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THE USE OF OSMOTIC DEHYDRATION AND MICROWAVE-VACUUM DRYING FOR THE PRODUCTION OF APPLE SNACKS®

Zastosowanie odwadniania osmotycznego i suszenia mikrofalowo-próżniowego do wytwarzania przekąsek z jabłek®

Key words: dried fruit, fruit snacks, reduced pressure, microwave power.

The influence of time, microwave power, reduced pressure, and initial osmotic dehydration on selected indicators of microwave-vacuum drying of apple slices was investigated. 5 drying variants were used, differing in microwave power and pressure, and with osmotic treatment: A: 250 W / 3.5 kPa; B: 300 W / 3.5 kPa; C: 300 W / 5.5 kPa; D: 300 W / 6.5 kPa; E: 300 W / 6.5 kPa / initial osmotic dehydration. Apple drying was the most intensive in the case of variant B. Water activity of apples without pretreatment was at the level of 0.71-0.81, and initial osmotic dehydration caused a decrease to 0.52. All samples showed a darkening of the color and increased red color.

Słowa kluczowe: suszone owoce, przekąski z owoców, obniżone ciśnienie, moc mikrofal.

Badano wpływ czasu, mocy mikrofal, obniżonego ciśnienia i wstępnego odwadniania osmotycznego na wybrane wskaźniki suszenia mikrofalowo-próżniowego jabłek. Zastosowano 5 wariantów suszenia różniących się mocą mikrofal i ciśnieniem oraz z obróbką osmotyczną: A: 250 W/3,5 kPa; B: 300 W/3,5 kPa; C: 300 W/5,5 kPa; D: 300 W/6,5 kPa; E: 300 W/6,5 kPa/ wstępne odwadnianie osmotyczne. Suszenie jabłek najintensywniej przebiegało w przypadku wariantu B. Aktywność wody jabłek bez wstępnej obróbki była na poziomie 0,71-0,81, a wstępne odwadnianie osmotyczne spowodowało obniżenie do 0,52. Obróbka osmotyczna wpłynęła istotnie na ograniczenie skurczu suszarniczego. Próbki odznaczały się pociemnieniem barwy i zwiększeniem udziału barwy czerwonej.

INTRODUCTION

A characteristic feature of fruit and vegetable farming is the seasonality of harvesting and the occurrence of raw materials, which results in the limited availability of fresh fruit and vegetables. It is therefore necessary to process the raw materials so they can be available to consumers all year round. One of the main components of plant raw materials is water. Fresh apples contain about 85% water [8, 9]. Drying to reduce the water content is one of the oldest methods of food preservation and ensuring the microbiological safety of food and extending the use-by date. By drying, attractive snack products of high quality and nutritional value can be produced. It also makes it possible to process the production surplus of fruit and vegetable raw materials in the event of their abundant harvest [11]. Many changes occur in the material during drying, both physical and biochemical. The main noticeable phenomenon is the evaporation of moisture (water loss) and the associated physicochemical changes. The cell structure of the dried material shrinks, sometimes hardening or cracking. An undesirable effect of drying may be the loss of thermally sensitive compounds, for example, vitamins [2]. Inadequate drying conditions and methods contribute to the reduction of important nutritional and aromatic compounds and cause unfavorable organoleptic changes in the material. Obtaining high-quality dried material with the sublimation method is associated with high costs. Recently, a good solution seems to be the use of microwave-vacuum drying to preserve fruit and vegetables [3, 4, 12]. This method may develop on a larger scale, as it allows for shortening the drying time and at the same time maintaining the high quality of the product [4, 8].

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Properly dried fruit can be counted among products that are a source of health-promoting nutrients, such as fiber, vitamins, minerals, and antioxidant compounds. They are often an ingredient of breakfast cereals, muesli, granola, and bars. Such use of dried fruit can meet the needs of consumers focused on proper nutrition, and looking for high-quality products. Hence, the role of producers is to select appropriate processing processes, including taking into account the specificity of the raw material, in order to maintain its nutritional value [2].

The aim of the article is to investigate the effect of microwave power and reduced pressure as well as initial osmotic treatment on the kinetics of drying apple slices and their selected physicochemical properties.

MATERIALS AND METHODOLOGY

The research material was apples of the Royal Gala variety purchased in one of the supermarkets (Lidl). The fruits were stored in refrigerated conditions at a temperature of 4–5°C and relative air humidity of 85–90%. The seed chamber was removed from the apples with a special device (a cork borer) and then the apples were cut into slices 5 mm thick. Each slice was then cut into smaller pieces (quarters). In order to inhibit the color change, before drying, the raw material was immersed in a 0.5% citric acid solution at a temperature of about 20°C for 10 minutes, and then dried on a filter ball. An approximately 60% sucrose solution was prepared by dissolving sucrose in distilled water.

Table 1. Microwave-vacuum drying conditions for apples; variants of the drying kinetics

Tabela 1. Warunki suszenia mikrofalowo-próżniowego jabłek; warianty kinetyki suszenia

Drying parameters / Variants	Initial treatment	Microwave power [W]	Pressure [kPa]	Maximum temperature [°C]
A	-	250	3.5	70
B	-	300	3.5	70
C	-	300	5.5	70
D	-	300	6.5	70
E	Osmotic dehydration	300	6.5	70

Source: The own study

Źródło: Badania własne

Osmotic dehydration was carried out in a JW.ELECTRONIC type T-OSM water bath at a constant temperature of 50°C for 15 minutes. A sucrose solution with a concentration of 60% was used for the osmotic dehydration of samples weighing about 100 g. After dehydration, the material was rinsed under running water for 3–5 seconds and dried on filter paper. The pre-dehydrated samples (about 40 g) were dried in a PROMIS-µLAB microwave-vacuum oven with a maximum vapor temperature of 70°C, microwave power in the range of 250-350 W and reduced pressure in the range of 3.5–6.5 kPa. Drying consisted of four cycles, the second and fourth were without microwaves. By operating the duration of the process while maintaining constant microwave power parameters and the value of reduced pressure, the drying kinetics were determined (Table 1). The samples were assessed for changes in activity and water content, weight loss, color parameters, and shrinkage. Statistical analysis for three series of tests was performed using the Statistica 13 Trial program. One-way ANOVA and Tukey's test with significance level $\alpha = 0.05$ were used.

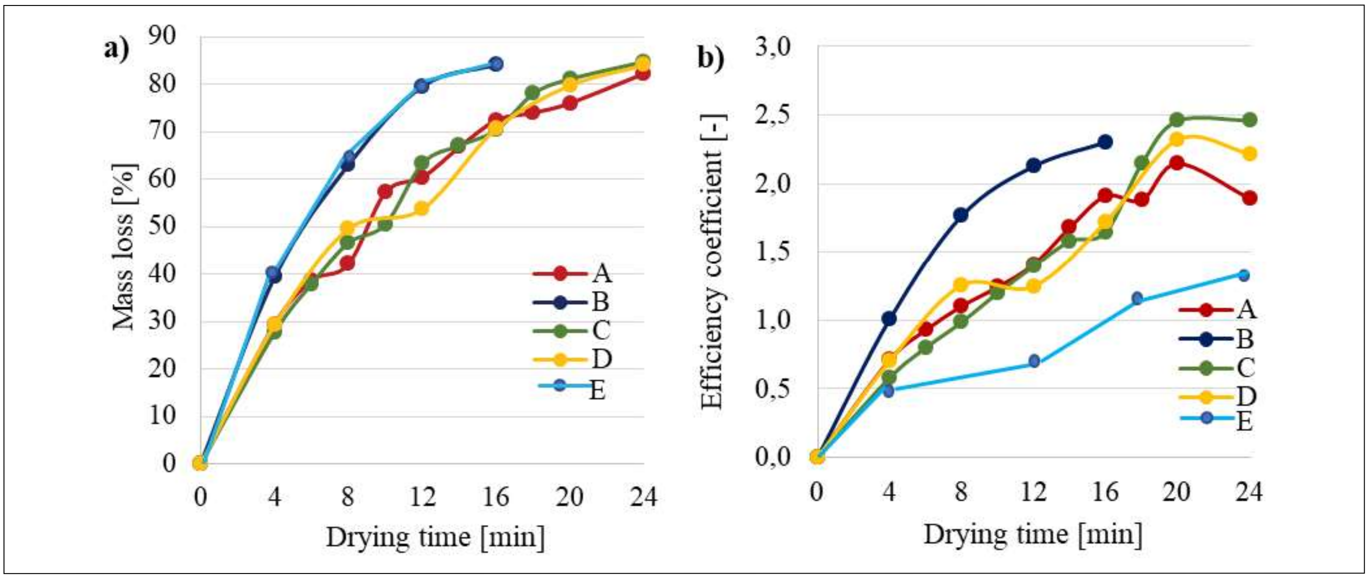
RESULTS AND DISCUSSION

Effect of microwave-vacuum drying parameters on the mass loss of apples

A significant effect of time on the mass loss of dried apples was observed. When using a shorter drying time, from 4 to 10 minutes, a mass loss of 28–57% was noted and significantly higher in samples dried for 20–24 minutes (76–85%) (Fig. 1).

Microwave power and reduced pressure did not significantly affect the mass loss of apples. Significantly greater mass losses were observed in the dried fruit of variant B (microwave power 300 W, pressure 3.5 kPa). After 12 minutes, the mass loss of these samples amounted to 79.6% and was 16.3–25.9% higher than for the other variants (Fig. 1a). The use of lower microwave power of 250 W (variant A) at the same pressure value resulted in a lower weight loss in the entire duration of the process. The change in pressure value at constant microwave power (300 W) did not cause significant differences in the mass loss for higher pressure values, i.e. 5.5 and 6.5 kPa (variants C and D). A significant effect was observed for the lowest pressure value (variant B), at which a significant increase in the mass loss of dried apples was noted in comparison with higher pressure values (variants C and D). There was no significant effect of the application of preliminary osmotic dehydration of apples in a 60% sucrose solution at 50°C on the mass loss of dried apples. Samples not subjected to initial osmotic dehydration (D) showed very similar values of mass loss in relation to the samples subjected to this treatment (E) in the entire drying time range (Fig. 1a).

There was no significant influence of microwave power on the efficiency coefficient calculated on the basis of the ratio of water loss to dry matter weight gain [7] (Fig. 1b), but some trends were observed. Higher values of the coefficient were found in apples dried using higher microwave power (300 W) compared to drying at lower power of 250 W, with constant values of other parameters (variants A and B). Drying at the pressure of 3.5 kPa (B) was characterized by a higher process efficiency coefficient than drying at the pressures of 5.5 and 6.5 kPa (variants C and D), but only at a higher microwave power (300 W). For shorter drying times, higher values were obtained for samples dried at a pressure of 6.5 kPa, however, for longer times, higher values of the efficiency coefficient were recorded at a pressure of 5.5 kPa (Fig. 1b). Such diversity of data probably contributed to the lack of a significant influence of pressure on the examined index. The use of initial osmotic dehydration significantly influenced the efficiency of the drying process (Fig. 1b). For samples initially osmotically dehydrated (variant E) in the whole range of the process duration, lower values of this coefficient were recorded compared to the samples



Factors	Time [min]	Microwave power [W]	Pressure [kPa]	Initial osmotic dehydration
Tested parameters	p - probability			
Mass loss	0.000*	0.899	0.924	0.554
Efficiency coefficient	0.000*	0.275	0.407	0.032*

Fig. 1. Kinetics: a) mass loss, b) apple drying efficiency coefficient; influence of microwave power and reduced pressure: A – 250 W / 3.5 kPa; B – 300 W / 3.5 kPa; C – 300 W / 5.5 kPa; D – 300 W / 6.5 kPa, E – osmotic dehydration / 300 W / 6.5 kPa. The standard deviation of the presented data did not exceed 7%.

Rys. 1. Kinetyka: a) ubytku masy, b) współczynnika efektywności suszenia jabłek; wpływ mocy mikrofal i obniżonego ciśnienia: A – 250 W / 3,5 kPa; B – 300 W / 3,5 kPa; C – 300 W / 5,5 kPa; D – 300 W / 6,5 kPa, E – odwadniaie osmotyczne / 300 W / 6,5 kPa. Odchylenie standardowe prezentowanych danych nie przekraczało 7%.

Source: The own study

Źródło: Badania własne

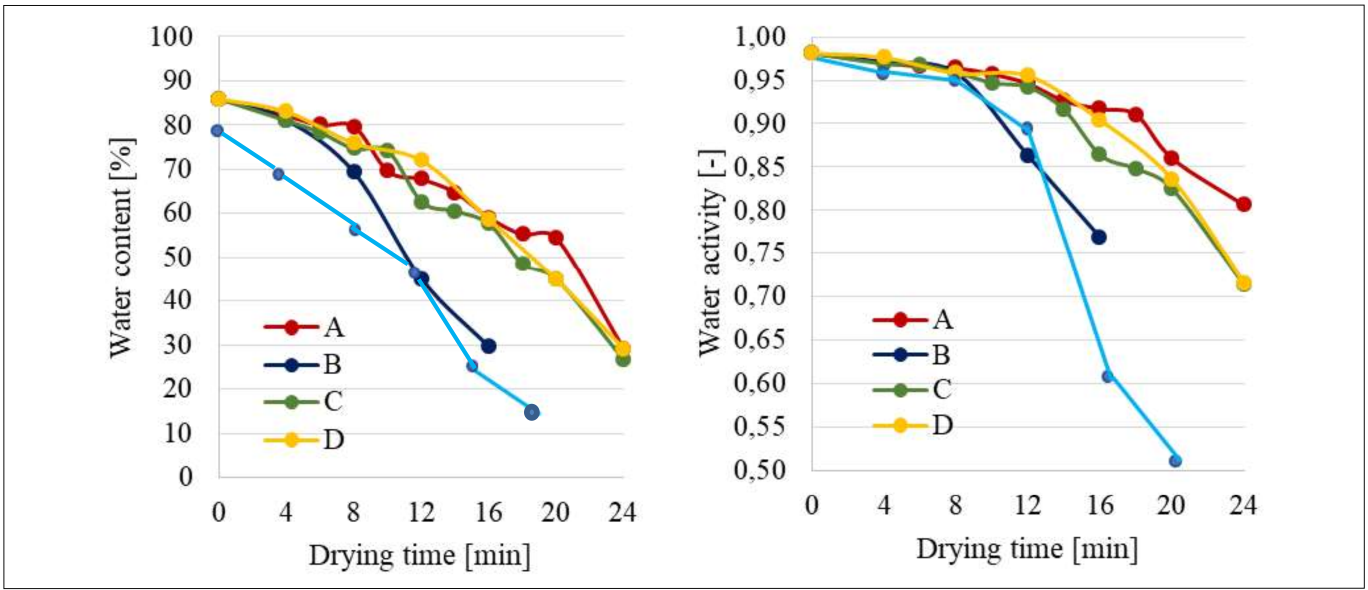
not subjected to preliminary dewatering (variant D) (Fig. 1b). For samples initially osmotically dehydrated (variant E), in the entire range of the process duration, lower values of this coefficient were recorded compared to samples not subjected to pre-osmotic treatment (variant D).

The use of preliminary osmotic dehydration before microwave-vacuum drying resulted in obtaining a lower water content and activity throughout the process (Fig. 2). After the short drying times, especially for the water activity, the differences were small. However, along with the extension of the processing time, significantly lower values of both indices of the samples of variant E were observed. Drying the samples pre-osmotically dehydrated for 16–20 minutes resulted in a decrease in water activity by 29–32% in relation to the non-dehydrated samples. Water activity for variant E during 20 minutes of drying was 0.519. This value was at the level showing full microbiological stability [10].

EFFECT OF MICROWAVE-VACUUM DRYING PARAMETERS ON THE COLOR OF APPLES

A significant effect of drying on the lightness of apple color was noted (Table 2). All the dried samples were characterized by lower values of the L* parameter than the color of fresh apples, i.e. at the level of 78.4. Depending on the process parameters, these values decreased by 3.1–33.0 units. This proves that the samples were darkening as a result of drying. Michalska et al. [9] showed that this effect can be attributed to non-enzymatic browning reactions that dried products undergo as a result of heat treatment. The use of microwave power of 250 W (A) and 300 W (B) caused a significant difference in the L* parameter in the samples dried for 16 minutes; those dried with more power were much darker. The significant influence of pressure and initial osmotic dehydration in sucrose solution on the brightness of the color of the dry was not shown.

Samples subjected to drying showed higher values of the a* parameter than in the case of the color of fresh apples (Table 2). In the study by Michalska et al. [9], changes in the values of the a* coordinate were noted during microwave-vacuum drying of apple slices, which was explained by the degradation of red pigments of dried fruit. The values of the b* and C parameters (Table 2) were quite varied and did not show any significant dependence on the drying conditions. In most of the samples, an increase in the share of the yellow color (parameter b*) was noted in comparison to the color of raw apples. Similarly, higher values of the C parameter in most samples may indicate a greater color saturation compared to the color of fresh apples. However, after longer drying times, a lower saturation was noted depending on the pressure used.



Factors	Time [min]	Microwave power [W]	Pressure [kPa]	Initial osmotic dehydration
Tested parameters	p - probability			
Mass loss	0,000*	0,899	0,924	0,554
Efficiency coefficient	0,000*	0,275	0,407	0,032*

Fig. 2. Kinetics: a) changes in water content, b) water activity of microwave-vacuum-dried apples; influence of microwave power, reduced pressure and osmotic treatment: A – 250 W / 3.5 kPa; B – 300 W / 3.5 kPa; C – 300 W / 5.5 kPa; D – 300 W / 6.5 kPa, E – osmotic dehydration / 300 W / 6.5 kPa. The standard deviation of the presented data did not exceed 7%.

Rys. 2. Kinetyka: a) zmiany zawartości wody, b) aktywności wody jabłek suszonych mikrofalowo-próżniowo; wpływ mocy mikrofal, obniżonego ciśnienia i obróbki osmotycznej: A – 250 W / 3,5 kPa; B – 300 W / 3,5 kPa; C – 300 W / 5,5 kPa; D – 300 W / 6,5 kPa, E – odwadniaie osmotyczne / 300 W / 6,5 kPa. Odchylenie standardowe prezentowanych danych nie przekraczało 5%.

Source: The own study

Źródło: Badania własne

Samples dried in 3.5 kPa (A and B) were characterized by the values of the C index at a fairly even level (24.0–32.2), while at 5.5 and 6.5 kPa (C and D), the initial color saturation was similar to the color of the raw material, and then increased or decreased significantly to 16.1-18.3. On the other hand, in the dried osmotically dehydrated (E), initially, the C values were the highest (about 35.0) and decreased to about 17.0. The values of the h parameter (Table 2), which were responsible for the color shade for all samples, were lower than the color of the raw material, the more so, the longer the drying time, and the shade on the color wheel became more yellow.

The absolute color difference ΔE (Table 2) was calculated on the basis of the difference in the L*, a*, and b* color parameters of dried apples in relation to the color of fresh fruit. The ΔE value in the range of 2.0–3.5 represents a slight color difference, while ΔE > 5 indicates a very large color difference between the samples, which is clearly noticeable by the human eye [1]. For all analyzed samples, regardless of the drying parameters used, the ΔE value was greater than 5.0, so drying caused a significant change in the color of apples in the range of 10.0–37.5, visible to the naked eye.

EFFECT OF MICROWAVE-VACUUM DRYING PARAMETERS ON SHRINKAGE OF DRIED APPLES

There was a slight effect of microwave power and lowered pressure on the shrinkage of dried apples (Table 3). Comparing the samples dried at the microwave power of 250 and 300 W (variants A and B), while maintaining constant values of the other parameters, greater shrinkage was recorded at the lower power (250 W), which was approximately 73.3%. Lower values, but a similar relationship was observed for the material pre-osmotically dehydrated. The use of higher microwave power during drying significantly reduced the material shrinkage of these samples. For variant E (300 W), the shrinkage was 66.7%, for variant F (350 W) – 60.0%. Jałoszyński et al. [5] obtained a similar relationship for quince fruit. They showed that with the increase in microwave power, the drying volume shrinkage decreased. In other studies, Jałoszyński et al. [6] noted the same tendency; lower microwave power determined greater root shrinkage of scorzonera, and higher power significantly limited it.

Table 2. Color parameters of selected microwave-vacuum-dried samples
Tabela 2. Parametry barwy wybranych próbek suszonych mikrofalowo-próżniowo

Variant	Time [min]	L*	a*	b*	C	h	∆E
Fresh	-	78,4±1,2	-2,7±1,2	23,8±1,2	24±1,2	94±1,2	-
A	4	67,0±1,0	1,8±0,8	23,7±1,2	24,0±0,5	86,1±0,4	12,1±2,1
	8	49,2±1,4	7,6±1,7	24,9±1,2	28,2±0,8	72,2±1,6	31,4±1,4
	12	55,8±1,1	5,6±1,1	29,4±1,2	30,1±1,4	80,3±5,2	25,0±1,1
	16	75,4±1,2	3,9±1,6	31,9±1,2	32,2±1,7	81,2±3,2	11,0±1,7
	20	70,4±1,5	5,4±0,6	30,3±1,2	31,2±0,4	83,1±1,1	13,1±1,1
	24	61,4±2,2	8,7±0,9	26,4±1,2	25,0±1,5	65,3±1,5	21,5±1,2
B	4	59,1±0,2	5,5±1,2	24,7±1,2	25,1±1,9	78,1±0,5	21,1±1,4
	8	60,2±3,7	6,3±1,8	27,7±1,2	29,0±2,2	76,0±1,6	21,0±2,2
	12	68,2±0,5	6,8±1,4	30,3±1,2	31,3±2,3	78,0±1,4	15,0±0,2
	16	53,0±1,3	13,4±0,5	23,7±1,2	27,4±0,8	60,1±1,1	31,2±2,2
	20	52,4±1,1	13,0±1,2	22,5±1,4	27,1±0,2	59,8±1,2	31,2±1,3
C	4	67,0±1,4	-0,6±1,2	21,9±1,2	23,0±0,6	91,1±1,4	12,3±0,9
	8	47,0±3,2	10,1±04	26,3±1,2	32,1±3,2	70,3±1,5	34,4±2,3
	12	58,6±2,4	5,0±0,6	32,0±1,2	32,2±2,2	80,4±1,7	23,1±3,2
	16	73,8±0,9	3,1±0,2	30,0±1,2	29,0±082	87,0±1,2	10,0±0,8
	20	47,6±1,0	10,2±1,4	15,4±1,2	16,1±1,5	52,0±1,1	35,0±1,2
D	4	57,7±1,3	3,5±0,4	27,9±1,2	29,0±1,1	83,3±2,2	22,2±1,2
	12	61,6±1,1	2,4±0,2	29,2±1,2	31,2±1,0	86,0±3,0	18,3±1,8
	20	45,4±1,7	11,1±1,5	15,0±1,2	18,3±1,3	53,1±1,2	37,5±1,4
E	8	62,2±0,5	2,6±2,2	33,5±1,2	35,0±1,5	87,1±2,2	20,6±1,2
	16	63,4±0,8	6,9±1,3	25,3±1,2	27,3±1,7	76,2±2,4	18,0±1,6
	20	47,5±1,4	8,5±1,1	15,7±1,2	17,0±1,0	57,3±0,5	34,0±1,1

Source: The own study
Źródło: Badania własne

Table 3. Effect of microwave-vacuum drying conditions on apple shrinkage
Tabela 3. Wpływ warunków suszenia microwave-vacuum na skurcz jabłek

Drying parameters / Variants	Initial treatment	Microwave power [W]	Pressure [kPa]	Drying time [min]	Shrinkage [%]
A	-	250	3.5	16	73.3
B	-	300	3.5	16	70.0
C	-	300	5.5	16	70.0
D	-	300	6.5	16	70.0
E	Osmotic dehydration	300	6.5	16	66.7
F*	Osmotic dehydration	350	6.5	16	60.0

* dla wariantu F nie wyznaczano kinetyki suszenia a jedynie skurcz suszarniczy

Source: The own study
Źródło: Badania własne

No influence of pressure on drying shrinkage of samples without preliminary dewatering was demonstrated, at a pressure in the range of 3.5–6.5 kPa it was about 70%. The effect of osmotic dehydration on shrinkage has been reported; pre-dehydrated apples (variant E) showed lower shrinkage compared to the sample not subjected to preliminary drainage treatment (variant D).

CONCLUSIONS

Microwave-vacuum drying of apples in laboratory conditions, lasting up to 16–24 minutes, resulted in significant weight loss, up to 85%, and a decrease in water content and activity of up to 15–30%, higher with higher microwave power (in the range of 250–300 W) and higher pressure (in the range of 3.5–6.5 kPa) and after osmotic treatment. There was no effect of osmotic dehydration on mass loss. The osmotic treatment significantly reduced the efficiency of the process related to the reduction of water loss. Extending the drying time in the range of 0–24 minutes had a significant effect on the tested apple mass exchange indexes. The highest dry-ing efficiency occurred for variant B, with a power of 300 W and a pressure of 3.5 kPa. The lowest water activity (0.52) characterized the osmotically pre-dehydrated samples. The use of osmotic pre-treatment and microwave-vacuum drying with sufficiently high microwave power can be used to produce dried apples, i.e. a product that can be classified as a safe food.

Microwave-vacuum drying, regardless of the parameters used and the initial treatment resulted in diversified changes in the color of apples. All dried samples had a darker color and a higher red color. The absolute color difference of all dried samples was noticeable to the naked eye in relation to the color of the raw material.

The power of the microwaves slightly limited the drying shrinkage. Increasing the power from 250 to 300 W reduced the shrinkage from 73 to 70%. The beneficial effect was pre-osmotic dehydration and higher microwave power, which limited the shrinkage to 60–67%.

WNIOSKI

Suszenie mikrofalowo-próżniowe jabłek w warunkach laboratoryjnych trwające do 16–24 minut powodowało znaczące ubytki masy, sięgające 85% oraz obniżenie zawartości i aktywności wody sięgające 15–30%, większe przy większej mocy mikrofal w zakresie 250–300 W i większym ciśnieniu w zakresie 3,5–6,5 kPa oraz po obróbce osmotycznej. Nie stwierdzono wpływu odwadniania osmotycznego na ubytki masy. Obróbka osmotyczna w dużym stopniu zmniejszyła wydajność procesu związaną z ograniczeniem ubytku wody. Wydłużenie czasu suszenia w zakresie 0–24 minut miało istotny wpływ na badane wskaźniki wymiany masy jabłek. Największa efektywność suszenia wystąpiła dla wariantu B, przy mocy 300 W i ciśnieniu 3,5 kPa. Najniższą aktywnością wody charakteryzowały się próbki wstępnie odwadniane osmotycznie (0,52). Zastosowanie wstępnej obróbki osmotycznej i suszenie mikrofalowo-próżniowe przy odpowiednio wysokiej mocy mikrofal możne być wykorzystane do wytwarzania suszu z jabłek, tj. produktu, który można zaliczyć do żywności trwałej.

Suszenie mikrofalowo-próżniowe, niezależnie od zastosowanych parametrów oraz obróbki wstępnej, wpłynęło na zróżnicowane zmiany barwy jabłek. Wszystkie susze charakteryzowały się ciemniejszą barwą oraz większym udziałem barwy czerwonej. Bezwzględna różnica barwy wszystkich próbek suszonych była zauważalna „gołym okiem" w odniesieniu do barwy surowca.

Moc mikrofal wpłynęła na nieznaczne ograniczenie skurczu suszarniczego. Zwiększenie mocy z 250 do 300 W ograniczyło skurcz z 73 do 70%. Korzystny efekt powodowało wstępne odwadnianie osmotyczne i wyższa moc mikrofal, które ograniczyły skurcz do 60–67%.

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REFERENCES

[1] **CZAJKOWSKA K., H. KOWALSKA, J. CICHOWSKA, M. WOJNOWSKI. 2016.** „Odwadnianie osmotyczne jabłek w koncentracie soku z aronii". Postępy Techniki Przetwórstwa Spożywczego 26/49(2): 5–11.

[2] **DEFRAEYE T., A. RADU. 2018.** "Insights in convective drying of fruit by coupled modeling of fruit drying, deformation, quality evolution and convective exchange with the airflow". Applied Thermal Engineering 129: 1026–1038.

[3] **IGNACZAK A., E. MASIARZ, K. KOWALSKA. 2021.** "Nutritional trends and methods of producing fruit and vegetable health-promoting snacks". Postępy Techniki Przetwórstwa Spożywczego 31/59(2): 143–154.

REFERENCES

[1] **CZAJKOWSKA K., H. KOWALSKA, J. CICHOWSKA, M. WOJNOWSKI. 2016.** „Odwadnianie osmotyczne jablek w koncentracie soku z aronii". Postepy Techniki Przetworstwa Spozywczego 26/49(2): 5–11.

[2] **DEFRAEYE T., A. RADU. 2018.** "Insights in convective drying of fruit by coupled modeling of fruit drying, deformation, quality evolution and convective exchange with the airflow". Applied Thermal Engineering 129: 1026–1038.

[3] **IGNACZAK A., E. MASIARZ, K. KOWALSKA. 2021.** "Nutritional trends and methods of producing fruit and vegetable health-promoting snacks". Postepy Techniki Przetworstwa Spozywczego 31/59(2): 143–154.

[4] **IGNACZAK A., A. SALAMON, J. KOWALSKA, H. KOWALSKA. 2022.** "The use of reduced pressure in methods of drying food". Postępy Techniki Przetwórstwa Spożywczego 32/60(1): 174–185.

[5] **JAŁOSZYŃSKI K., M. PASŁAWSKA, M. SURMA, B. STĘPIEŃ, R. SERAFIN. 2017.** „Wpływ mocy mikrofal i ciśnienia w czasie suszenia mikrofalowo-próżniowego na jakość końcową suszu z owoców pigwy. W: Innowacje w zarządzaniu i inżynierii produkcji (red. R. Knosal)". Opole: Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją: 314–323.

[6] **JAŁOSZYŃSKI K., M. SURMA, B. STĘPIEŃ, M. PASŁAWSKA. 2018.** „Analiza suszenia mikrofalowo-próżniowego korzenia skorzonery, kinetyka suszenia i skurcz suszarniczy. W: Innowacje w zarządzaniu i inżynierii produkcji (red. R. Knosal)". Opole. Oficyna Wydawnicza Polskiego Towarzystwa Zarządzania Produkcją: 239–250.

[7] **KOWALSKA H., A. MARZEC, J. KOWALSKA, A. CIURZYŃSKA, K. CZAJKOWSKA, J. CICHOWSKA, K. RYBAK, A. LENART. 2017.** "Osmotic dehydration of *Honeoye* strawberries in solutions enriched with natural bioactive molecules". LWT – Food Science and Technology 85: 500–505.

[8] **KOWALSKA H., A. MARZEC, J. KOWALSKA, U. TRYCH, E. MASIARZ, A. LENART. 2020.** "The use of a hybrid drying method with pre-osmotic treatment in strawberry bio-snack technology". International Journal of Food Engineering 16(1-2): 80318-80319.

[9] **MICHALSKA A., K. LECH, A. FIGIEL, G. P. ŁYSIAK. 2017.** "The influence of selected drying methods on the physical properties of dried apples cv. Jonagold grown in different locations in Europe". International Journal of Food Engineering 13(6): 1–8.

[10] **PAŁACHA Z., P. MAZUR. 2019.** „Analiza aktywności wody w wybranych produktach owocowych". Postępy Techniki Przetwórstwa Spożywczego 1: 18–22.

[11] **PŁOCHARSKI W., J. MARKOWSKI, K. RUTKOWSKI, D. KONOPACKA. 2017.** „Wartości odżywcze i zdrowotne owoców i warzyw". POL-Print, Skierniewice: 21–23.

[12] **WOJDYŁO A., A. FIGIEL, K. LECH, P. NOWICKA, J. OSZMIAŃSKI. 2014.** "Effect of convective and vacuum-microwave drying on the bioactive compounds, color and antioxidant capacity of sour cherries". Food and Bioprocess Technology 7: 829–841.

[4] **IGNACZAK A., A. SALAMON, J. KOWALSKA, H. KOWALSKA. 2022.** "The use of reduced pressure in methods of drying food". Postępy Techniki Przetwórstwa Spożywczego 32/60(1): 174–185.

[5] **JALOSZYNSKI K., M. PASLAWSKA, M. SURMA, B. STEPIEN, R. SERAFIN. 2017.** „Wplyw mocy mikrofal i cisnienia w czasie suszenia mikrofalowo-prozniowego na jakosc koncowa suszu z owocow pigwy. W: Innowacje w zarzadzaniu i inzynierii produkcji (red. R. Knosal)". Opole: Oficyna Wydawnicza Polskiego Towarzystwa Zarzadzania Produkcja: 314–323.

[6] **JALOSZYNSKI K., M. SURMA, B. STEPIEN, M. PASLAWSKA. 2018.** „Analiza suszenia mikrofalowo-prozniowego korzenia skorzonery, kinetyka suszenia i skurcz suszarniczy. W: Innowacje w zarzadzaniu i inzynierii produkcji (red. R. Knosal)". Opole. Oficyna Wydawnicza Polskiego Towarzystwa Zarzadzania Produkcja: 239–250.

[7] **KOWALSKA H., A. MARZEC, J. KOWALSKA, A. CIURZYNSKA, K. CZAJKOWSKA, J. CICHOWSKA, K. RYBAK, A. LENART. 2017.** "Osmotic dehydration of *Honeoye* strawberries in solutions enriched with natural bioactive molecules". LWT – Food Science and Technology 85: 500–505.

[8] **KOWALSKA H., A. MARZEC, J. KOWALSKA, U. TRYCH, E. MASIARZ, A. LENART. 2020.** "The use of a hybrid drying method with pre-osmotic treatment in strawberry bio-snack technology". International Journal of Food Engineering 16(1-2): 80318-80319.

[9] **MICHALSKA A., K. LECH, A. FIGIEL, G. P. LYSIAK. 2017.** "The influence of selected drying methods on the physical properties of dried apples cv. Jonagold grown in different locations in Europe". International Journal of Food Engineering 13(6): 1–8.

[10] **PALACHA Z., P. MAZUR. 2019.** „Analiza aktywnosci wody w wybranych produktach owocowych". Postepy Techniki Przetworstwa Spozywczego 1: 18–22.

[11] **PLOCHARSKI W., J. MARKOWSKI, K. RUTKOWSKI, D. KONOPACKA. 2017.** „Wartosci odzywcze i zdrowotne owocow i warzyw". POL-Print, Skierniewice: 21–23.

[12] **WOJDYLO A., A. FIGIEL, K. LECH, P. NOWICKA, J. OSZMIANSKI. 2014.** "Effect of convective and vacuum-microwave drying on the bioactive compounds, color and antioxidant capacity of sour cherries". Food and Bioprocess Technology 7: 829–841.