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Mathematical Modeling of Fresh Green Pepper (*Capsicum L.*) Dried at Different Powers in Microwave Oven#

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ABSTRACT

In this research, fresh green peppers were dried in a kitchen microwave oven at 600W, 700W and 800W. The drying curves of the study were compared with 5 different thin layer drying models in the literature. The changes in the moisture values of the samples against time were expressed graphically. R^2, χ^2 and RMSE values were used to determine the most suitable model for dried green peppers. Color values of fresh and dried peppers were determined. It was found that the L* and b* values of the dried peppers were lower, and the a* value was higher than the fresh green peppers. In addition, the rehydration rate of dried peppers was calculated. It was determined that the rehydration ability of the peppers decreased as the applied microwave power increased. For this reason, it was found that the peppers with the highest rehydration rate were those dried with 600W. Also, it was found that the most suitable model for all microwave powers among the five drying models was the Logarithmic drying model. It was calculated that the R^2 values of the drying models ranged between 0.830-0.999, χ^2 values between 0.0001- 0.4684 and RMSE values between 0.0014-0.6121. It was determined that the highest R^2 (0.997-0.999), the lowest χ^2 (0.0001-0.0002) values, and the lowest RMSE (0.0014-0.0035) values for all microwave powers belong to the Logarithmic drying model.

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Introduction

Drying is one of the oldest known preservation methods. The drying and preservation of fruits and vegetables date back centuries. The drying process essentially reduces the amount of unbounded water in the food, providing long-term preservation. Basically, drying is divided into two as natural (solar energy) and artificial drying, and both drying methods have their own advantages and disadvantages (Coskun-Topuz and Pazır, 2017; Coşkun-Topuz and Pazır, 2020) Nowadays, new technologies are tried for minimum quality loss during drying of fresh products, and modifications are made in existing systems. Thus, it is aimed to deliver products of desired color, shape and taste to consumers. In addition, today, most of the consumers have observed eating habits such as fast eating, and ready-to-eat tendency depending on the intensity of their working life. As a result, it has become important for consumers how to obtain the food they need in their kitchens in the shortest and best quality way.

Green pepper is mostly used as a flavor-enhancing spice and a product added to ready meals after being dried, in pickles, as well as for fresh consumption. Fresh pepper has been dried by different civilizations for centuries. Leading pepper producers and exporting countries can be listed as India, Iran, Turkey, Australia, Hungary, Morocco, Tunisia and Israel (Darvishi et al., 2013). The most commonly used dryer types for drying peppers are conventional dryers. However, it has serious disadvantages as it takes a long time to dry with hot air and causes quality loss. Eliminating these problems, reducing significant quality losses, and the desire for effective and fast heat treatment have increased the use of microwave ovens in pepper drying. Microwave drying is a faster, more homogeneous and more efficient drying technique than infrared and conventional hot air drying (Darvishi et al., 2014). Estimation of drying kinetics of foods under different parameters is beneficial in the design and design of dryers (Aghbashlo et al., 2009). Thin plate drying kinetics study is the most studied area of food products

(Gandalfi et al., 2018). Microwave drying kinetics researches have increased in the last 20 years, and the drying kinetic behavior of foods continues today.

In this study, it was aimed to reveal the drying behavior and kinetics of fresh green peppers, which are frequently and fondly consumed in daily life, in a kitchen type microwave oven. In addition, it was aimed to determine the optimum dried pepper by obtaining the moisture content, color and rehydration capacity data of the peppers left to dry at different microwave powers.

Materials and Methods

In the research, the drying process was applied to the hot fresh green peppers collected from Antalya-Phoenicia region. The peppers were stored in the refrigerator at +4 °C until drying. The hot green peppers were taken in certain weights, washed, weighed and sliced to 3 mm each.

Drying Process

In the study, an adjustable 7-stage Samsung MS23F300EEW/TR 23 L (South Korea) kitchen type microwave oven was used for drying. Microwave power for drying was decided as a result of preliminary trials. Considering that the long drying time at powers below 600W may damage the physical and rehydration ability of the pepper, the drying process was started at 600W. If the drying process was continued after 14 minutes at 800W power, it was determined that the peppers burned at a high rate, so the drying process at 800W was terminated at the 14th minute. It was recorded that the final drying times of the slices dried with 600W, 700W and 800W were 20, 16 and 14 minutes, respectively. During drying, the drying process was stopped for some periods and the weight was taken. Weighing times are shown in Table 1. The drying process was continued until the moisture values of the peppers reached 7%. Drying processes were done in 3 replications.

Mathematical Modeling

The experimental data obtained in the drying of the dried green pepper slices in the research were compared with the drying curve of 5 different models found in the literature. The equations and names of the models used are given in Table 2. The moisture ratio (MR) of the peppers was calculated on the basis of kg water/kg KM and expressed graphically against time. The MR & time graph is shown in Figure 1. MR was calculated according to Equation 1 given below. M_t in the formula represents the moisture content at any time, and M_0 (kg water/kg KM) represents the initial moisture content. Because of the value of M_e is numerically very small, it is neglected while calculating.

$$MR = \frac{Mt - Me}{M0 - Me} \qquad (1)$$

Rehydration capacity (RC)

The rehydration ability of a dry food product is measured by the amount of water it absorbs as a result of soaking the product in water under certain conditions. In this study, the rehydration capacity of dried peppers was calculated according to the Equation 2 below by modifying the Güler and Doğan, 2022 method. An average of 1 gram of dried pepper was weighed on a precision scale. 25 ml of distilled water was added to it. After this step, pepper samples were removed from the water at 10., 20., 30., 60. and 1440. minutes, and weighed.

$$RC = \frac{W2 - W1}{W1} \qquad (2)$$

In the formula, w_2 represents the pepper weight after rehydration, and w_1 represents the initial pepper weight. Results are calculated based on kg water/kg DM.

Color

Today, there are different color measurement systems that can detect color values. In this study, L*(whiteness), a*(red-green), b*(yellow-blue), C*(saturation), h (hue angle) and ΔE (difference between color values) values of peppers were measured. Color values were measured with Minolta CR 400 (Tokyo, Japan). Measurements were taken randomly from 5 different points of the peppers. Values of ΔE of dried pepper samples were calculated according to Equation 3.

$$\Delta E = [(L^* - L_0^*)^2 + (a^* - a_0^*)^2 + (b^* - b_0^*)^2]^{1/2} \qquad (3)$$

L_0^*, a_0^* and b_0^* indicate the color values of dried pepper. L*, a* and b* express the initial color values of green pepper.

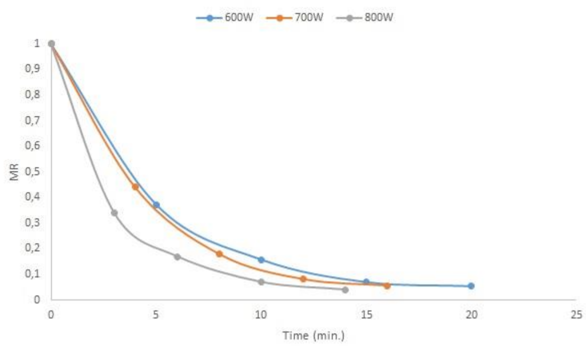

Figure 1. Moisture ratios of pepper slices dried at different microwave powers versus time

Table 1. Weighing times during drying

Power (W)	Time (min.)
600	0, 5, 10, 15 and 20.
700	0, 4, 8, 12 and 16.
800	0, 3, 6, 10 and 14.

Statistical Evaluation

Experimental results in the study were given as mean and standard deviation. For the data, a 3x2 factorial trial design was used. Data analysis was done with SPSS 20.0 (IBM, USA) ANOVA. The difference between the means was determined by applying Duncan's multiple comparison test at 95% confidence interval ($P<0.05$).

R^2 values in the study were determined using the SPSS 20 program (IBM SPSS, USA). χ^2 and RMSE values were calculated according to Equation 4 and Equation 5, respectively.

$$\chi^2 = \frac{\sum_{i=1}^{N}(MR_{exp} - MR_{pre})^2}{N - z} \qquad (4)$$

$$\text{RMSE} = \left[\frac{1}{N}\sum_{i=1}^{N}\left(\text{MR}_{pre} - \text{MR}_{exp}\right)^2\right]^{1/2} \quad (5)$$

MR_{exp} and MR_{pre} are the experimental and estimated humidity ratios, respectively, N is the number of observations, and z is the number of constants used in the model. Low χ^2 and RMSE and high R^2 indicate high compatibility of the model.

Results and Discussion

The drying curves of pepper slices dried at 600, 700 and 800 W microwave powers are shown in Figure 1. The dry matter content of fresh pepper was found to be 6.95%. The drying process was continued until the moisture values of the dry samples fell below 7%. The time taken until the moisture values of the peppers fell below 7% varied between 14 minutes and 20 minutes. It was determined that the drying time was shortened with increasing microwave power.

Within the scope of the research, the drying behavior of green peppers was compared with five different thin layer drying models in the literature. These models are Henderson and Pabis, Page, Aghbashlo et al., Parabolic and Logarithmic. The constants and coefficients of the models calculated according to the results of nonlinear regression analysis based on microwave power are given in Table 3. R^2, χ^2 and RMSE values indicating model compatibility were also given in the same table. It was determined that the R^2 values of the five thin layer drying models varied between 0.830-0.999, χ^2 values between 0.0001- 0.4684 and RMSE values between 0.0014-0.6121. It was found that the highest R^2 (0.997-0.999), lowest χ^2 (0.0001-0.0002) and lowest RMSE (0.0014-0.0035) values for the applied microwave powers belong to the Logarithmic drying model. In order to determine which model fit the experimental data in this study, high R^2 values (closest to 1), low χ^2 and RMSE values (closest to 0) were taken as a basis. Four thin layer drying models were used according to a study in which red pepper was dried in the microwave, and its drying behavior was examined. It has been determined that the model that is closest, and most compatible with the drying behavior of pepper is the Logarithmic model (İncedayı, 2020).

In addition to mathematical modeling and kinetics of dried peppers, rehydration capacity and color values were also measured. The results of the rehydration capacities of dried peppers at different times are given in Table 4. while the results of L*, a*, b*, C*, h and ΔE of fresh and dried peppers are shown in Table 5.

Table 2. Thin layer drying models used in microwave drying process

Model	Model Name	Reference
MR= a exp(-kt)	Henderson and Pabis	Buzrul, 2022
MR= a exp(-kt) + c	Logaritmik	Kipcak and Doymaz, 2020
MR= exp (kt^n)	Page	Karaaslan et al., 2021
MR= a+bt+ct^2	Parabolik	Sabareesh et al., 2021
MR= exp($-k_1t/(1+k_2t)$)	Aghbashlo et al.	Aghbashlo ve et al., 2009

Tablo 3. Constants and coefficients determined for green peppers dried at different microwave powers by the regression method

Model	Power (W)	Constants and coefficients			R^2	χ^2	RMSE
Henderson and Pabis	600	k=0.845	a=2.297		0.987	0.0014	0.0349
	700	k=0.814	a=2.237		0.996	0.0040	0.0490
	800	k=0.850	a=2.300		0.985	0.0045	0.0522
Page	600	k=0.137	n=2.532		0.923	0.0014	0.0349
	700	k=0.044	n=8.406		0.928	0.0013	0.0336
	800	k=0.152	n=2.297		0.914	0.0010	0.0301
Aghbashlo et al.	600	k_1=0.012	k_2=0.036		0.833	0.1488	0.3591
	700	k_1=0.017	k_2=0.047		0.837	0.1423	0.3512
	800	k_1=0.009	k_2=0.027		0.830	0.1629	0.3757
Parabolic	600	a=1.613	b=-0.728	c=0.085	0.986	0.4252	0.5832
	700	a=1.572	b=-0.674	c=0.076	0.990	0.4561	0.6041
	800	a=1.590	b=-0.726	c=0.086	0.961	0.4684	0.6121
Logarithmic	600	a=2.865	k=1.131	c=0.074	0.999	0.0001	0.0014
	700	a=2.265	k=0.859	c=0.041	0.999	0.0001	0.0021
	800	a=3.045	k=1.186	c=0.067	0.997	0.0002	0.0159

Table 4. RC (kg water/kg DM) results of dried green peppers

Güç (W)	10 min.	20 min.	30 min.	60 min.	1440 min.
600	2.43^{aA}	3.94^{aB}	4.78^{aC}	6.52^{aD}	11.51^{aE}
700	2.96^{bA}	3.83^{bB}	4.91^{bC}	6.04^{bD}	10.24^{bE}
800	1.91^{cA}	2.94^{cB}	3.74^{cC}	4.75^{cD}	8.70^{cE}

Lowercase letters represent the difference between microwave powers according to Duncan multiple comparison test, and uppercase letters represent the difference between different immersion times at the same microwave power (P<0.05).

Table 5. Color values of fresh and dried peppers

	L*	a*	b*	C*	h	ΔE
Fresh	52.67±5.00	-15.65±1.45	26.44±5.57	30.76±5.54	121.12±2.80	-
600W	48.54±1.91[a]	-3.10±1.32[a]	12.88±2.58[a]	13.30±4.01[a]	110.60±4.74[a]	18.93±2.03[a]
700W	50.09±2.94[b]	-3.15±1.41[b]	13.96±2.24[b]	14.09±2.29[b]	103.02±5.57[b]	17.85±3.11[b]
800W	51.40±1.95[c]	-3.78±1.16[c]	14.92±1.31[c]	15.42±1.50[c]	97.26±3.35[c]	16.58±2.89[c]

Lowercase letters indicate the difference between microwave powers according to Duncan's multiple comparison test (P<0.05).

Rehydration capacity refers to the ability of a dry product to recover. The high rehydration capacity may reveal that the product is less exposed to structural deterioration and that the drying process is carried out successfully. When the data in Table 4 are examined, it is seen that the rehydration capacity decreases with increasing microwave power. The highest rehydration capacity was detected in peppers dried at 600W. It can also be said that the samples showing the highest rehydration capacity have the highest rehydration rate. It is thought that the reason for this is that high microwave reduces the rehydration ability of peppers, especially by disrupting their porous structure. Similar results were obtained for eggplant slices (Doymaz and Aktaş, 2018).

One of the criteria that consumers pay the most attention to when choosing foods is the color of the food product. The food product, which has a desirable and interesting color, attracts the attention of the consumer, whether it is dry or fresh. According to the data in Table 5., it is seen that the L*, b*, C* and h values of the fresh pepper are higher, and the a* value is lower than the dried samples. On the other hand, in peppers dried at different microwave levels, L*, b* and C* values increased with increasing microwave power, while a* and h values decreased. Although the differences between the drying times were on the basis of minutes, it was concluded that the short-term drying differences were quite effective on the color values. The difference between L*, a*, b*, C* and h values at different microwave powers was also statistically significant (P<0.05). It was determined that the lowest L* and b* values, and the highest a* values among microwave powers were in the samples dried with 600W. It can be said that the long drying time has a negative effect on the brightness-whiteness value of the pepper, and it preserves its green color character better than the other two microwave levels (700W and 800W). It was concluded that long-term (600W) drying caused local browning in peppers, which reduced the L* value. In a study in which orange slices were dried in a temperature-controlled microwave oven, it was noted that fresh orange slices had higher L* and b* values, and lower a* values than dry slices. It was revealed that the ΔE value of slices dried in a microwave oven at different temperatures (55 ºC, 65 ºC and 75 ºC) decreased as the drying temperature increased (Polatcı and Taşova, 2020). In a study in which orange peels were dried with hot air and a microwave dryer, it was stated that the C* and h values of fresh orange peels were higher than the C* and h values of dried samples (Kaynarca and Aşkın, 2020). When the color values in this study are examined, it can be said that the color values of the dried peppers are close to the fresh ones.

Conclusion

Fresh green pepper is a plant variety that has been included in recipes that vary greatly by various cultures in the world for centuries. The fact that it can be grown in different geographical regions, its usage area is high and it has an appetite-increasing character advances the demand for these plants. In this study, fresh green peppers were dried using 3 different levels in a kitchen scale microwave oven. When the drying kinetics and behavior were examined, it was determined that the drying character of hot green peppers was best adapted to the Logarithmic thin layer model. It was concluded that increased microwave power significantly reduced the rehydration capacity, so peppers should not be dried at high microwave power. It was determined that the green value, which is the characteristic color of the pepper, decreased compared to the fresh pepper. In addition, it can be said that the microwave oven provides drying in a shorter time compared to the ovens that provide drying with the hot air principle used in the kitchen. Therefore, the microwave oven can be considered as an alternative to the kitchen oven. The main purpose of the study is to enable consumers to use dried peppers to the degree they want in a short time, in homemade soup, homemade chips or as a spice. With this research, it is thought that the consumers will be able to obtain the desired degree of dried pepper by using the time and power specified in the study.

Conflict of Interest

The author declares no conflict of interest.

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