POLISH JOURNAL OF FOOD AND NUTRITION SCIENCES

www.pan.olsztyn.pl/journal/
e-mail: joan@pan.olsztyn.pl

Pol. J. Food Nutr. Sci.
2007, Vol. 57, No. 4(B), pp. 317-323

INFLUENCE OF MICROWAVE HEATING ON MASS TRANSFER DURING OSMOTIC DEHYDRATION OF APPLES

Hanna Kowalska, Magdalena Belka, Andrzej Lenart

Department of Food Engineering and Process Management, Faculty of Food Technology, Warsaw University of Life Sciences

Key words: microwave pretreatment, osmotic dehydration, mass transfer, apple

The aim of this work was to analyse the influence of microwave heating on mass transfer during osmotic dehydration of apples. The samples in 10 mm-cube shape were pre-dried at 200 and 300W microwave power for 10 min. After that, osmotic dehydration of apples was carried out in a glucose solution of 49% concentration at 30 and 50°C temperature. Osmotic process time was 15 and 30 min. An influence of microwave heating on mass transfer in osmodehydrated apples was found. Mass loss from apples with microwave treatment before osmotic dehydration was 3-10 times lower than in the samples without pretreatment. Microwave application decreased water content (14-28%) and increased water loss (15-46%). However, there was no significant effect on water activity in the investigated apples. The highest effect of microwave pretreatment was observed in solids gain. It was 2-3 times higher than in apples without pretreatment. Moreover, in apples exposed to microwave treatment the water loss to solids gain ratio was 2-5 times smaller than in apples without pretreatment. Microwave treatment before osmotic dehydration caused slightly more darkness of apples in comparison with non-treated samples.

INTRODUCTION

Osmotic dehydration of fruits and vegetables as a pretreatment before convective or microwave drying has been the subject of many investigations. The advantages are the influence on high quality of the final product and cost reduction [Lenart & Lewicki, 1996].

Research carried out in recent years proves that use of osmotic dehydration in the processing of fruits and vegetables leads to a very good effects on lowering water content in the product with simultaneous increase of dry matter content [Kowalska & Lenart, 2001a] while achieving an attractive, tasty and appealing product [Janowicz & Lenart, 2001; Piotrowski *et al*., 2004].

Various parameters of osmotic dehydration have been analysed in order to control chemical composition (mainly water content, solids gain) and physical and sensory properties. Mild conditions of the process save characteristic features of plant tissue, like fresh fruits and vegetables. Simultaneously, semi-permeability of the cell membrane can make it possible to obtain a product with controlled water content, solids gain or other substances added (vitamins, minerals, probiotics) [Kowalska, 2006].

Microwave heating is especially useful in drying to intensify moisture removal. Microwave drying is a rapid dehydration technique that can be applied to specific foods, particularly to fruits and vegetables [Zhang *et al*., 2006]. Many research reports focus on drying fruits and vegetables, including apples [Prothon *et al*., 2001; Funebo *et al*., 2002; Contreras *et al*., 2005].

The main advantage of combining microwave with other drying methods is to sharply reduce drying times [Zhang *et al*., 2006]. Combination of osmotic dehydration with microwave-convective drying appears to be a promising possibility to obtain in a short time and with reasonable energy consumption dried fruits with a suitable shelf life and quality. Microwave--convective drying of osmotically dehydrated products proved to improve the drying rate and to retain product quality compared to air drying [Venkatachlapathy & Raghavan, 1999; Raghavan & Silveira, 2001; Funebo *et al.*, 2002; Piotrowski *et al*., 2004; Torringa *et al*., 2001; Contreras *et al*., 2005].

The application of microwave treatment before osmotic dehydration of apples may be interesting in terms of mass transfer during osmotic dehydration and high quality of plant tissue. Not much research is concerned with this issue. Microwave heating as a blanching pretreatment before osmotic dehydration influenced the volatile fraction content of strawberries. Enzyme activity was reduced to 80% with a minimum effect on fruits' sensory quality. It can reduce plant tissue darkness during pretreatment and storage [Escriche *et al*., 2000].

The aim of this work was to analyse the influence of microwave heating on mass transfer during osmotic dehydration of apples.

MATERIALS AND METHODS

Idared apples were used to study mass transfer during osmotic dehydration with microwave pretreatment. Fruits were

Author's address for correspondence: Hanna Kowalska, Department of Food Engineering and Process Management, Faculty of Food Technology, Warsaw University of Life Sciences, ul. Nowoursynowska 159c, 02-776 Warsaw, Poalnd; tel.: (48 22) 593 75 65; fax: (48 22) 593 75 76; e-mail: hanna kowalska@sggw.pl

stored at 5°C temperature and 80-90% RH in a refrigerator until use (about 1 month). Before each experiment raw material was washed, peeled and cut into 10 mm cubes. Before osmotic dehydration, samples were treated for 10 min at 200 or 300W microwave power in a PROMIS laboratory microwave dryer.

Osmotic dehydration of apples in 49.5% glucose solution was carried out in an ELPAN-357 water bath with continuous mixing (100 rotations/min) at constant temperature (30 and 50°C). Osmotic process time was 15 and 30 min. The mass ratio of the raw material to the osmotic solution was 1:4.

After dehydration, the samples were immersed briefly (2 s) in water at room temperature to remove osmotic solution from the surface and blotted with absorbent paper. Water activity A_w (fraction) was read from AquaLab model CX-2 and lightness coefficient L from Minolta CM-508i in the Hunter Lab system.

The measured values were expressed as:

– mass loss ML (%): $ML = 100 \cdot (m_o - m_\tau)/m_o$

– water content WC (g/g d.m.): $WC = (1 - s_\tau)/s_o$

– water loss WL (g/g i.d.m.): $WL = [(1 - s_o) \cdot m_o - (1 - s_\tau) \cdot m_\tau]/s_o \cdot m_o$

– solids gain SG (g/g i.d.m.): $SG = (s_\tau \cdot m_\tau - s_o \cdot m_o)/s_o \cdot m_o$

– rate of water loss to solids gain WL/SG *(fraction)*.

where: m_o – sample mass of raw material (g); m_τ – sample mass of osmodehydrated apple (g); s_o – dry solids mass of raw material (g); s_τ – dry solids mass of osmodehydrated apple (g); and τ – time of osmotic dehydration (min).

Multifactor ANOVA and hypothesis verification as the p-value test (α=0.05) were applied to statistical analysis of results. Fisher's least significant difference (LSD) between each pair was estimated as well.

RESULTS AND DISCUSSION

Osmotic dehydration comprises a stream of water leaving the osmosed material and a stream of osmoactive substance replacing in part water loss. Higher water loss from material to outer solution than osmoactive substance (in opposite direction) stream causes mass loss from the material during this process.

For most mass transfer indices (mass loss, water content, water loss, solids gain), a statistically significant influence of microwave heating, temperature and process time on mass change in apples during osmotic dehydration was observed (Table 1).

Mass loss

ML in osmodehydrated apples without pretreatment during 15 min was about 13% at 30°C and even more than 15% at 50°C. After 60 min of dehydration, mass loss was higher and ranged from 23 to 27% (Figures 1, 2).

Microwave treatment before osmotic dehydration of apples caused lower mass loss from samples in comparison with mass loss from the samples without pretreatment (Figures 1, 2). The highest difference was noted by applying short time (15 min) and low temperature (30°C) (Figure 1). In this case mass loss from apples treated with 200W microwave power was over 10 times lower than for osmodehydrated samples without treatment, but higher microwave power (300W) caused

TABLE 1. Statistical analysis for mass loss *ML,* water content *WC,* water loss *WL,* water activity A_w, solids gain *SG*, lightness coefficient *L*. MV-200W – 200W microwave power, MV-300W – 300W microwave power, deh. – osmodehydrated apples without pretreatment.

Mass loss				Water content			
Factors	P-value	Difference	LSD	Factors	P-value	Difference	LSD
MV200-deh.		*-11.5400	4.0882	MV200-deh.		*-0.4744	0.2192
MV300-deh.	0.0721	*-12.8225	4.0882	MV300-deh.	0.0004	*-0.6793	0.2192
MV200-MV300		-1.2825	4.0882	MV200-MV300		-0.2048	0.2192
30-50°C	0.0186	-3.1100	3.3380	30-50°C	0.0012	*0.3939	0.1789
15-60 min	0.0000	*-9.4300	3.3380	15-60 min	0.0000	*0.9484	0.1789
Water loss				Water activity			
Factors	P-value	Difference	LSD	Factors	P-value	Difference	LSD
MV200-deh.		*-0.3804	0.2412	MV200-deh.		-0.0023	0.0038
MV300-deh.	0.0141	*-0.3369	0.2412	MV300-deh.	0.0721	*-0.0045	0.0038
MV200-MV300		0.0435	0.2412	MV200-MV300		-0.0023	0.0038
30-50°C	0.0066	*-0.3175	0.1969	30-50°C	0.0186	*0.0040	0.0031
15-60 min	0.0000	*-0.8554	0.1969	15-60 min	0.0000	*0.0133	0.0031
Solids gain				Lightness coefficient			
Factors	P-value	Difference	LSD	Factors	P-value	Difference	LSD
MV200-deh.		*0.3807	0.0997	MV200-deh.		-0.1750	6.4717
MV300-deh.	0.0000	*0.5114	0.0997	MV300-deh.	0.1993	-5.5000	6.4717
MV200-MV300		*0.1308	0.0997	MV200-MV300		-3.3250	6.4717
30-50°C	0.0147	*-0.1107	0.0814	30-50°C	0.6732	-0.0983	5.2841
15-60 min	0.0003	*-0.2317	0.0813	15-60 min	0.8913	0.3166	5.2841

* denotes a statistically significant difference

3.2 times lower mass loss. The same dependence was observed at temperature 50°C (Figure 2). When longer time was applied, mass loss was higher when using lower microwave power independently of temperature value (Figures 1, 2). For those results, no statistically significant difference was found in the range 200-300W microwave power and 30-50°C temperature for mass loss of osmodehydrated apples (Table 1).

Water content

WC in raw apples was about 5.6 gH_2O/g d.m., but in samples after a short time of osmotic dehydration (15 min) at 30 and 50°C water content was 30-38% lower and 48-57% lower after longer dehydration time (60 min) (Figures 3, 4). There was a statistically significant influence of microwave pretreatment (not including microwave power), time and temperature of osmotic dehydration of apples on their water content (Table 1).

As a result of microwave application as a pretreatment before osmotic dehydration of apples water content decreased by 14-20% at 200W and 18-28% at 300W of microwave power in comparison with the non-pretreated samples (Figures 3). Moreover, there was no significant influence of microwave power between 200 and 300W on water content (Table 1).

Water loss

WL from apples expressed as water content per initial dry matter content of the sample increased with increasing dehydration time and temperature (Figures 5, 6). A statistically significant influence of the applied osmotic parameters and microwave pretreatment on water loss from apples was found (Tables 1). Water loss from samples after 15 min of osmosis was 1.0-1.3 gH_2O/g i.d.m. at 30-50°C and 1.8-2.2 gH_2O/g i.d.m. after 60 min.

The influence of microwave heating as a pretreatment on water loss was similar to mass loss. Regardless of temperature, lower microwave power (200W) caused the lowest water loss from apples after a short time of dehydration (15 min), whereas after a longer time (60 min) the lowest value of *WL* was obtained by higher microwave power (300W). Again a statistically significant influence of microwave power on water loss from osmodehydrated apples was not found (Table 1).

In apples treated with 200W microwave power water loss was 40-46% less after 15 min of osmotic dehydration and only 14-17% less in the samples after 60 min of dehydration than untreated samples at the same temperature (Figures 5, 6). However, using higher microwave power of 300W caused a 15-28% lower difference between microwave treated and non-

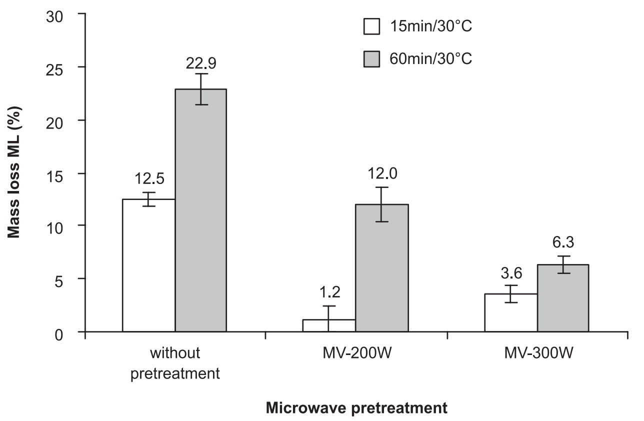

FIGURE 1. The influence of microwave pretreatment on mass loss *ML* from osmodehydrated apples in glucose solution at 30°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

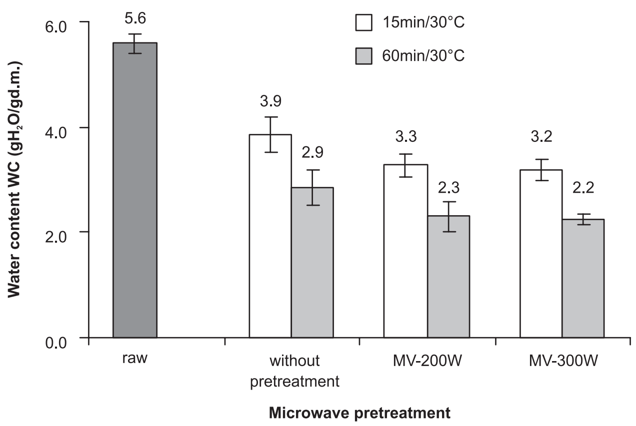

FIGURE 3. The influence of microwave pretreatment on water content *WC* in osmodehydrated apples in glucose solution at 30°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

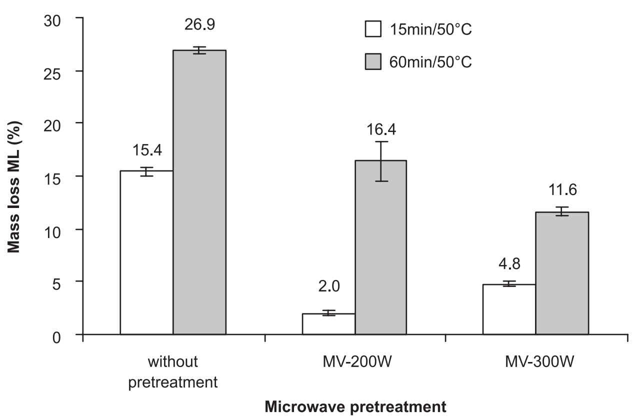

FIGURE 2. The influence of microwave pretreatment on mass loss *ML* from osmodehydrated apples in glucose solution at 50°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

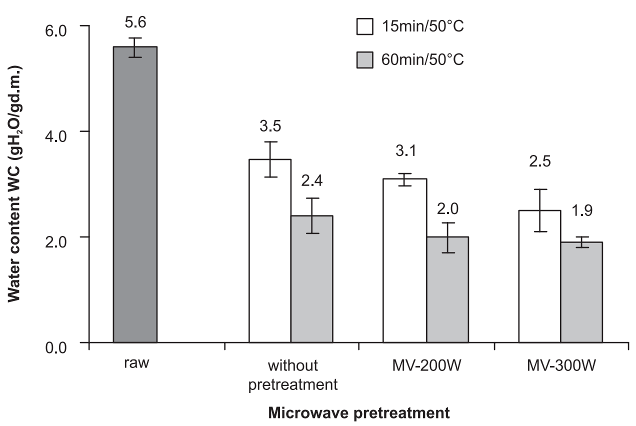

FIGURE 4. The influence of microwave pretreatment on water content *WC* in osmodehydrated apples in glucose solution at 50°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

treated samples, independently of process time and temperature (Figures 5, 6).

There was noticed an influence of microwave pretreatment on osmotic dehydration of apples as statistically significant water removal from samples, as well as a significant effect on water activity A_w in the investigated apples, but that effect was not found when 200W microwave power as a pretreatment was used (Table 1, Figure 7).

Kowalska *et al.* [in press] showed that after pretreatment (blanching / freezing) water loss from raw and blanched pumpkin proceeded similarly with no statistically significant differences, but freezing before osmotic dehydration showed 2-3 times less water loss from pumpkin than from other samples.

Osmotic dehydration reduced water content and caused penetration of sugar (solids gain) into dehydrated material. Application of microwave pretreatment caused more intensive solids gain *SG* to osmodehydrated apples (Figures 8, 9). The influence of microwave heating before osmotic dehydra-

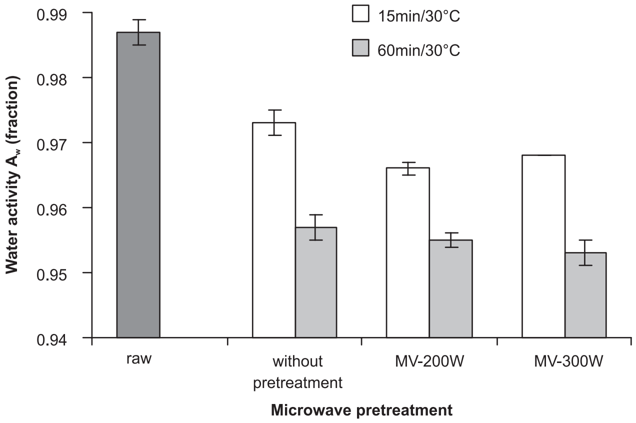

FIGURE 7. The influence of microwave pretreatment on water activity A_w of osmodehydrated apples in glucose solution at 50°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

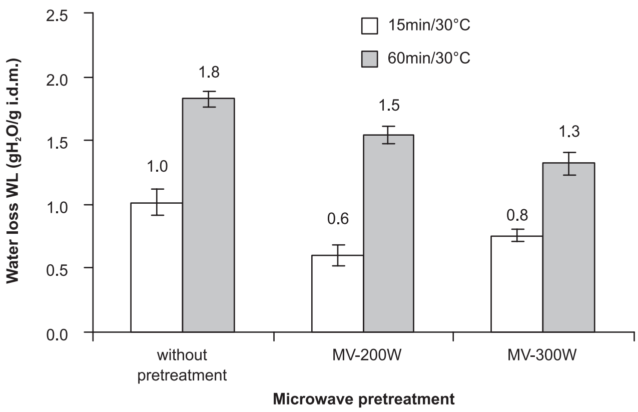

FIGURE 5. The influence of microwave pretreatment on water loss *WL* from osmodehydrated apples in glucose solution at 30°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

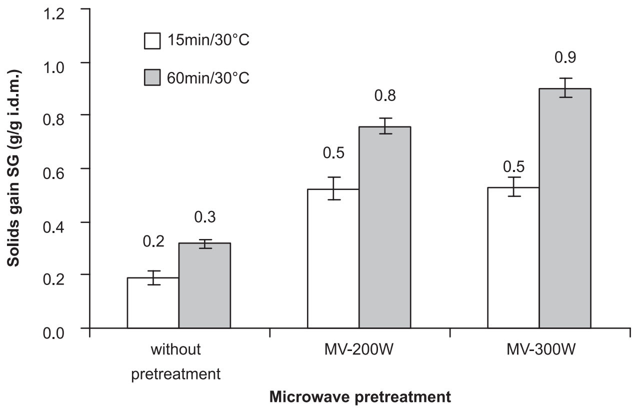

FIGURE 8. The influence of microwave pretreatment on solids gain *SG* in osmodehydrated apples in glucose solution at 30°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

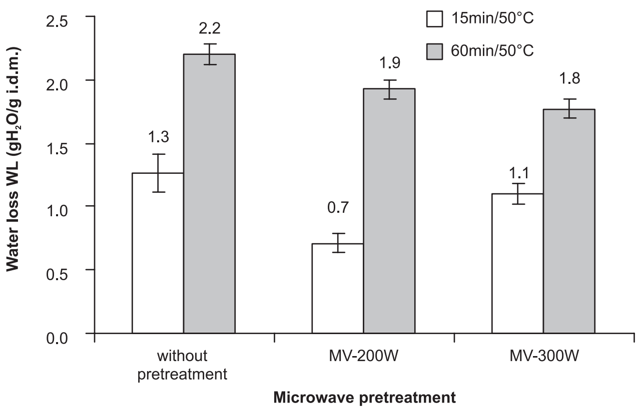

FIGURE 6. The influence of microwave pretreatment on water loss *WL* from osmodehydrated apples in glucose solution at 50°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

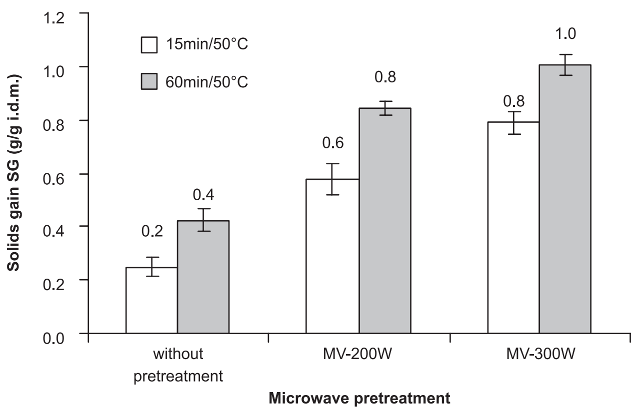

FIGURE 9. The influence of microwave pretreatment on solids gain *SG* in osmodehydrated apples in glucose solution at 50°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

tion and osmotic parameters on solids gain in apples was statistically significant (Table 1). The highest effect of microwave pretreatment on solids gain in osmodehydrated apples was observed. While apples osmotically dehydrated for 15 min at 30°C temperature without pretreatment obtained solids gain of 0.19 g/g i.d.m., in microwave-treated samples *SG* was nearly 3 times higher (Figure 8). In this case, a significant influence of microwave power value on solids gain in apples was found. In other cases statistically significant influences of microwave power value were noticed. Moreover, in apples exposed to microwave treatment solids gain increased with extension of process time, higher temperature value and higher microwave power value (15 min, 30°C) (Figures 8, 9). The lowest solids gain value in apples was obtained by applying 60 min time and 50°C temperature of osmotic process (0.42 g i.d.m.), whereas in apples treated with 200 and 300 W microwave power solids gain amounted to 0.84 and 1.00 g i.d.m. (Figure 8).

In Wang's study papaya, guava and sweet potato strips (3x3x0.5cm^3) were heated by microwave (480 or 800W for 6-15 min) before osmotic dehydration. The microwave pretreatment caused a strong increase of sugar uptake of papaya from 23 to 29Brix during the first 3 h of soaking, while 4 and 1Brix increment were found for guava and sweet potato, respectively. Data showed no significant difference in water activity or hardness. Final products from microwave pretreatment were found to be brighter than traditional ones; less oxidation/browning could be the reason. The osmotic dehydration rate could be increased up to 5 to 34% by microwave pretreatment. Quality of final products showed no significant difference, which indicates that microwave pretreatment could save processing time without sacrificing product's quality.

This resulted from the fact that the microwave-treated apples had a much more open structure, which entails easier penetration of osmoactive substances than into raw fruits. Comparing water loss to solids gain ratio *WL/SG* it can be observed that water loss increases much more when apples were not microwave treated before osmotic dehydration (Figures 10, 11). After 15 min of osmotic dehydration at 30 and 50°C the *WL/SG* ratio in apples obtained a value of about 5.2, but when microwave pretreatment was used, *WL/SG* was in the range between 1.2 and 1.4 (Figures 10, 11). When longer time of dehydration was applied, *WL/SG* was only insignificantly higher and amounted to 1.5-2.3 (Figures 10, 11).

Pereira *et al*. [2007] affirmed that increasing microwave power during the final drying of banana slices increased the drying rate and consequently decreased drying time. In the case of osmotic dehydration of apples, microwave pretreatment increased the efficiency of mass transfer in investigated apples. Microwave treatment before osmotic dehydration of apples had a positive effect on solids gain and process time; thus it would be a significant factor in predicting mass transfer in food material.

Microwave pretreatment before osmotic dehydration caused slightly more darkness of apples in comparison with the non-treated samples (Figure 12), but the difference was not statistically significant (Table 1). The lightness coefficient *L* of raw apples was about 76. Osmotic dehydration for 15 min at 30 and 50°C caused a slight decrease of thatcoefficient in apples (2-3%). Similarly, in comparison with raw apples, insig-

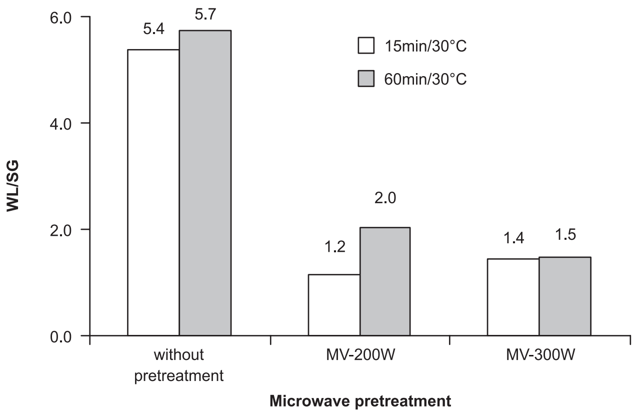

FIGURE 10. The influence of microwave pretreatment on water loss to solids gain ratio WL/SG in os-modehydrated apples in glucose solution at 30°C temperature. MV-200W – means 200W micro-wave power, MV-300W – means 300W microwave power.

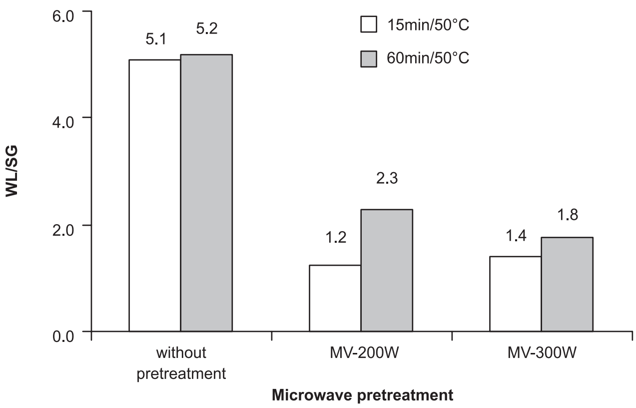

FIGURE 11. The influence of microwave pretreatment on water loss to solids gain ratio WL/SG in os-modehydrated apples in glucose solution at 50°C temperature. MV-200W – means 200W micro-wave power, MV-300W – means 300W microwave power.

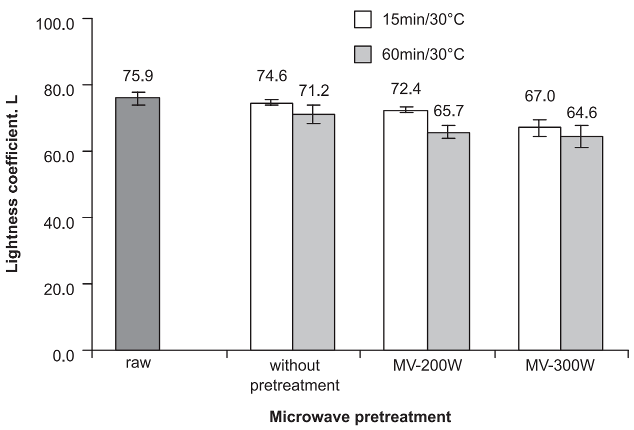

FIGURE 12. The influence of microwave pretreatment on coefficient of lightness L in osmodehydrated apples in glucose solution at 30°C temperature. MV-200W – means 200W microwave power, MV-300W – means 300W microwave power.

nificantly smaller *L* coefficient was obtained after longer time of dehydration (60 min). It ranged from 3 to 8%. Osmodehydrated apples treated by microwave heating showed a 5-17% lower lightness coefficient than the non-pretreated samples.

Pereira *et al.* [2007] showed that higher microwave power also caused temperature runaway leading to charring of the dried product, but no effects on the colour of the dried banana were observed.

CONCLUSIONS

An influence of microwave heating on mass transfer in osmodehydrated apples was found. Osmotic dehydration causes partial water removal. It could be applied to produce minimally-processed food or as a pretreatment before drying or freezing.

Mass loss from microwave-heated apples was 3-10 times lower than for osmodehydrated samples without treatment. Water content of osmodehydrated apples with microwave pretreatment was 14-28% lower than for the non-treated samples. Apples exposed to microwave treatment were characterised by a water loss to solids gain ratio 2-5 times smaller than for apples without pretreatment.

In most cases, especially for water removal, there was not noticed a statistically significant influence of microwave power value on water loss during osmotic dehydration of apples. Therefore it is more advantageous to apply a lower microwave power (200W).

Microwave heating before osmotic dehydration of apples can be useful in controlled mass transfer during osmotic dehydration to obtain a lower water loss to solids gain ratio as a cause of much higher solids gain.

ACKNOWLEDGEMENTS

This work was supported by the Polish Scientific Committee. MNiSW. Under grant No. N N312 0351 33 in the years 2007-2010.

REFERENCES

1. Contreras C., Martin M. E., Martinez-Navarrete N., Chiralt A., Effect of vacuum impregnation and microwave application on structural changes which occurred during air-drying of apple. LWT-Food Sci. Technol., 2005, 38, 471-477.
2. Escriche I., Chiralt A., Moreno J. Serra J.A., Influence of Blanching-osmotic Dehydration Treatments on Volatile Fraction of Strawberries. Food Chem. Toxicol., 2000, 65, 7, 1107-1111.
3. Funebo T., Ahrné L.M., Prothon F., Kidman S., Langton M., Skjoldebrand C., Microwave and convective dehydration of ethanol treated and frozen apple-physical properties and drying kinetics. Int. J. Food Sci. Technol., 2002, 37, 603-614.
4. Janowicz M. Lenart A., Effect of osmotic dehydration on the course of convective drying of apples. Part 1 – Mass and heat exchange. Part 2 – Changes of physical properties. Inż. Roln., 2001, 12, 89-108 (in Polish).
5. Kowalska H., Minimalny-processed food – fruits and vegetables. Przem. Spoż., 2006, 6, 24-27, 31 (in Polish).
6. Kowalska H., Lenart A., Mass exchange during osmotic pretreatment of vegetables. J. Food Eng., 2001a, 49, 2-3, 137-140.
7. Kowalska H., Lenart A., Leszczyk D., The effect of blanching and freezing on osmotic dehydration of pumpkin. J Food Eng. (in press).
8. Lenart A., Łakomiec D., The newest directions of microwave applying in food industry. Przem. Spoż., 1992, 46, 11, 283–286 (in Polish).
9. Lenart A., Lewicki P.P., Fruits and vegetables saved by osmodehydrated way. Przem. Spoż., 1996, 50, 70-72 (in Polish).
10. Pereira N.R., Marsaioli A.Jr., Ahrne L.M., Effect of microwave power, air velocity and temperature on the final drying of osmotically dehydrated bananas. J. Food Eng., 2007, 81, 79-87.
11. Prothon F., Ahrné L. M., Funebo T. Kidman S., Maud L., Ingegerd S., Effects of combined osmotic and microwave dehydration of apple on texture, microstructure and rehydration characteristics. LWT-Food Sci.Technol., 2001, 34, 2, 95-10.
12. Piotrowski D., Lenart A., Wardzyński A., Influence of osmotic dehydration on microwave-convective drying of frozen strawberries. J. Food Eng., 2004, 65, 519-25.
13. Raghavan G. S. V., Silveira A.M., Shrinkage characteristics of strawberries osmotically dehydrated in combination with microwave drying. Drying Technol., 2001, 19.2, 405-414.
14. Torringa E., Esveld E., Scheewe I., van den Berg R., Bartels P., Osmotic dehydration as a pre-treatment before combined microwave-hot-air drying of mushrooms. J. Food Eng., 2001, 49, 185--191.
15. Venkatchalapathy K., Raghavan G. S.V., Combined osmotic and microwave drying of strawberries. Drying Technol., 1999, 17, 4/5, 837-853.
16. Wang W. C., Improving the effectiveness of osmotic dehydration by microwave pretreatment. (Abstract), 2001 IFT Annual Meeting – New Orleans, Louisiana.
17. Zhang M., Tang J., Mujumdar A.S., Wang S., Trends in microwave related drying of fruits and vegetables. Trends Food Sci. Technol., 2006, 17, 524-534.

WPŁYW OGRZEWANIA MIKROFALOWEGO NA WYMIANĘ MASY W JABŁKACH ODWADNIANYCH OSMOTYCZNIE

Hanna Kowalska, Katarzyna Domurat, Andrzej Lenart

Katedra Inżynierii Żywności i Organizacji Produkcji, Wydział Technologii Żywności, Szkoła Główna Gospodarstwa Wiejskiego, Warszawa

Celem pracy była analiza wpływu wstępnego ogrzewania mikrofalowego na wymianę masy w odwadnianych osmotycznie jabłkach. Próbki w kształcie kostek o boku 10mm były wstępnie podsuszane przy zastosowaniu mikrofal o mocy 200 i 300W przez 10 min, a następnie odwadniane osmotycznie w roztworze glukozy o stężeniu 49,5%. Czas odwadniania osmotycznego jabłek wynosił 15 i 30 min a temperatura 30 i 50°C.

Wstępne ogrzewanie mikrofalowe wpływa na wymianę masy w odwadnianych osmotycznie jabłkach. Ubytki masy z jabłek wstępnie podsuszanych mikrofalowo i odwadnianych osmotycznie były o 50-90% mniejsze w porównaniu z jabłkami odwadnianymi bez stosowania mikrofal. Natomiast większemu obniżeniu uległa zawartość wody, o 15-28%, przy 15-45% mniejszych ubytkach wody. W największym stopniu zastosowanie mikrofal miało wpływ na przyrost masy suchej substancji, który był 2-3-krotnie większy w porównaniu z jabłkami odwadnianymi bez wstępnego podsuszania. Ponadto stosunek ubytku wody do przyrostu masy suchej substancji był 2-5 krotnie mniejszy w jabłkach poddanych wstępnej obróbce mikrofalowej. Zastosowanie mikrofal wpłynęło na nieznaczne ciemnienie jabłek w porównaniu z próbkami poddanymi tylko odwadnianiu osmotycznemu.