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DRYING KINETICS AND DRYING SHRINKAGE OF GARLIC SUBJECTED TO VACUUM-MICROWAVE DEHYDRATION

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Abstract. Whole garlic cloves and cut into slices were subjected to pulsed vacuum-microwave drying at three microwave power levels: 240, 480 and 720 W. The pressure in the dryer drum was from 4 to 6 kPa. It was found that the process of drying can be divided into three periods described by power, linear and exponential functions. Increase of microwave power caused increase in the rate of drying, and had no effect on drying shrinkage. Cutting garlic cloves into slices resulted in longer drying time. The rate of drying sliced garlic was lower compared with that of drying whole cloves in all the three periods at 480 W power. At microwave power of 240 and 720 W the rate of drying sliced garlic was greater at the end of second period and in the third one. A relative volume increase, as a result of the puffing phenomenon, was observed only when whole cloves were drying.

Keywords: garlic, vacuum-microwave drying, drying kinetics, shrinkage

INTRODUCTION

Garlic has been and is cultivated all over the world because of its culinary and medicinal advantages. That vegetable spice is produced and consumed in abundant quantities. However, like other biological crops, garlic is exposed to waste due to respiration and microbial spoilage during storage. Dehydration is an alternative method of biological material preservation. Hot air drying method is currently applied to reduce the moisture content of garlic [3]. The method has several disadvantages and limitations. It takes long time during the falling rate period even at high temperature. Air dryer temperatures usually need to be in the range of 60 to 90°C. Such a drying regime generates degradation of important flavour and nutritional substances as well as colour alteration. Hot air drying causes structural changes in foods due to local hardening and tissue collapse and this way provides shrinkage. Vacuum microwave dehydration has been reported to reduce these limitations [5,8]. In that process of dehydration microwaves penetrate to the interior of the food causing water to boil within the food at relatively low temperature. This creates a large vapour pressure in the centre of the product, allowing rapid transport of moisture out of the product and preventing structural collapse. This process, referred to as the puffing phenomenon, creates a porous texture of the food [10].

Microwave energy has been already applied to convective drying of garlic [1,11,12]. However, no work has been reported on the vacuum-microwave drying of garlic. The evolution of this method to produce high quality dried garlic in a short time could make a significant contribution to the vegetable processing industry. Therefore the aim of the work was to determine the effect of microwave power on the time and rate of drying whole and sliced garlic cloves with vacuum-microwave method.

MATERIALS AND METHODS

Whole garlic cloves and cut into slices of 4.5 mm thickness were subjected to vacuum–microwave drying in a VM 200 Plazmatronika dryer that had two magnetrons of 1200 W combined power and a revolving drum of approximately 0.18 m radius and 0.27 m length. Three levels of microwave power were applied: 240, 480 and 720 W. Garlic was dried with 60-second microwave pulses followed by 5-second breaks. Investigations conducted by Gunasekaran showed that pulse drying of cranberry is more effective than continuous drying [6]. The pressure in the drum revolving at 6 rev min^{-1} was from 4 to 6 kPa. Excessive lowering of pressure, necessitating the use of more expensive vacuum pumps [7], did not result in significant shortening of the drying time [2]. The kinetics of garlic drying was determined on the basis of mass losses of 60 g portions of garlic with 66% initial moisture content. With successive portions of fresh material longer and longer drying times were applied. Therefore, the number of measurement points necessary for drying curve fitting amounted to the number of fresh material portions. Absolute values of derivatives of the functions describing garlic drying allowed the drying rate determination and estimation of the critical points K1 and K2. The critical points divided the drying process into three periods – I, II and III (Fig. 1). Assuming that the drying rate in period II should assume a constant value, it was necessary to reduce the other two ranges I and III to the same value to ensure continuity of the drying curve. Sometimes in period II, characterised by constant drying rate, only one point remained. Obviously, the only one point could not be used to fit the linear function which was a part of the drying curve between the critical points K1 and K2.

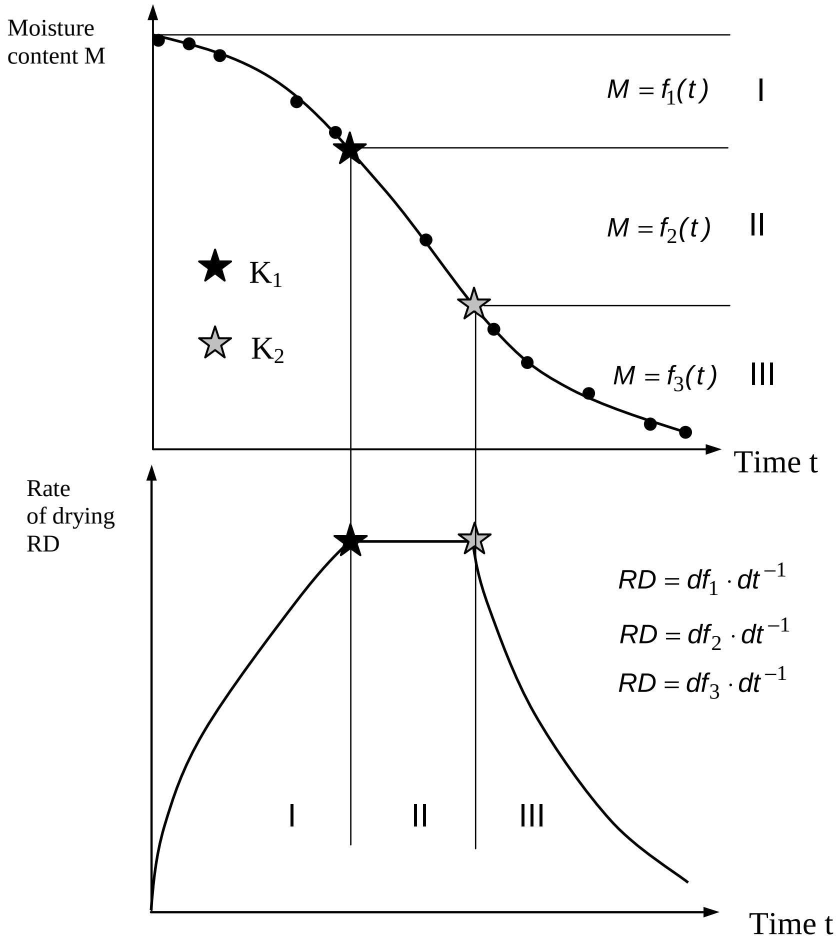

Fig. 1. Drying rate determination and estimation of the critical points K1 and K2 (I, II, III – drying periods)

Drying shrinkage (*S*) was determined as a function of dry mass (*D*) by calculating the ratio of garlic volume after drying (*V*) to garlic volume before drying (V_0):

$$S = \frac{V}{V_0} \tag{1}$$

The volume of fresh garlic was measured with a graduated cylinder filled with distilled water, while that of dried garlic with the use of toluene.

RESULTS AND DISCUSSION

Based on the measurement points obtained from the drying experiments, it was found that the process of garlic cloves drying with the vacuum-microwave method can be divided into three periods separated by the critical points K1 and K2, irrespective of the microwave power applied (Fig. 2). The decrease in moisture content in the first drying period, between the starting point and K1, was described by a power function, in the second period, between points K1 and K2 – by a linear function, and in the third period, between K2 and the final point – by an exponential function (Tab. 1). Increased microwave power from 240 to 720 W resulted in shorter drying time – from 21 to 6.6 min at final moisture content of 7%.

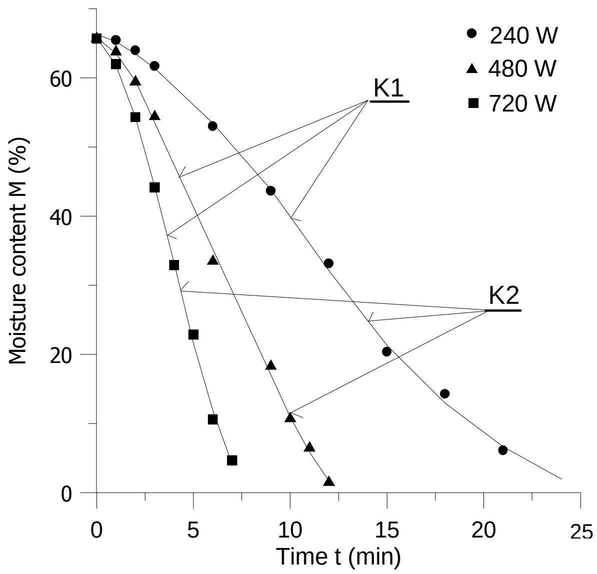

Fig. 2. Drying curves of garlic cloves obtained at different microwave power levels

Size reduction of the material under drying by the method of natural or forced convection usually causes a shortening of drying time as a result of increased areas for mass and energy exchange. However, the results of the investigations performed indicate that size reduction of the raw material caused an increase in drying time with the vacuum-microwave method (Fig. 3). The larger deference in drying time of whole and sliced garlic cloves was observed for the lowest power level 240 W. For other power levels, particularly 480 W, the difference was not significant. This is only a tendency which was not statistically proved. Nevertheless, the tendency was confirmed by the results of microwave drying of banana, reported by Maskan [9].

Table 1. Parameters of functions describing the decrease in moisture content of whole garlic cloves and cut into slices in the three drying periods at different microwave power levels

Period	Function	Parameter	Microwave Power (W)					
			240		480		720	
			cloves	slices	cloves	slices	cloves	slices
I	$M = a + b \cdot t^{c}$	a	66.3	65.7	65.8	65.4	65.8	65.6
		b	–1.09	–0.66	–2.19	–2.13	–4.05	–2.66
		c	1.38	1.48	1.5	1.39	1.51	1.59
II	$M = a + b \cdot t$	a	75.5	76	71.8	72.3	77.5	81.8
		b	–3.62	–3.19	–6.08	–5.95	–11.1	–10.3
III	$M = a + b \cdot e^{-\frac{t}{c}}$	a	–11.6	–2.64	–12.4	0	–32.2	–42.4
		b	146	238	309	517	144	157
		c	10.1	7.4	3.89	2.75	5.1	6.44

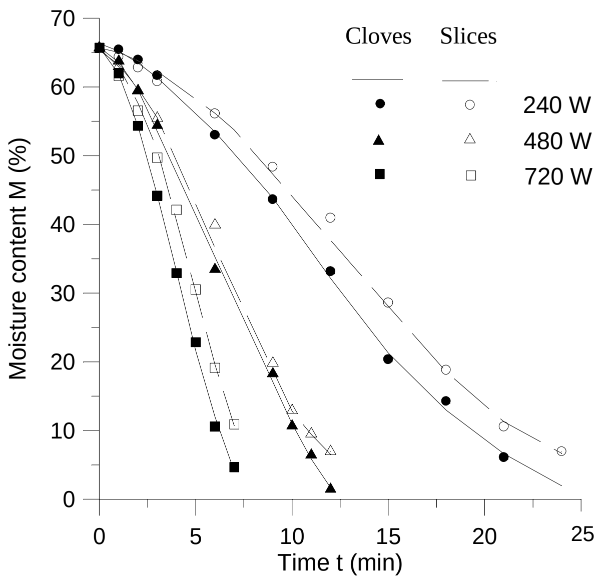

Fig. 3. Drying curves of whole garlic cloves and cut into slices obtained at different microwave power levels

Decreased thickness of banana slices resulted in increased time of drying. Apparently, size reduction of material results in lower temperatures reached within the material heated with microwaves. A uniform colour of the dried garlic slices indicates that no local overheating took place, which, however, occurred in whole cloves of highly dehydrated garlic. The risk of the material reaching too high temperatures occurs in the final phase of vacuum-microwave drying when the dynamics of water evaporation is much decreased [4].

Absolute values of derivatives of the functions describing garlic drying (Tab. 2) allowed determination of the rate of drying, which is represented by the plots in Figure 4. The increase in drying rate in the first period was due to the increase in the internal temperature of the material to the level determined by the lowered pressure inside the drum. The constant rate of drying in the second period was connected with stabilization of the temperature and vapour pressure inside the material [13]. The decrease in drying rate in the third period resulted from substantially lowered water content and thus reduced diffusion rate [12]. Application of increasing microwave powers (240, 480 and 720 W) resulted in increased rates of garlic cloves drying, whose maximum values in the second period amounted to 11.1% min^{-1}. The drying rate of sliced garlic cloves was lower, compared with that found for whole cloves, in all the periods at 480W microwave power. However, at 240 and 720 W power the drying rate of sliced cloves was higher at the end of the second period and in the third one.

Table 2. Parameters of functions describing the drying rate of whole garlic cloves and cut into slices in the three drying periods at different microwave power levels

Period	Function	Parameter	Microwave Power (W)					
			240		480		720	
			cloves	slices	cloves	slices	cloves	slices
I	$RD = a \cdot t^b$	a	–1.5	–0.98	–3.28	–2.96	–6.11	–4.23
		b	0.38	0.48	0.5	0.39	0.51	0.59
II	$RD = a$	a	–3.62	–3.19	–6.08	–5.95	–11.1	–10.3
III	$RD = a \cdot e^{-\frac{t}{b}}$	a	–14.4	–32.2	–79.4	–188	28.2	–24.4
		b	10.1	7.4	3.89	2.75	5.1	6.44

The observed shrinkage resulting from garlic slices drying was described using an exponential function (2) fitted to experimental points obtained at various levels of microwave power (Fig. 5).

The shrinkage remained constant beyond critical dry mass content of 60%. It turned out that microwave power had no significant influence on drying shrinkage, both for slices and for whole garlic cloves.

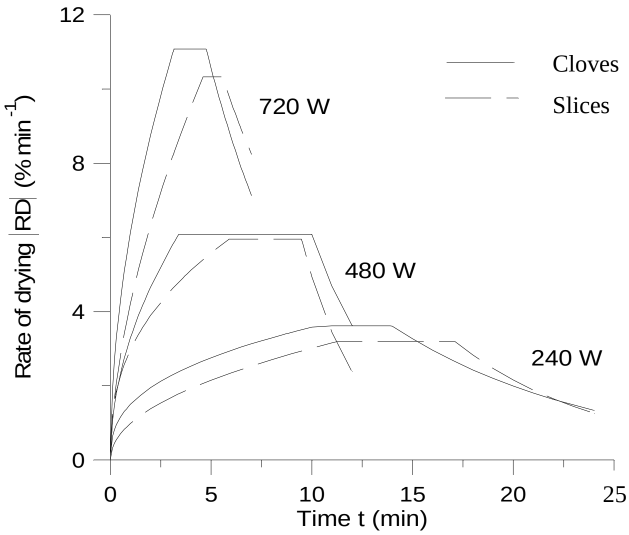

Fig. 4. Drying rate of whole garlic cloves and cut into slices estimated at different microwave power levels

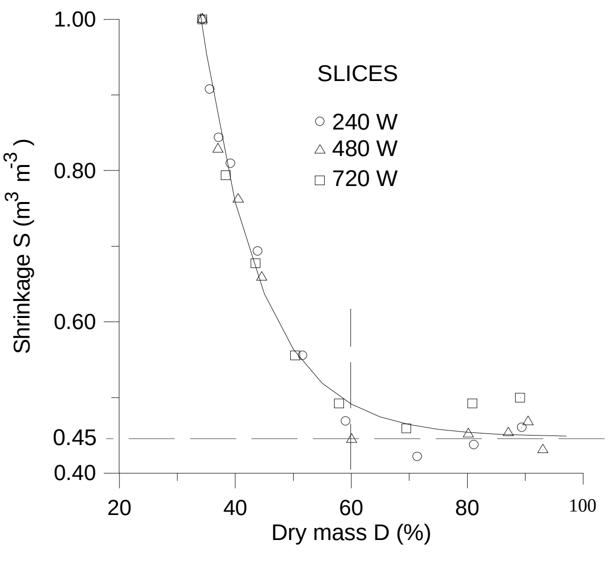

Fig. 5. Shrinkage during drying of garlic slices

However, in the case of whole cloves the result of the puffing phenomenon was clearly observed, that is a relative volume increase after reaching 64% of dry mass. Similar tendency was observed for garlic slices when the highest power level of 720 W was applied. Garlic cloves relative volume change after drying to certain dry mass contents at the range of 34 to 94% (Fig. 6) was described by a polynomial with a logarithmic term (3). The shrinkage was not estimated for samples under reduced pressure inside the drum.

$$S = 0.45 + 15.96 \cdot e^{-\frac{D}{10.15}} \qquad R^2 = 0.99 \tag{2}$$

$$S = 10.92 + 0.051 \cdot D - 3.32 \cdot \ln D \qquad R^2 = 0.94 \tag{3}$$

where: S – shrinkage, D – dry mass of garlic, R^2 – coefficient of determination.

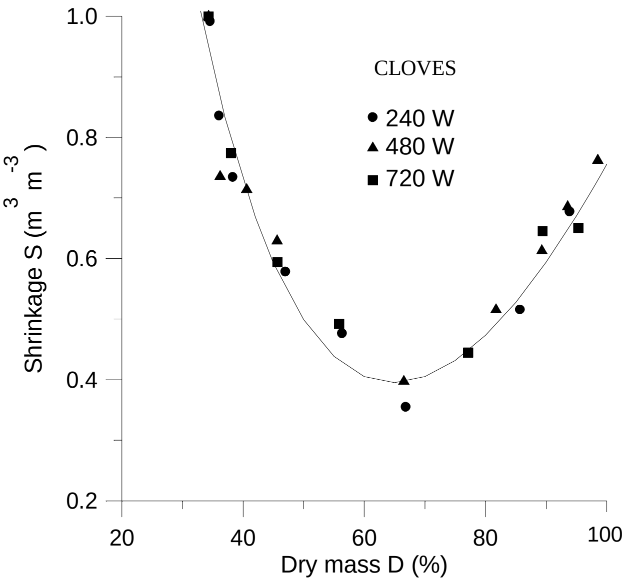

Fig. 6. Shrinkage during drying of whole garlic cloves

The results of shrinkage investigations show that whole cloves of garlic are more susceptible to puffing than sliced cloves. Apparently, volumetric heating, generating high pressure inside the whole cloves, resulted in bubbling of the samples [14]. Therefore, the density of whole cloves (0.52 g cm^{-3}) was much lower as compared to that of sliced ones (0.79 g cm^{-3}) dehydrated to the same dry mass content of 93%. Lin *et al.* reported [8] that, due to the puffing effect, the density of vacuum-microwave dried carrot slices was much lower than that of air-dried ones. Similar results concerning vacuum-microwave dehydrated apple chips were obtained by Sham *et al.* [10].

CONCLUSIONS

1. Drying of garlic with the vacuum-microwave method can be divided into three periods: with increasing, constant and decreasing rates of drying.
2. Microwave power increase in the range from 240 to 720 W causes a shortening of drying time and an increase in the rate of drying, and has no effect on drying shrinkage.
3. Cutting garlic cloves into slices results in longer drying time, particularly at the 240 W microwave power applied.
4. The rate of drying sliced garlic is lower compared with that of drying whole cloves in all the three periods at 480 W power. At microwave power of 240 and 720 W the rate of drying sliced garlic is greater at the end of the second period and in the third one.
5. Whole cloves of garlic are more susceptible to puffing than sliced cloves.

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KINETYKA SUSZENIA I SKURCZ SUSZARNICZY CZOSNKU ODWADNIANEGO METODĄ MIKROFALOWO-PODCIŚNIENIOWĄ

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S t r e s z c z e n i e. Całe ząbki czosnku oraz ząbki pokrojone w plastry poddano pulsacyjnemu suszeniu mikrofalowo-podciśnieniowemu przy zastosowaniu trzech poziomów mocy mikrofal 240, 480 oraz 720 W. Ciśnienie w bębnie suszarki wynosiło od 4 do 6 kPa. Stwierdzono, że proces suszenie czosnku można podzielić na trzy okresy opisane przy użyciu funkcji potęgowej, liniowej i wykładniczej. Wzrost mocy mikrofal spowodował skrócenie czasu suszenia i nie miał wpływu na skurcz suszarniczy. Rozdrobnienie czosnku spowodowało wydłużenie czasu suszenia. Prędkość suszenia rozdrobnionych ząbków czosnku była mniejsza w porównaniu z prędkością suszenia wyznaczoną dla całych ząbków we wszystkich okresach przy zastosowaniu mocy mikrofal 480 W. Natomiast przy zastosowaniu mocy mikrofal 240 i 720 W prędkość suszenia ząbków rozdrobnionych była większa pod koniec okresu drugiego i w trzecim okresie. Wzrost względnej objętości wskutek „puffingu” można było zaobserwowane jedynie podczas suszenia całych ząbków czosnku.

S ł o w a k l u c z o w e: czosnek, suszenie mikrofalowo-podciśnieniowe, kinetyka suszenia, skurcz suszarniczy