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Examination of rehydration ratio, color properties and drying kinetics of microwave dried garlic (Allium sativum L.)

Mikrodalga'da kurutulan sarımsağın (Allium sativum L.) rehidrasyon oranı, renk değerleri ve kurutma kinetiğinin incelenmesi

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Abstract

In this study, color values and rehydration ratios of dried garlic slices at four different microwave power (300W, 450W, 600W, and 700W) were determined. Thin-layer drying models were used for drying kinetics. It was determined that L* and b* values were lower and a* values were higher in microwave-dried garlic compared to fresh garlic slices. It was observed that the C* (Chroma) and h (hue angle) values of garlic decreased as the microwave power increased compared to fresh garlic. It was determined that the rehydration ratio decreased significantly with increasing microwave power. Therefore, the highest rehydration ratio was detected in the garlic samples applied at 300W. Moisture ratio (MR) versus time calculated as a result of microwave drying was compared with 5 (Lewis, Page, Henderson, and Pabis, Midilli et al. and Logarithmic) drying models in the literature. R^2 (coefficient of expression), χ^2 (chi-square), and RMSE (root mean square error) were calculated by SPSS and nonlinear regression analysis of dried garlic samples. It was determined that the highest R^2 (0.994-0.998), the lowest RMSE (0.016-0.022) and χ^2 (0.00033-0.00064) values belonged to the Lewis model.

Keywords: Drying, Garlic, Microwave, Modelling, Nonlinear analyses

Öz

Bu araştırmada, dört farklı mikrodalga gücünde (300W, 450W, 600W ve 700W) kurutulan sarımsak dilimlerinin renk değerleri ve rehidrasyon oranları tespit edilmiştir. Kurutma kinetiği için ince tabak kurutma modelleri kullanılmıştır. Taze sarımsak dilimlerine göre mikrodalgada kurutulan sarımsakların L* ve b* değerlerinin daha düşük, a* değerlerinin ise daha yüksek olduğu belirlenmiştir. Taze sarımsağa göre, mikrodalga gücü arttıkça sarımsakların C* (kroma) ve h (hue açısı) değerlerinin düştüğü görülmüştür. Artan mikrodalga gücü ile rehidrasyon oranının belirgin bir şekilde azaldığı saptanmıştır. Bu nedenle, en yüksek rehidrasyon oranı 300W uygulanan sarımsak örneklerinde tespit edilmiştir. Yapılan mikrodalga kurutma sonucunda hesaplanan zamana karşı nem oranı (MR) verileri literatürde bulunan 5 (Lewis, Page, Henderson ve Pabis, Midilli ve ark. ve Logaritmic) kurutma modeli ile karşılaştırılmıştır. Kuru sarımsak örneklerinin SPSS ve nonlinear regrasyon analizleri ile R2 (belirtme katsayısı), χ^2 (ki kare) ve RMSE (hataların karelerinin karekök ortalamaları) hesaplanmıştır. En yüksek R^2 (0.994-0.998), en düşük RMSE (0.016-0.022) ve χ^2 (0.00033-0.00064) değerlerinin Lewis modeline ait olduğu belirlenmiştir.

Anahtar kelimeler: Kurutma, Sarımsak, Mikrodalga, Modelleme, Nonlineer analiz

1 Introduction

Garlic plant has some using areas like spice or flavoring agent for food products. Garlic spice is known as the earliest food-flavoring vegetable, and this vegetable has been used in folk medicine for human diseases, and its medicinal benefits such as antioxidants and antimicrobial have lately been demonstrated by scientific studies [1, 2]. Fresh garlic is prone to germination and rot during storage, resulting in limited shelf life and significant economic losses for vendors. So, fresh garlic is mostly dried to remove 90% moisture to increase shelf life, create new products, and decrease transportation and storage costs. In addition, garlic powder, one of the most popular commercial garlic products, is obtained by drying and grinding garlic slices, and the demand for garlic powder is increasing day by day. Today, garlic drying methods are divided into two, non-thermal and thermal drying methods. One of the best non-thermal drying methods is vacuum freeze-drying. For thermal drying systems, hot air, infrared, microwave, spray drying, belt dryers, etc. techniques are used. Compared to other thermal methods, the hot air drying technique is mostly used in industrial production. [3, 4]. Also, it can be said that the usage of microwave drying technology in the food industry has increased in the last two decades.

The microwave was first used in the communication field. Owing to the increased studies and with the development of microwave technology, the microwave has been mostly used in different industries like medicine, the food industry and wood industry, etc. [5]. Microwave drying with volumetric heating is a successful method for drying fresh foodstuffs. [6, 7]. The biggest reasons for this can be

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shown as the microwave technique's shorter, faster drying, and improved quality, resulting in products with the high nutritional and sensorial quality compared to other traditional thermal drying techniques [8]. While drying, the microwave provides a heat flow in the same direction as the moisture flow, increases the drying speed, and decreases the processing time with high energy yield and less structural diversity.

This research focused on the changes in color and rehydration ability of garlic slices during drying and the determination of suitable thin-layer drying models for garlic samples. In addition, it can be said that garlic, which is used as a strong aroma and antimicrobial additive in the food industry, can be produced in a simple way at home. Unlike other garlic drying studies, it was aimed to obtain garlic slices that could be easily applied in daily recipes.

2 Materials and methods

2.1 Materials

Fresh garlics were purchased from a greengrocer in Kahramanmaraş region. The garlics have been preserved in the refrigerator at 4 °C until drying trials were conducted. Garlic samples were sliced 3 mm thick with a knife for drying in the microwave oven.

2.2 Drying process

At the end of the preliminary trials, it was decided to dry the sliced garlic at 300W, 450W, 600W, and 700W microwave powers. There have been encountered longer drying times at microwave power below 300 W and burning problems at levels above 700 W. To preserve the physical state of the samples, drying was done at the specified microwave powers. After 3-5 grams of samples were taken at certain minutes, while drying process was continued. The duration of the garlic samples was given in Table 1. Thus, weight loss during drying was detected. The final drying times of garlic slices at 300W, 450W, 600W, and 700W microwave powers were recorded as 30, 25, 20, and 15 minutes, respectively.

Table 1. Sampling times for different microwave powers from garlic slices

Sample name	Sample time (min)
300W	10., 15., 20. and 30.
450W	10., 15., 20. and 25.
600W	5., 10., 15., and 20.
700W	4., 8., 12. and 15.

2.3 Mathematical modelling

The experimental data obtained from the drying of garlic slices were fitted with 5 different drying models (Table 2) usually used for the modelling of drying curves. The moisture ratio (MR) of the samples was calculated according to Equation (1):

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

M_t, M_0, and M_e are moisture content at any time while the drying process, initial moisture content, and equilibrium moisture content (kg water/kg d.m.), respectively, and lastly "t" is drying time (min). The numerical values of M_e are relatively small compared to M_t or M_0, hereby the Me is equal to zero is insignificant [14]. Moisture ratios of samples are given in Fig 1.

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

Model	Model's name	Reference
MR=exp(-kt)	Lewis	[9]
MR=exp(-ktn)	Page	[10]
MR=a exp(-kt)	Henderson and Pabis	[11]
MR=a exp(-ktn)+bt	Midilli et al.	[12]
MR=a exp(-kt)+c	Logarithmic	[13]

MR: moisture ratio, k, t, n, a, b, c, l, o: represent constants and coefficients.

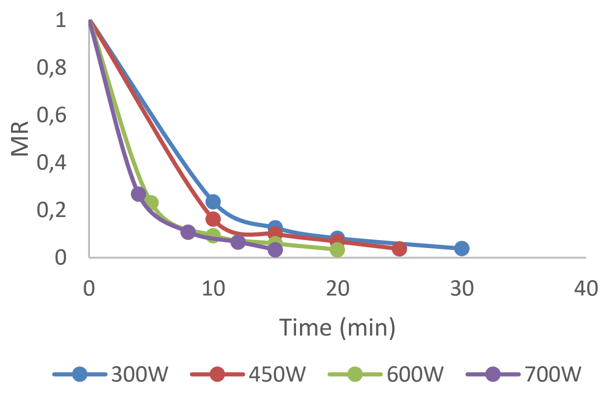

Fig 1. MR (kg water/kg d.m.) of garlic slices at 300W, 450W, 600 W, and 700W (Moisture ratio vs. drying time).

2.4 Rehydration ratio (RR)

Rehydration experiments were made according to the method described by Kırmızıkaya and Çınar [15] with some modifications. 2 grams of dried garlic slices were immersed in 50 mL distilled water. After immersion, the dried garlic pieces were weighed. At the end of 10., 20., 30., 60. and 1440. minutes at room temperature, they were filtered and their weights were recorded. The rehydration ratio was calculated according to Equation (2) below:

Rehydration Ratio= (Rehydrated sample weight) / (Dried sample weight)

2.5 Color measurements

L* (brightness, darkness), a* (redness, greenness), b* (yellowness, blueness), C* (chroma), h (hue angle), and ΔE values of the samples were measured and recorded with the Minolta CR 400 (Tokyo, Japan).

2.6 Statistical evaluation

All experimental values were expressed as mean ± SD. In this study, a 3x2 factorial trial design was used. Analysis of the data was carried out using ANOVA (SPSS 20 program, IBM, USA). Differences between means were tested using Duncan's multiple range tests at $p< 0.05$. Results of R^2 were determined using SPSS 20.0 program. RMSE and χ^2 values of models have been calculated with the following equations Equation (3) and Equation (4).

$$\chi^2 = \frac{\sum_{i=1}^{N}\left(MR_{exp} - MR_{pre}\right)^2}{N - z} \tag{3}$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(MR_{pre} - MR_{exp}\right)^2\right]^{1/2} \tag{4}$$

MR_{exp} and MR_{pre} are experimental and predicted moisture rates, respectively, N is the number of observations, and z is the number of constants. The lower the values of the χ^2 and RMSE indicate the high compatibility of the model [14].

3 Results and discussion

Drying curves of garlic slices at 100 W, 200W, and 300W were given in Fig 1. The moisture value of fresh garlic was found to be 63.05%. The moisture content reduced rapidly at the beginning and then decreased slowly with an increase in drying time. In the last stage of drying, the change in the moisture content was insignificant, and the drying process was terminated when the moisture content fell below 6% (w.b). The time needed to reach under moisture content of 6% (w.b.) changed from 30 to 15 min, when the microwave power was increased from 300 to 700 W. The final drying time of samples was also reduced with the increase of microwave power, as expected.

L*, a*, b*, C*, h, and ΔE results of fresh and dried garlic slices were given in Table 3. L*, b*, C*, and h values of dried garlic were lower and a* value was higher than fresh garlic. For all microwave powers, it was observed that L*, b*, C*, and h color results decreased while a* results increased during the drying time. Browned areas were formed on the garlic surface with increasing microwave power. This problem was encountered especially with slices dried with 600W and 700W. While a tolerable level of browning was observed in slices dried with 450W, browning problems were not observed in samples that were applied 300W. As the microwave power increases, the decrease in L*, b*, C*, and h values and the increase in a* value are thought to be due to enzymatic browning reactions (Maillard reactions). For all microwave powers, the difference between drying times was statistically significant ($p<0.05$). Among the microwave powers, only the difference in C* value was found to be statistically significant ($p<0.05$). For the C* value, the differences between 300W-450W and between 600W-700W were found to be insignificant ($p>0.05$). The color change between fresh and dry samples was evaluated based on the ΔE value. Significantly, it was determined that the highest color change was at 700W for dry samples and 300W for the lowest. It was thought that the reason why the color change in the products at 700 W was higher than the other microwave levels was the rapid drying at high microwave power. In addition, it was concluded that the color change occurred due to the degradation of pigments with increasing microwave power and enzymatic or non-enzymatic (Maillard) browning reactions. In a study, the color values of pears dried in different dryers were examined. It was stated that the total amount of color change (ΔE) increased with increasing microwave power [16].

According to another study, rosehip was dried in a microwave oven at 5 different levels (100W, 300W, 500W, 700W, and 1000W), and the color values of fresh rosehip and dry samples were compared. It has been stated that the L*, b* and C* values of dried rosehips were lower than that of fresh rosehips [17]. According to another study in which carrot leathers were dried in a microwave oven (90W and 180W), it was noted that after drying, the L* and b* values decreased, while the a* value increased [18].

Table 3. Color measurements of fresh and dried garlic slices

Sample name	Drying time (min)	L*	a*	b*	C*	h	ΔE
Fresh garlic	-	81.03 ± 2.43	-1.79 ± 0.29	26.84 ± 0.94	26.98 ± 0.26	92.98 ± 0.68	-
300W	10.	76.34 ± 3.45^{dA}	-0.70 ± 0.11^{aA}	25.52 ± 0.80^{bA}	25.70 ± 0.37^{bB}	85.59 ± 1.29^{cA}	4.99 ± 0.61^{aA}
	15.	71.80 ± 2.43^{cA}	2.05 ± 0.59^{bA}	23.72 ± 3.51^{abA}	23.19 ± 1.43^{bB}	81.04 ± 1.31^{bA}	10.47 ± 1.89^{bA}
	20.	64.70 ± 1.87^{bA}	5.04 ± 0.94^{cA}	22.63 ± 2.92^{bA}	22.32 ± 0.43^{bA}	77.65 ± 2.67^{bA}	18.19 ± 2.07^{cA}
	30.	56.89 ± 2.79^{aA}	5.67 ± 0.31^{cA}	19.90 ± 1.02^{aA}	17.87 ± 3.22^{aA}	73.55 ± 0.17^{aA}	26.20 ± 4.02^{dA}
450W	10.	74.95 ± 4.21^{cA}	0.78 ± 0.15^{aA}	23.74 ± 2.49^{bA}	23.18 ± 3.63^{bB}	86.89 ± 4.46^{bA}	7.29 ± 0.78^{aA}
	15.	69.21 ± 5.51^{bcA}	3.89 ± 0.86^{aA}	21.43 ± 2.99^{bA}	22.90 ± 1.32^{bB}	78.86 ± 2.94^{aA}	14.19 ± 2.11^{bA}
	20.	62.81 ± 3.91^{abA}	5.84 ± 0.68^{aA}	21.13 ± 2.96^{abA}	19.81 ± 1.54^{abA}	76.09 ± 2.13^{aA}	20.56 ± 3.87^{cA}
	25.	53.32 ± 1.57^{aA}	5.86 ± 0.59^{aA}	19.40 ± 2.10^{aA}	18.20 ± 2.60^{aA}	71.63 ± 0.74^{aA}	29.69 ± 4.75^{dA}
600W	5.	74.44 ± 1.49^{bA}	1.58 ± 0.12^{aA}	23.37 ± 3.97^{bA}	24.04 ± 2.30^{aB}	88.12 ± 2.10^{cA}	8.17 ± 1.24^{aA}
	10.	65.82 ± 4.34^{bA}	3.43 ± 0.12^{aA}	20.69 ± 1.63^{bA}	19.50 ± 1.27^{aB}	76.06 ± 3.54^{bA}	17.22 ± 3.10^{bA}
	15.	57.97 ± 2.73^{aA}	5.51 ± 1.98^{aA}	19.41 ± 2.03^{abA}	17.60 ± 2.69^{aA}	72.15 ± 2.72^{aA}	25.30 ± 3.93^{cA}
	20.	49.16 ± 3.72^{aA}	6.74 ± 1.08^{aA}	17.17 ± 2.15^{aA}	14.32 ± 3.16^{aA}	70.96 ± 3.23^{abA}	34.38 ± 4.44^{dA}
700W	4.	73.82 ± 1.82^{dA}	-0.86 ± 0.20^{aA}	22.89 ± 0.20^{bA}	16.81 ± 1.18^{bB}	89.70 ± 2.15^{cA}	8.27 ± 1.76^{aA}
	8.	66.84 ± 3.23^{cA}	2.50 ± 0.51^{bA}	19.85 ± 4.04^{bA}	15.38 ± 1.67^{cB}	79.21 ± 1.85^{bA}	16.39 ± 3.90^{bA}
	12.	54.17 ± 2.66^{bA}	5.65 ± 1.40^{cA}	17.58 ± 2.60^{bA}	13.97 ± 1.26^{aA}	71.31 ± 4.63^{aA}	29.37 ± 3.23^{cA}
	15.	46.13 ± 2.46^{aA}	8.36 ± 1.05^{abA}	16.56 ± 2.55^{aA}	13.43 ± 0.72^{bA}	68.55 ± 2.73^{aA}	37.77 ± 4.56^{dA}

Lowercase letters indicate the difference in drying times for different microwave powers, and uppercase letters show the difference between microwave powers ($p<0.05$).

Table 4. Conformance of experimental data for garlic slices with thin layer drying models

Model	Watt (W)	Constant and Coefficients				χ^2	RMSE	R^2
	300	k=0.138				**0.00037**	**0.017**	**0.998**
Lewis	450	k=0.166				**0.00033**	**0.016**	**0.996**
	600	k=0.273				**0.00064**	**0.022**	**0.994**
	700	k=0.307				**0.00040**	**0.018**	**0.994**
	300	k=0.389	n=16.642			0.00145	0.038	0.883
Page	450	k=0.544	n=12.415			0.00135	0.036	0.937
	600	k=0.556	n=13.316			0.00113	0.033	0.900
	700	k=0.512	n=16.580			0.00113	0.033	0.865
	300	k=1.000	a=0.266			0.00109	0.038	0.998
Henderon and Pabis	450	k=1.000	a=0.199			0.00101	0.036	0.996
	600	k=1.000	a=0.247			0.00085	0.033	0.994
	700	k=1.000	a=0.281			0.00084	0.033	0.994
	300	k=4.667	a=0.884	c=0.120		0.11665	0.140	0.966
Logaritmik	450	k=7.517	a=0.915	c=0.091		0.08530	0.111	0.987
	600	k=15.241	a=0.902	c=0.104		0.10149	0.127	0.965
	700	k=6.303	a=0.876	c=0.129		0.12997	0.152	0.948
	300	k=0.392	a=1.004	b=0.004	n=31.582	0.02011	0.063	0.936
Midilli	450	k=4.729	a=1.007	b=0.004	n=10.879	0.01209	0.049	0.968
	600	k=3.818	a=1.006	b=0.005	n=20.810	0.01350	0.051	0.927
	700	k=3.493	a=1.005	b=0.007	n=25.694	0.01785	0.059	0.900

The rehydration ratio of garlic slices dried at different microwave powers was determined. Most of the weight gain (>70%) for all microwave powers occurred in the first 30 minutes. This rapid increase in weight is due to the fact that the final moisture content of the garlic (6%) is very low. It was determined that the rehydration ratio decreased as the applied microwave power increased. After 24 hours, it was observed that the rehydration ratio of dried garlic applied 300W was 15% higher on average than those applied 700W. The reason for this was thought to be that high microwave power disrupts the porous structure of the garlic and reduces its rehydration ability. For the rehydration ratio analysis, the difference between the microwave powers for all the minutes (10th, 20th, 30th, 60th, and 1440th) was found to be statistically significant ($p<0.05$). Studies with similar results to this study have been available in the literature. According to one of these, the garlic samples were dried in the microwave oven at 100W, 200W, and 300W, and the highest rehydration ratio was found in the samples applied at 100W [19]. Doymaz and Aktaş [20], dried eggplant samples at 40, 50, 60, and 70 ºC with a cabinet dryer and stated that the rehydration ratio of eggplants was low at 70 ºC.

The coefficients in these models are determined by performing a nonlinear regression analysis. Some statistical parameters need to be calculated to determine the most suitable model. These are the RMSE, $R^{2,}$ and χ^2 values. The estimated standard error (RMSE) shows the deviation between the estimated and experimental data obtained from the model and (χ^2) indicates the degree of goodness of fit. When choosing the most suitable model, it is taken into account that the RMSE and chi-square value are close to 0 and the coefficient of determination is close to 1 [21]. The nonlinear analysis results of some thin layer drying models used for garlic slices dried at different microwave powers were given in Table 4. According to the results of the analysis, it is seen that the highest R^2 values of the garlic samples (closest to 1) were obtained with the Lewis model and Henderson and Pabis model. The lowest RMSE and χ^2 (closest to 0) values were calculated in the Lewis model. According to the data obtained, the most suitable drying model for all microwave powers (300W, 450W, 600W, and 700W) applied to the garlic slices was the Lewis model. With the use of Lewis model, the closest results to the experimental data can be obtained. İlter et al [22], made kinetic modeling of garlic samples dried in the microwave at 3 different levels (180W, 360W, and 540W). They stated that the most appropriate model was the Page model.

4 Conclusion

This research has shown that dried garlic slices can be easily produced in home kitchens. It has been demonstrated that garlic powders can be easily produced in this way to add flavor to prepared foods (fries, stews, chips, etc.). It was determined that 700W microwave power caused serious damage to the garlic tissue against the short drying time, thus the rehydration ability of dried garlic was significantly reduced. Compared to other microwave powers, it was determined that the color values, especially L* and a* values of the samples applied with 700W adversely affected. Therefore, it was concluded that among the microwave powers used, garlic dried with 300W would be more suitable for foods to be prepared at home. The MR values of the garlic slices were compared with the 5 drying models in the literature, and it was determined that the model most compatible with the experimental data was Lewis.

Conflict of interest

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Similarity rate (iThenticate): 17%

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