenness ($-a^*$) and yellowness ($+b^*$) decreased for all drying applications. The deviation from fresh product color (ΔE^*) increased as pulse ratio increased and drying air temperature decreased. Considering the product quality, continuous microwave-convective air drying combinations gave better results than intermittent microwave-convective air drying in terms of color and sensory evaluation results.

Keywords: Microwave drying; Dill; *Anethum graveolens*; Drying kinetics; Color

Kesikli ve Sürekli Mikrodalga-Taşınım Hava Uygulamaları ile Kurutulan Dereotunun Kuruma Özelliklerinin ve Kalite Parametrelerinin Belirlenmesi

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ÖZET

Bu çalışmada, farklı mikrodalga-taşınım sıcak hava kurutma uygulamalarının dereotu yapraklarının (*Anethum graveolens*) kuruma kinetiği, renk kalitesi ve duyusal kalitesi üzerine etkileri araştırılmıştır. Kurutma işleminde uygulanan hava sıcaklığı arttıkça kuruma süresi kısalmış, kuruma hızı ise artmış ve kesiklilik oranı arttıkça kuruma süresi uzamıştır. Deneysel olarak elde edilen kuruma eğrileri Page, Logarithmic, Midilli et al, Wang & Singh ve Logistic eşitlikleri kullanılarak modellenmiştir. Dereotu yapraklarının mikrodalga-taşınım hava kuruma eğrilerinin matematiksel olarak ifade edilmesinde Page modeli tatmin edici bulunmuştur. Taze ürünle kıyaslandığında, mikrodalga-taşınım hava ile kurutulan ürünlerin tamamında renk parlaklığı (L^*), renk yeşilliği ($-a^*$) ve renk sarılığı ($+b^*$) azalmıştır. Mikrodalga kesiklilik oranı arttıkça ve kullanılan hava sıcaklığı düştükçe taze ürün renginden sapma (ΔE^*) artmıştır. Renk ve duyusal değerlendirme sonuçlarına göre ürün kalitesi dikkate alındığında, sürekli mikrodalga-taşınım hava kurutma uygulamaları kesikli mikrodalga-taşınım hava uygulamalarına göre daha iyi sonuç vermiştir.

Anahtar sözcükler: Mikrodalga kurutma; Dereotu; *Anethum graveolens;* Kuruma kinetiği; Renk

1. Introduction

Dill (*Anethum graveolens* L.) is an annual herb of parsley (*Apiaceae*) family native to Southwest Asia. It is cultivated in Mediterranean, Aegean and Marmara regions of Turkey. Fresh and dried dill used in pickles, salads, soups, sauces and savory meals.

Drying is one of the oldest methods of food preservation preventing microbial growth and delaying onset of some unwanted biochemical reactions. However, drying may cause thermal damage thus affecting the physical and chemical properties of the product adversely. It is very important to protect physical and chemical properties of the product for the consumer acceptance since there is an increased consumer demand for the processed products keeping more of their original characteristics.

Hot air drying is a simple and common drying method used for the drying of vegetables or fruits. Product quality is usually below the desired level due to inefficient heat transfer method. Long drying time results in shrinkage, reduced rehydration capacity, loses in color and aroma (Nijhuis et al 1996). Due to rapid reduction of surface moisture especially during the falling rate periods, hot air drying often results in reduced moisture transfer and, sometimes, reduced heat transfer. Microwave drying offers an alternative way to improve the quality of dried products by reducing the drying time (Beaudry et al 2003; Nindo et al 2003; Torringa et al 2001; Venkatesh & Raghavan 2004). Microwave drying has the advantages of selective heating since water molecules in the product are directly targeted by microwave energy and heat is produced inside the product. Therefore, compared to conventional hot air drying, microwave drying is rapid, more uniform and more energy-efficient and the removal of moisture is accelerated.

Microwave drying techniques were effectively used for a number of aromatic plants such as oregano (Yousif et al 2000), thyme (Soysal et al 2005), rosemary (Arslan & Ozcan 2008), mint (Soysal 2005; Therdthai & Zhou 2009) and parsley (Soysal 2004). Although microwave drying may be regarded as a rapid dehydration process, non-uniformity of electromagnetic field could create hot spots during microwave drying resulting in rapid mass transfer which in return could damage the texture in some cases. In addition, at the final stage of drying, product temperature might be increased rapidly to the level that causes scorching (Zhang et al 2006). Therefore, instead of sole microwave drying, microwave-convective air drying (Funebo & Ohlsson 1998; Prabhanjan et al 1995), vacuum microwave drying (Yongsawatdigul & Gunasekaran 1996) and intermittent microwave drying (Chua & Chou 2005; Gunasekaran 1999) techniques could be used to prevent excess heating in the dried product, to increase energy efficiency and to produce better quality dried product.

The objective of this study was to determine the effect of intermittent and continuous microwave-convective air drying on dried product quality (color and sensory), drying time and drying rate of dill leaves.

2. Materials and Methods

2.1. Plant material

Fresh plant material (*Anethum graveolens*) used in the drying experiments was harvested from a local farm and immediately brought to the laboratory. The samples were stored at 4.0 ± 0.1°C. The initial moisture content of the fresh dill leaves is determined using the oven method (AOAC 2000) and the average initial moisture content of the material ranged from 5.67 to 6.29 kg [H_2O] kg^{-1}[DM].

2.2. Drying experiments

Continuous and intermittent microwave drying was carried out in a custom designed and fabricated microwave-convective air drying system (Soysal et al 2009) (Figure 1). The power of microwave oven has been determined as 597.20 ± 6.89 W by using IMPI 2-liter test (Buffler 1993). Before each drying experiment, the material was allowed to reach room temperature. Dill leaves separated from stems and placed uniformly on the rotating glass tray. In each drying experiment, about 100 g fresh material was dried at an air flow speed of 1.2 ± 0.20 m s^{-1}. The air velocity was measured by an anemometer (Extech Instruments CFM thermo-anemometer 407113, Waltham, MA, USA, accuracy ± 0.01m s^{-1}). The sample weight was measured without stopping the drying process by a digital balance (Sartorius TE3102S, Germany, 3200 ± 0.01 g) placed under the rotating glass tray (diameter: 314 mm, mass: 1150 g) to continuously measure the mass of the material being dried. Drying experiments were stopped when the moisture content decreased below 0.10 kg [H_2O] kg^{-1}[DM] and the mass of the sample was recorded in every minute. For microwave-convective air drying treatments, the pulse ratio was calculated using the Equation 1:

$$\mathrm{PR} = \frac{(t_{on} + t_{off})}{t_{on}} \qquad (1)$$

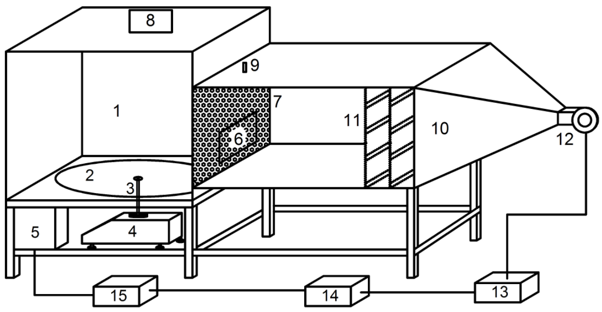

Figure 1-Experimental microwave-convective air drying system. 1: microwave drying chamber; 2: rotating glass tray; 3: tray rotating rod; 4: digital balance; 5: PID control unit and solid-state relay; 6: air entrance; 7: wire mesh; 8: moist air exit opening; 9: temperature sensor; 10: air duct; 11: electric heaters; 12: fan; 13: fan speed adjuster; 14: digital wattmeter; 15: PLC control unit (Soysal et al 2009, with permission from Elsevier)
Şekil 1-Mikrodalga-taşınım sıcak hava kurutma deney düzeneği

where; PR is the pulse ratio, t_{on} is the microwave on time in s, and t_{off} is the microwave off time in s.

The on-off timings used in the microwave drying treatments were as following:

Continuous microwave (PR1) + convective air drying at 30, 40, 50°C,

30 s on-30 s off (PR2) + convective air drying at 30, 40, 50°C,

30 s on-60 s off (PR3) + convective air drying at 30, 40, 50 °C,

30 s on-90 s off (PR4) + convective air drying at 30, 40, 50°C.

2.3. Mathematical modeling of drying curves

The experimental data were fitted to five different moisture ratio (*MR*) models, namely Page, Logarithmic, Midilli et al, Wang & Singh and Logistic, to determine the most suitable drying equation (Table 1). The equilibrium moisture content (M_e) was assumed to be zero for microwave drying and the *MR* equation (Equation 2) was simplified as Equation 3 (Soysal et al 2006):

$$MR = \frac{(M - M_e)}{(M_o - M_e)} \quad (2)$$

$$MR = \frac{M}{M_o} \quad (3)$$

where; *MR* is the moisture ratio (dimensionless), M_e and M_o are the equilibrium and initial moisture contents (kg [H_2O] kg^{-1}[DM]), respectively.

Non-linear regression technique was used to analyze the experimental data using SigmaPlot package (Version 9.0). The residual sum of squares (*RSS*), the standard error of estimate (*SEE*), and the adjusted *R*-square ($\overline{R}^2$) were used as the primary criterions to select the best equation.

2.4. Sensory evaluation

Sensory evaluation of dried dill leaves were performed by a sensory panel of 8 trained judges. Panelists were asked to evaluate visual appearance, color, texture, flavor and overall acceptability using 9 point scale, where 9 corresponded to excellent and 1 corresponded to unacceptable. Scores of 5 and above were considered as acceptable for commercial purposes.

2.5. Color analysis

The color of dried product was measured by using a Minolta (CR-400) Chromameter (Osaka, Japan) using the CIE scale $L^*a^*b^*$. The values of L^*, a^* and b^* present darkness-lightness, greenness-redness and blueness-yellowness, respectively. The equipment was set up for illuminant C and calibrated using a standard white reflector plate. Ground material color measurement apparatus was used to measure the color of dried material. The deviation from the raw material color was represented as ΔE^* and was calculated according to Equation 4:

$$\Delta E^* = \sqrt{(L_o^* - L^*)^2 + (a_o^* - a^*)^2 + (b_o^* - b^*)^2} \quad (4)$$

where; L_o, a_o and b_o refers to the color reading of fresh dill leaves. The data were presented as means of 30 independent measurements for each treatment.

2.6. Statistical analysis

The research was conducted using randomized plots factorial experimental design. The factors were drying temperature (30, 40, 50°C) and pulse ratio (PR1, PR2, PR3, PR4). All the experimental treatments were conducted in three replicates. Data were subjected to analysis of variance (ANOVA) using Statistical Analysis System software program (version 8.02, SAS Institute, Cary, NC, USA). Duncan's test was used to compare means at the 5% significance level ($P \leq 0.05$). Contrast comparisons were also applied for color parameters.

3. Results and Discussion

3.1. Drying kinetics

Figure 2 shows the drying curves (a: 30°C; b: 40 °C; c: 50°C) of dill leaves during microwave-convective air drying on dry basis. The drying time of continuous microwave (PR1)-convective air drying applications to reach the moisture content of 0.10 kg [H_2O] kg^{-1} [DM] were 9-10 min. Intermittent microwave (PR2, PR3, PR4)-convective air drying applications, however, took 17-84 min depending on the PR and drying air temperature.

In general, as the PR decreased, the drying curve exhibited a steeper slope for all microwave-convective air drying treatments, implying that drying rate increased with decrease in PR. This resulted into a substantial decrease in the drying time when the PR decreased. The drying time decreased with the increase in drying air temperature at the same level of PR. Similar drying curves were reported for intermittent and continuous microwave-convective air drying of red pepper (Soysal et al 2009). The drying times of dill leaves to fell 0.10 kg [H_2O] kg^{-1} [DM] moisture content were 47 to 89.3% shorter in continuous microwave-convective air drying compared to intermittent microwave-convective air drying applications depending on drying conditions. It has been reported that the drying process took 39, 12 and 4.4 times longer in the convective air drying treatments conducted at 50, 75, and 100°C temperatures compared with the continuous microwave drying of chard leaves conducted at 650 W microwave output power (Alibas 2006).

The drying rates generally decreased as PR increased. The drying rates (kg [H_2O] kg^{-1} [DM] min^{-1}) obtained under different PR levels are given in Figure 2 (d: 30°C; e: 40°C; f: 50°C). The average drying rates during the drying of dill leaves at the PR1, PR2, PR3 and PR4 were 0.56, 0.28, 0.11 and 0.07 kg [H_2O] kg^{-1} [DM] min^{-1}, respectively.

A constant drying rate period was not observed in the drying of the dill leaves at continuous microwave-convective air drying. An absence of constant drying period indicates that moisture removal, which is driven internally by microwave energy absorption, takes places only in the falling rate period. Similar results were obtained for continuous microwave drying of potato (Wang et al 2004), banana (Maskan 2000), leek (Dadali & Ozbek 2008), garlic (Sharma & Prasad 2001) and parsley (Soysal et al 2006). During the early stages of drying, after a short heating period, the drying rate increased reaching a maximum value corresponding to a moisture content of 0.95, and then a fast falling rate period was observed (Figure 2). For intermittent microwave-convective air drying, after reaching the peak value, a relatively long constant rate period was observed followed by a fast falling rate period. The existence of a constant drying rate period indicates an efficient internal mass transfer through capillary forces (Perre & May 2007). Increasing the PR increases the power off time providing the rest time necessary for uniform moisture and temperature redistribution resulting in increased constant drying rate period.

In microwave-convective air drying applications, 41%, 42% and 47% of the total drying time were observed at constant drying rate at the PR4-30°C, PR4-40°C, PR4-50°C drying applications, respectively. No significant effect of the drying air temperature on drying time was observed ($P = 0.465$). The average drying rates for 30, 40 and 50°C air temperatures were found as 0.21, 0.21 and 0.23 kg [H_2O] kg^{-1} [DM] min^{-1}, respectively.

The moisture content of the material was very high during the initial phase of the drying, which resulted in a higher absorption of microwave energy and higher drying rates due to the higher moisture diffusion. As the drying progressed, the loss of moisture in the product caused a decrease in the absorption of microwave energy and resulted in a fall in the drying rate (Feng et al 2002).

3.2. Modeling microwave-convective air drying

The parameters of five semi-empirical equations (Table 1) for a given microwave-convective air drying condition of dill leaves were estimated using nonlinear regression technique (Table 2) and the fitness is illustrated in Figure 3.

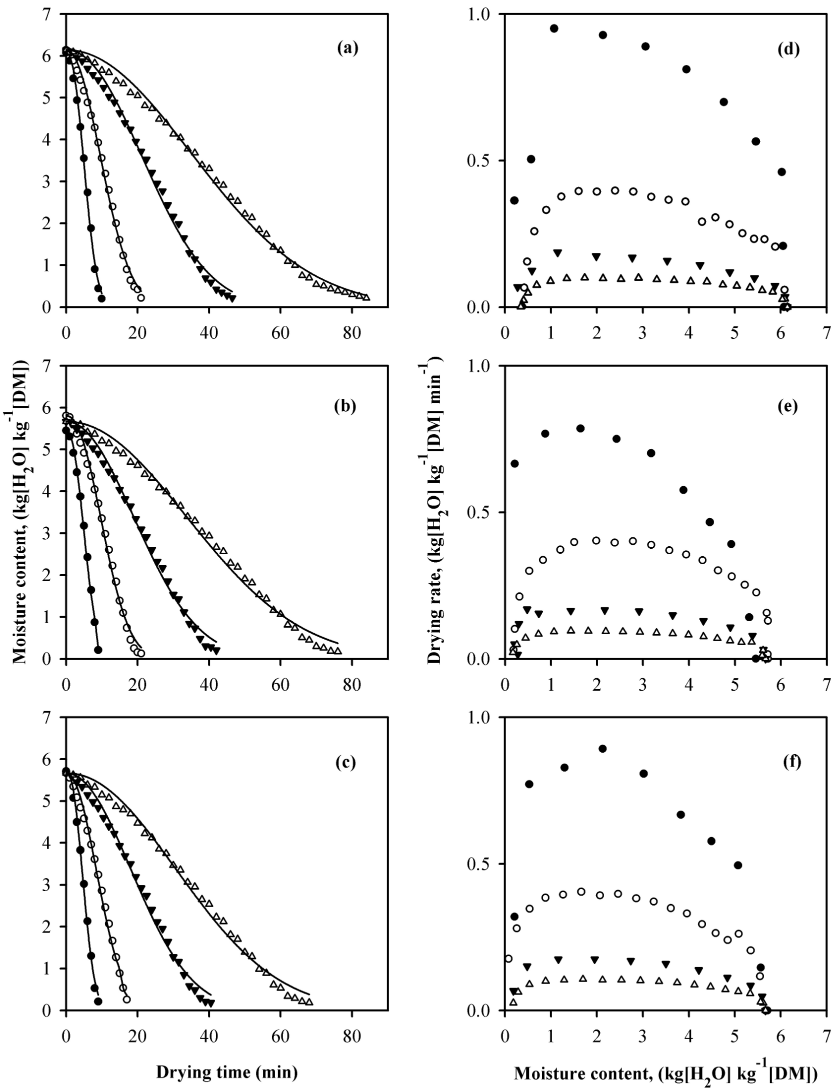

Figure 2-Microwave-convective air drying curves (a: 30°C; b: 40°C; c: 50°C) and drying rate curves of dill leaves (d: 30°C; e: 40°C; f: 50°C). ●: PR1; ○: PR2; ▼: PR3; Δ: PR4 (experimental); — Page model; DM: dry matter; PR: pulse ratio; v_h = 1.2 m s^{-1})

Şekil 2-Mikrodalga-taşınım sıcak hava sisteminde dereotu yaprakları kurutma eğrileri (a: 30°C; b: 40°C; c: 50°C) ve kuruma hızı eğrileri (d: 30°C; e: 40°C; f: 50°C)

Table 1-Mathematical models applied to drying curves

Çizelge 1-Kuruma eğrilerine uygulanan matematiksel modeller

	Model name	Model equation[1]	Sources
1	Page	$MR = \exp(-kt^n)$	Diamante & Munro 1993
2	Logarithmic	$MR = a\exp(-kt) + b$	Yaldiz et al 2001
3	Midilli et al	$MR = a\exp(-kt^n) + bt$	Midilli et al 2002
4	Wang & Singh	$MR = 1 + at + bt^2$	Soysal et al 2006
5	Logistic	$MR = b/(1 + a\exp(kt))$	Soysal et al 2006

[1] *MR*: moisture ratio; *k*: drying coefficient; *n*: exponent; *t*: time in min; *a* and *b*: coefficients

Table 2-Modelling of moisture ratio according to drying time for dill leaves

Çizelge 2-Dereotu yaprakları nem oranının kuruma süresine göre modellenmesi

Model	*T*, °C	PR	*k*	*n*	*a*	*b*	*RSS*	*SEE*	$\overline{R}^2$	*P* values
Page	30	1	0.01271	2.34963			0.0067	0.0273	0.9942	<0.000001
		2	0.00451	2.10955			0.0115	0.0240	0.9949	<0.000001
		3	0.00083	2.11815			0.0206	0.0262	0.9938	<0.000001
		4	0.00035	2.04811			0.0237	0.0241	0.9947	<0.000001
	40	1	0.01430	2.30448			0.0082	0.0320	0.9914	<0.000001
		2	0.00492	2.08465			0.0164	0.0287	0.9932	<0.000001
		3	0.00122	2.05416			0.0199	0.0272	0.9931	<0.000001
		4	0.00037	2.05403			0.0311	0.0290	0.9922	<0.000001
	50	1	0.01563	2.35011			0.0053	0.0257	0.9949	<0.000001
		2	0.00555	2.12950			0.0192	0.0336	0.9900	<0.000001
		3	0.00132	2.06313			0.0216	0.0288	0.9924	<0.000001
		4	0.00042	2.07705			0.0263	0.0282	0.9926	<0.000001
Logarithmic	30	1	0.00209		51.99924	-50.91024	0.0228	0.0533	0.9781	<0.000001
		2	0.00103		50.66920	-49.59670	0.0242	0.0357	0.9888	<0.0001
		3	0.00048		49.35721	-48.28193	0.0337	0.0341	0.9895	<0.000001
		4	0.00027		49.08490	-48.03480	0.0599	0.0387	0.9864	<0.0001
	40	1	0.00395		28.86903	-27.76662	0.0259	0.0608	0.9690	0.000002
		2	0.00129		41.82531	-40.74051	0.0298	0.0396	0.9869	<0.000001
		3	0.00051		51.08809	-50.01672	0.0216	0.0289	0.9923	<0.000001
		4	0.00029		49.74586	-48.67560	0.0285	0.0281	0.9926	<0.000001
	50	1	0.00839		14.50689	-13.41172	0.0222	0.0563	0.9758	<0.000001
		2	0.00214		28.06679	-26.98956	0.0186	0.0341	0.9896	<0.000001
		3	0.00054		50.10843	-49.03978	0.0226	0.0300	0.9918	<0.000001
		4	0.00031		51.88456	-50.81062	0.0284	0.0298	0.9918	<0.000001
Midilli et al	30	1	0.00872	2.42897	0.97495	-0.00816	0.0027	0.0195	0.9971	<0.000001
		2	0.00372	2.09832	0.97863	-0.00419	0.0037	0.0143	0.9982	<0.000001
		3	0.00083	2.03110	0.98280	-0.00262	0.0052	0.0137	0.9983	<0.000001
		4	0.00037	2.00282	0.97482	-0.00060	0.0122	0.0177	0.9972	<0.000001
	40	1	0.01122	2.15732	1.00908	-0.02577	0.0005	0.0088	0.9994	<0.000001
		2	0.00422	2.03380	0.99490	-0.00618	0.0040	0.0149	0.9982	<0.000001
		3	0.00143	1.88554	0.99151	-0.00432	0.0032	0.0113	0.9988	<0.000001
		4	0.00047	1.88862	0.98870	-0.00247	0.0049	0.0119	0.9987	<0.000001
	50	1	0.01547	2.19682	0.99613	-0.01378	0.0013	0.0144	0.9984	<0.000001
		2	0.00508	1.92882	1.00177	-0.01469	0.0011	0.0084	0.9994	<0.000001
		3	0.00218	1.76965	0.98069	-0.00536	0.0046	0.0207	0.9961	<0.000001
		4	0.00052	1.91855	0.98946	-0.00266	0.0046	0.0138	0.9983	<0.000001
Wang & Singh	30	1			-0.06193	-0.00424	0.0182	0.0449	0.9845	<0.000001
		2			-0.03253	-0.00086	0.0338	0.0411	0.9851	<0.000001
		3			-0.01625	-0.00014	0.0399	0.0365	0.9880	<0.000001
		4			-0.00965	-0.00004	0.0995	0.0493	0.9779	<0.000001
	40	1			-0.06295	-0.00493	0.0095	0.0344	0.9901	<0.000001
		2			-0.03494	-0.00077	0.0356	0.0422	0.9852	<0.000001
		3			-0.01776	-0.00017	0.0244	0.0300	0.9916	<0.000001
		4			-0.01008	-0.00005	0.0326	0.0297	0.9918	<0.000001
	50	1			-0.06493	-0.00552	0.0146	0.0427	0.9860	<0.000001
		2			-0.03732	-0.00115	0.0099	0.0242	0.9948	<0.000001
		3			-0.01897	-0.00017	0.0253	0.0312	0.9911	<0.000001
		4			-0.01089	-0.00007	0.0307	0.0305	0.9914	<0.000001
Logistic	30	1	0.61246		0.03451	1.01846	0.0046	0.0239	0.9956	<0.000001
		2	0.27086		0.05373	1.03675	0.0059	0.0176	0.9973	<0.000001
		3	0.12424		0.05057	1.02828	0.0112	0.0197	0.9965	<0.000001
		4	0.06758		0.06859	1.05028	0.0116	0.0170	0.9974	<0.000001
	40	1	0.63158		0.03234	1.01871	0.0060	0.0293	0.9928	<0.000001
		2	0.28913		0.04314	1.02579	0.0092	0.0220	0.9960	<0.000001
		3	0.13015		0.05936	1.04008	0.0123	0.0217	0.9956	<0.000001
		4	0.07353		0.05701	1.03295	0.0191	0.0230	0.9951	<0.000001
	50	1	0.66206		0.03652	1.02647	0.0041	0.0241	0.9955	<0.000001
		2	0.31342		0.04766	1.02044	0.0121	0.0275	0.9932	<0.000001
		3	0.13841		0.05615	1.03242	0.0130	0.0228	0.9953	<0.000001
		4	0.08206		0.05559	1.03387	0.0165	0.0227	0.9952	<0.000001

[1] *T* drying air temperature; PR pulse ratio; *k* drying coefficient; *n* exponent; *t* time in min; *a* and *b* coefficients; *RSS* the residual sum of squares; *SEE* the standard error of estimate; $\overline{R}^2$ the adjusted *R*-square

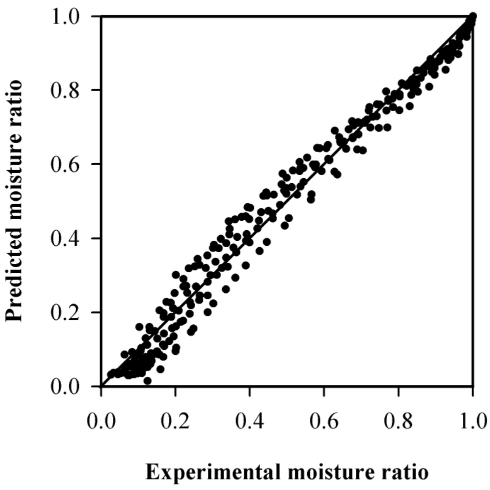

Figure 3-Experimental and predicted moisture ratio (Page model) changes of microwave-convective air dried dill leaves

Şekil 3-Mikrodalga-taşınım sıcak hava sistemi ile kurutulan dereotu yaprakları deneysel ve tahmin edilen (Page modeli) nem oranı değişimleri

For modeling, the experimental moisture content data on a dry weight basis at various times during the drying process obtained under different PRs and drying air temperatures were converted to moisture ratio values and fitted against the drying time. The 5 thin layer drying models were compared in terms of the statistical parameters the residual sum of squares (*RSS*), the standard error of estimate (*SEE*), and the adjusted *R*-square ($\overline{R}^2$) for adequacy of the model fit. The best model describing the thin layer drying characteristics of dill leaves was chosen as the one with the highest $\overline{R}^2$ value and the lowest *RSS* and *SEE* values. Similar $\overline{R}^2$, *RSS* and *SEE* values were obtained from Page, Logarithmic, Midilli et al, Wang & Singh and Logistic models. The Page model was chosen to represent the drying behavior of dill leaves since it contains less number of coefficients than that of other models used in this study. The Page model can be written as:

$$MR = \exp(-kt^n) \qquad (5)$$

where; *MR* moisture rate, *k* drying constant, *t* drying time (min), *n* exponent.

The effects of PR and drying air temperature were examined on the Page model constants and coefficients by multiple regression analysis using the all drying data and included in the combined model. $\overline{R}^2$, *RSS* and *SEE* values for this model were found as 0.9824, 0.5593 and 0.0436, respectively. The model constants and coefficients are as follows:

$$k = -0.0019T^{0.0616} + 2.0456\times10^{-5} P_i \qquad (6)$$

$$n = -0.0016P_i + 1.102T^{0.1147} \qquad (7)$$

where; *T* drying air temperature (°C), P_i applied microwave power (P_i= P/PR), P microwave output power (W), PR pulse ratio.

On comparing the experimental moisture ratio values with the predicted values at any particular drying condition for validation of the established model, the values lay around a straight line for dill leaves (Figure 3) suggesting that the generalized model is valid at drying air temperatures of 30-50 °C, pulse ratios of 1-4, and microwave output power of 597.2 W.

3.3. Color analysis

Lightness (*L**), greenness (-*a**) and yellowness (+*b**) of fresh dill leaves were 40.15 ± 1.400, -10.91 ± 0.719 and 17.86 ± 2.758, respectively (Table 3). After the microwave-convective air drying, the lightness, greenness and yellowness of the dried dill leaves were significantly decreased ($P \leq 0.05$). Drying air temperature, pulse ratio and drying air temperature × pulse ratio interaction affected the *L** values significantly ($P \leq 0.05$) (Table 3). A positive effect of drying air temperature was observed. *L** values were increased as the drying air temperature increased from 30 to 40 or 50 °C. It has been reported that the continuous microwave-convective drying resulted in darker product color compared to intermittent microwave-convective drying or convective drying during the drying of red pepper possibly due to the non-enzymatic browning (Soysal et al 2009). Greenness values were significantly affected from PRs, drying air temperature and drying air temperature × pulse ratio interaction ($P \leq 0.05$). Continuous microwave applications preserved the green color of dill leaves better (larger negative *a**) compared to the intermittent (PR2, PR3, PR4) microwave drying applications (Table 3). Inactivation of the chlorophyllase which breaks down chlorophyll turning the leaf yellow at lower PRs could be the reason for this outcome. The PR, drying air temperature and drying air temperature × pulse ratio interaction affected yellowness values

Table 3-Color parameters of fresh and dried dill samples

Çizelge 3-Taze ve kurutulmuş dereotu örneklerinin renk parametreleri

T, °C [1]	PR	*L**	*a**	*b**	*H*°	Δ*E**
Fresh	-	40.15 ± 1.400	-10.91 ± 0.719	17.86 ± 2.758	121.72 ± 2.013	
30	1	33.87 ± 0.752e[2]	-7.13 ± 0.197f	12.68 ± 0.217c	119.35 ± 0.273a	8.99 ± 0.569bc
	2	34.41 ± 0.450cd	-6.50 ± 0.204c	12.34 ± 0.279e	116.72 ± 0.901d	9.10 ± 0.429b
	3	33.72 ± 0.377e	-6.33 ± 0.157b	12.47 ± 0.401cde	115.67 ± 1.115e	9.59 ± 0.452a
	4	34.63 ± 0.266c	-6.23 ± 0.079ab	12.64 ± 0.142cd	116.25 ± 0.228fg	8.92 ± 0.277bcd
40	1	34.51 ± 0.644cd	-6.89 ± 0.146e	12.57 ± 0.231cd	118.74 ± 0.151b	8.72 ± 0.616cd
	2	35.43 ± 0.177ab	-6.74 ± 0.135d	12.63 ± 0.115cd	118.08 ± 0.540cd	8.18 ± 0.161f
	3	34.25 ± 0.313d	-6.62 ± 0.107cd	12.41 ± 0.409de	118.11 ± 0.591cd	9.10 ± 0.479b
	4	35.17 ± 0.540b	-6.12 ± 0.264a	12.59 ± 0.224cd	115.93 ± 0.760g	8.70 ± 0.521cd
50	1	35.70 ± 0.290a	-7.15 ± 0.154f	13.32 ± 0.147a	118.22 ± 0.425c	7.39 ± 0.291g
	2	33.82 ± 0.639c	-6.92 ± 0.094e	13.04 ± 0.290b	117.96 ± 0.550cd	8.27 ± 0.321ef
	3	35.43 ± 1.112ab	-6.66 ± 0.470d	12.60 ± 0.614cd	117.84 ± 0.536cd	8.26 ± 1.206ef
	4	34.65 ± 0.309c	-6.49 ± 0.325c	13.00 ± 0.422b	116.52 ± 0.446ef	8.57 ± 0.534de
Main effects						
T, °C						
30		34.16 ± 0.617c	-6.53 ± 0.402a	12.53 ± 0.307b	117.52 ± 1.390	9.15 ± 0.517a
40		34.84 ± 0.656b	-6.59 ± 0.336a	12.55 ± 0.275b	117.72 ± 1.202	8.67 ± 0.571b
50		35.14 ± 0.792a	-6.81 ± 0.387b	12.99 ± 0.476a	117.63 ± 0.819	8.12 ± 0.814c
	PR					
	1	34.69 ± 0.962ab	-7.06 ± 0.202d	12.86 ± 0.390a	118.77 ± 0.556a	8.36 ± 0.867c
	2	34.87 ± 0.612a	-6.72 ± 0.228c	12.67 ± 0.375b	117.94 ± 0.732b	8.52 ± 0.525bc
	3	34.47 ± 0.999b	-6.52 ± 0.340b	12.49 ± 0.453c	117.55 ± 0.913b	8.99 ± 0.961a
	4	34.82 ± 0.458a	-6.28 ± 0.287a	12.74 ± 0.338ab	116.23 ± 0.578c	8.73 ± 0.475b
P values						
T		<.0001	<.0001	<.0001	0.1107	<.0001
PR		0.004	<.0001	<.0001	<.0001	<.0001
T × PR		<.0001	<.0001	<.0001	<.0001	<.0001
Contrasts						
30 vs. Fresh		<.0001	<.0001	<.0001	<.0001	<.0001
40 vs. Fresh		0.0004	<.0001	<.0001	<.0001	<.0001
50 vs. Fresh		<.0001	<.0001	<.0001	<.0001	<.0001

[1] *T* drying air temperature; PR pulse ratio; *L** = lightness; -*a** = greenness; *b** = yellowness; *H*° hue angle; Δ*E** the color difference from the fresh material

[2] Means followed by the different letters in the same column indicate significant difference ($P \leq 0.05$)

significantly ($P \leq 0.05$) (Table 3). Increasing the drying air temperature preserved the green (-*a**) and yellow (+*b**) color better (Table 3). The deviation from the color of fresh dill leaves (Δ*E**) was significantly affected from PRs, drying air temperature and drying air temperature × pulse ratio interaction ($P \leq 0.05$). The total color difference increased by increasing the PR or decreasing the drying air temperature, possibly due to increased drying time. Although statistical differences were found for Δ*E**, no significant change was perceived by sensory panelists for the different drying applications (Table 3). The contrast analysis indicated that fresh sample color parameters were significantly different than that of microwave-convective air dried samples ($P \leq 0.05$) (Table 3).

3.4. Sensory evaluation

In general, the drying air temperature, the PR and drying air temperature × pulse ratio interaction had no significant effect on the sensory properties during the microwave-convective air drying of dill leaves except the effect of the drying air temperature on the visual appearance ($P > 0.05$) (Table 4). In general, increasing the PR decreased visual appearance and overall acceptance scores (Table 4).

Microwave-convective air dried dill leaves were acceptable (the sensory score of 5 or above out of 9) in terms of the product attributes such as visual appearance, color, texture, and flavor at all drying applications. Although continuous microwave-

Table 4-Sensory scores of microwave-convective air dried dill samples
Şekil 4-Mikrodalga-taşınım sıcak hava sistemi ile kurutulan dereotu yapraklarının duyusal değerlendirme sonuçları

Drying air temperature	PR	Visual appearance	Color	Texture	Flavor	Overall acceptance
30°C	1	6.82 ± 0.982	6.91 ± 1.640	6.55 ± 1.968	6.55 ± 2.339	6.91 ± 1.375
	2	6.58 ± 1.564	6.67 ± 1.670	7.00 ± 1.859	7.25 ± 1.138	6.75 ± 1.215
	3	6.58 ± 1.730	7.00 ± 1.758	7.00 ± 1.21	6.17 ± 1.850	7.00 ± 1.859
	4	5.33 ± 1.826	6.58 ± 1.021	7.33 ± 1.303	6.17 ± 1.410	6.08 ± 1.564
40°C	1	7.67 ± 1.303	7.31 ± 1.750	7.38 ± 1.502	6.85 ± 2.115	7.38 ± 1.446
	2	7.33 ± 1.231	6.83 ± 1.801	6.92 ± 1.379	6.75 ± 2.137	7.33 ± 1.371
	3	6.75 ± 1.288	6.92 ± 0.996	7.08 ± 1.084	6.08 ± 1.621	6.83 ± 1.193
	4	6.77 ± 1.536	6.25 ± 1.181	7.08 ± 0.996	6.25 ± 2.137	7.00 ± 1.414
50°C	1	6.83 ± 1.337	6.25 ± 1.603	7.33 ± 1.557	6.58 ± 2.193	7.00 ± 1.044
	2	6.58 ± 1.084	6.50 ± 1.168	7.08 ± 1.621	6.75 ± 2.006	7.08 ± 1.240
	3	6.58 ± 1.564	6.33 ± 1.969	7.17 ± 1.586	6.50 ± 1.679	6.92 ± 1.379
	4	6.50 ± 1.624	6.17 ± 1.749	6.92 ± 0.900	6.25 ± 1.485	6.92 ± 1.379
Main effects						
T, °C						
30		6.32 ± 1.630b[1]	6.53 ± 1.816	6.98 ± 1.580	6.53 ± 1.977	6.68 ± 1.520
40		7.12 ± 1.364a	6.84 ± 1.724	7.12 ± 1.235	6.49 ± 1.980	7.14 ± 1.339
50		6.63 ± 1.378ab	6.31 ± 1.600	7.13 ± 1.409	6.77 ± 1.824	6.98 ± 1.229
	PR					
	1	6.81 ± 1.283	6.83 ± 1.682	7.11 ± 1.670	6.67 ± 2.151	7.11 ± 1.282
	2	6.94 ± 1.393	6.67 ± 1.530	7.00 ± 1.586	6.92 ± 1.779	7.06 ± 1.264
	3	6.64 ± 1.496	6.75 ± 1.610	7.08 ± 1.273	6.25 ± 1.680	6.92 ± 1.461
	4	6.39 ± 1.754	6.00 ± 1.956	7.11 ± 1.063	6.56 ± 2.049	6.67 ± 1.474
P values						
T		0.0258	0.3405	0.8407	0.7422	0.2748
PR		0.4031	0.1625	0.9890	0.5452	0.5502
*T**PR		0.2012	0.8637	0.8334	0.8443	0.8638

[1] Means followed by the different letters in the same column indicate significant difference ($P \leq 0.05$)

convective air drying at 40 °C received the highest panelist scores, no significant difference was found among treatments (Table 4).

4. Conclusion

The drying technique is an important factor affecting the production of high quality dried product. The color of fresh dill leaves changed substantially during drying irrespective of the PR and drying air temperature used in this study. Decreasing the PR and increasing the drying air temperature reduced the drying time of dill leaves. In general, the continuous microwave-convective air drying treatments resulted in better quality product than intermittent microwave-convective air drying in terms of color and sensory evaluation. Results showed that the microwave-convective air drying could be used to save in drying time and to produce high quality dried dill leaves with better physical (color) and sensory attributes.

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Nomenclature	
a^*	redness (+) / greenness (-) color coordinate, dimensionless
a, b, n, k	constants in models
b^*	yellowness (+) / blueness (-) color coordinate, dimensionless
DM	dry matter
ΔE^*	total color difference from the fresh material
L^*	lightness color coordinate, dimensionless
M_E	equilibrium moisture content, kg [H_2O] kg^{-1}[DM]
M_o	initial moisture content, kg [H_2O] kg^{-1}[DM]
MR	moisture ratio, dimensionless
PR	pulse ratio
$\overline{R}^2$	adjusted R^2
RSS	residual sum of squares
SEE	standard error of estimate
T	drying air temperature, °C
t_{off}	microwave off time, s
t_{on}	microwave on time, s

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