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Evaluation of mass transfer kinetics and efficiency of osmotic dehydration of pork meat

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Abstract. In order to analyse mass transfer kinetics during osmotic dehydration, pork meat (*M. triceps brachii*) was dehydrated in three different osmotic solutions (sugar beet molasses, ternary solution and the combination of these solutions in a 1:1 ratio) under atmospheric pressure, at room temperature (20 °C), with and without manual stirring in every 15 minutes. The aim was to examine the influence of different osmotic solutions, immersion time and mixing on the mass transfer kinetics of water and solids, and the efficiency of osmotic treatment. The most significant kinetic parameters of the process, water loss-WL, solid gain-SG, weight reduction-WR, rate of water loss-RWL, rate of solid gain-RSG, rate of weight reduction-RWR and dehydration efficiency index-EI, were determined after 1, 3 and 5 hours of dehydration. Better results

Keywords and phrases: osmotic dehydration, pork meat, mass transfer kinetic, sugar beet molasses, ternary osmotic solution.

were obtained by performing the process with stirring. According to the results, all three solutions are satisfying osmotic agents and the diffusion occurred most rapidly during the first 3 hours of the process.

1 Introduction

The osmotic dehydration (OD) process is an important method for preserving solid food, which involves partial water removal from food stuff immersed in hypertonic aqueous solutions. Due to low energy consumption and mild temperatures, which is considered minimal processing, OD is suitable as a pretreatment for many processes to improve nutritional, sensorial and functional properties of food without changing its integrity (*Vieira et al.*, 2012; *Manivann et al.*, 2011; *Bellary et al.*, 2011; *Mavroudis et al.*, 1998; *Moreno et al.*, 2011). The difference in the chemical potential of water between the raw material and the osmotic medium is the driving force for dehydration. During this process, three types of mass transfer in counter-current flux take place: water loss from the sample to the solution, solute transference from solution to the sample and natural solute flux from sample to osmotic solution, which is quantitatively negligible compared to the other two, but it is significant for the final product quality. The existence of these simultaneous and opposite fluxes is one of the major difficulties in modelling osmotic dehydration kinetics (*Moreira et al.*, 2008; *Koprivca et al.*, 2010; *Mercali et al.*, 2010). Working temperature, concentration of osmotic solution and immersing time are the most important variables in the osmotic process. Increasing the osmotic solution concentration induces an increase in the mass transfer (*Ferrari et al.*, 2011; *Corrêa et al.*, 2010; *Silva et al.*, 2012). Great influence on the kinetics of water removal and solid gain has the type of osmotic agent. Ternary aqueous solutions containing salt and sugar are usually used as osmotic agents for meat dehydration (*Damez et al.*, 2008; *El-Aouar et al.*, 2006). Research has shown that sugar beet molasses represents an excellent osmotic medium for dehydration process, primarily due to the high content of dry matter (80%), which provides high osmotic pressure in the solution as well as the specific chemical composition characterized by high contents of vitamins, minerals, antioxidants and betaine (*Šušić et al.*, 1989; *Kowalska et al.*, 1998; *Mišljenović et al.*, 2009). Meat treatments by soaking in concentrated solutions allow the elimination of sequenced operations of salting and dehydration that are commonly practised in traditional meat processing by dehydrating the product and impregnating it with solutes, commonly with salt, in only one operation step (*Santchurn et al.*, 2007). Water content in meat has a major impact on its physicochemical, sensorial and technological properties. In meat, water is held in myofibrils, functional organelles, but also it may exist in the intracellular space between myofibrils and sarcoplasm. The water content in meat depends on many factors, including the tissue itself and how the product is handled (time, temperature, treatments) (*Barat et al.*, 2009). The knowledge of the kinetics of water and salt transfers during the processing is of great technological importance because it allows estimating the immersion time of meat cuts in an osmotic solution to obtain products with determined salt and moisture contents (*Schmidt et al.*, 2009). The aim of this work was to examine the influence of different types of osmotic solutions, immersion time and agitation on the efficiency of the osmotic dehydration process of pork meat. The most important kinetics parameters and the rate of mass transfer were defined.

2 Materials and methods

Experimental circumstances

Pork meat (*M. triceps brachii*) was purchased at the local butcher shop in Novi Sad, shortly before use. The initial moisture content of the fresh meat was $74.64 \pm 0.48\%$. Prior to the osmotic treatment, fresh meat was cut into cubes of nearly $1 \times 1 \times 1$ cm dimension. Three different solutions were used as hypertonic mediums. The first one, the ternary osmotic solution, was made from sucrose in the quantity of 1,200 g/kg water, NaCl in the quantity of 350 g/kg water and distilled water (in further text indicated as solution 1). The second osmotic solution was the combination of the first and third in a 1:1 ratio (in further text indicated as solution 2). The third, sugar beet molasses, with an initial dry matter content of 80.00%, was obtained from the sugar factory Pećinci, Serbia (in further text indicated as solution 3). The material to solution ratio was 1:5 (w/w). Dehydration was performed at room temperature (20 °C) with and without stirring in every 15 minutes under atmospheric pressure. Samples from all three solutions after 1, 3 and 5 were taken out to be lightly washed and gently blotted to remove excess water. The dry matter content of the fresh and treated samples was determined by drying at 105 °C for 24 hrs in a heat chamber (Instrumentaria Sutjeska, Serbia) until reaching a constant weight. All analytical measurements were carried out in accordance with *AOAC* (2000). In order to follow the mass transfer kinetics of the OD, three key process variables were measured: moisture content, change in weight and change in the soluble solids. Considering water loss (WL), weight reduction (WR) and solid gain (SG), the rate of water loss (RWL), rate of solid gain (RSG), rate of weight reduction (RWR) and the dehydration efficiency index (EI) were calculated as described by *Koprivica et al.*, 2010. The analysis of variance (ANOVA) was performed using StatSoft Statistica, for Windows, ver. 10 programme.

3 Results and discussion

Table 1. shows average values and standard deviations of dry matter content in the samples of pork meat during OD with and without agitation in every 15 minutes, as a function of different type of osmotic solution and dehydration time. Along with changes in dry matter content, changes in kinetic parameters occurred and they are shown as well in Table 1. The increase of immersion time during the process resulted in increased dry matter content in pork meat samples and the higher values were obtained when the process was performed with agitation. The highest value was obtained in solution 2 after five hours of immersion ($60.08 \pm 0.09\%$) with agitation, while the highest value when the process was performed without agitation was achieved in solution 3 after five hours ($58.01 \pm 0.53\%$). ANOVA showed that for DMC, WL and WR values there was no significant statistical difference between the values of the meat dehydrated in solutions 1, 2 and 3. There was a significant statistical difference between the values of the meat samples dehydrated for 1, 3 and 5 hours and between the values of the meat samples when the process was performed with and without agitation. This indicates that time and agitation have a significant influence, while the nature of the osmotic solution does not have a significant influence on the DMC, WL and WR of the meat samples. The agitation of the osmotic medium recovers the thick diffusion layer of water that diffused from the meat cube into the osmotic medium (*Filipović et al.*, 2012). As a consequence of the process, the weight of meat samples was reduced. The samples' weight was more reduced when the process was performed with agitation. The highest values of WR parameter were obtained after 5 hrs in solution 3, when the process was performed with (0.3922 ± 0.0366 g/g initial sample weight (in future text: i.s.w.)) and without agitation (0.3271 ± 0.0425 g/g i.s.w.). SG value shows the degree of penetration of solids from hypertonic solution into the meat samples (Koprivica et al., 2009). SG, during the osmotic dehydration of pork meat, showed a tendency to increase with increasing the immersion time. The lowest value of SG parameter after five hours of process was obtained in samples dehydrated in solution 2 (0.2641 ± 0.0011 g/g i.s.w.) when the process was performed with agitation.

Table 1: Average values and standard deviations of dry matter content and the kinetic parameters during the osmotic dehydration of pork meat without and with agitation

Type of osmotic solution	Time (h)	DMC, % dry matter content	WR, g/g initial sample weight	SG, g/g initial sample weight	WL, g/g initial sample weight	EI-dehydration efficiency index
Osmotic dehydration without agitation						
	1	42.36 ± 0.72^{a}	0.1518 ± 0.0180^{a}	0.2187 ± 0.0122^{a}	0.2585 ± 0.0061^{a}	1.1822 ± 0.0381^{a}
Solution 1	3	51.89 ± 0.44^{b}	0.2692 ± 0.0233^{b}	0.2660 ± 0.0064^{b}	0.3978 ± 0.0032^{b}	1.4952 ± 0.0238^{b}
	5	52.88 ± 0.11^{c}	0.2753 ± 0.0339^{c}	0.2713 ± 0.0017^{c}	0.4074 ± 0.0008^{b}	1.5020 ± 0.0061^{b}
	1	44.08 ± 0.28^{a}	0.1789 ± 0.0035^{a}	0.2063 ± 0.0045^{a}	0.2858 ± 0.0023^{a}	1.3854 ± 0.0195^{c}
Solution 2	3	52.43 ± 1.99^{b}	0.2677 ± 0.0083^{b}	0.2767 ± 0.0293^{c}	0.4013 ± 0.0148^{b}	1.449 ± 0.1006^{d}
	5	58.62 ± 0.64^{c}	0.3006 ± 0.0085^{c}	0.3322 ± 0.0089^{d}	0.4615 ± 0.0045^{c}	1.3892 ± 0.0239^{c}
	1	43.06 ± 1.24^{a}	0.1908 ± 0.0145^{a}	0.2006 ± 0.02003^{a}	0.2872 ± 0.0101^{a}	1.4318 ± 0.0932^{d}
Solution 3	3	52.89 ± 0.96^{b}	0.2758 ± 0.0316^{b}	0.2791 ± 0.0139^{d}	0.4094 ± 0.0071^{b}	1.4667 ± 0.0481^{b}
	5	58.01 ± 0.53^{c}	0.3271 ± 0.0425^{c}	0.2788 ± 0.0071^{b}	0.4651 ± 0.0035^{c}	1.6686 ± 0.0297^{e}
Osmotic dehydration with agitation						
	1	42.53 ± 0.09^{d}	0.1802 ± 0.0191^{d}	0.2158 ± 0.0015^{a}	0.2864 ± 0.0007^{a}	1.3268 ± 0.0058^{f}
Solution 1	3	50.90 ± 2.63^{e}	0.2995 ± 0.0012^{e}	0.2152 ± 0.0369^{a}	0.4105 ± 0.0183^{b}	1.9081 ± 0.2458^{g}
	5	57.03 ± 0.95^{f}	0.3321 ± 0.0179^{f}	0.2894 ± 0.0127^{e}	0.4731 ± 0.0064^{c}	1.6349 ± 0.0498^{e}
	1	43.27 ± 0.11^{d}	0.2057 ± 0.0084^{d}	0.2120 ± 0.0017^{a}	0.3082 ± 0.0008^{a}	1.4413 ± 0.0074^{d}
Solution 2	3	52.73 ± 0.57^{e}	0.3325 ± 0.0057^{e}	0.2138 ± 0.0076^{a}	0.4401 ± 0.0038^{b}	2.0757 ± 0.0566^{h}
	5	60.08 ± 0.09^{f}	0.3801 ± 0.0187^{f}	0.2641 ± 0.0011^{b}	0.5108 ± 0.0005^{d}	1.9339 ± 0.0059^{g}
	1	41.79 ± 0.60^{d}	0.2007 ± 0.0275^{d}	0.1749 ± 0.0097^{f}	0.2905 ± 0.0048^{a}	1.6614 ± 0.0644^{e}
Solution 3	3	51.83 ± 0.6236^{e}	0.3443 ± 0.0046^{e}	0.1813 ± 0.0082^{f}	0.4383 ± 0.0041^{b}	2.4175 ± 0.0867^{j}
	5	59.93 ± 2.3930^{f}	0.3922 ± 0.0366^{f}	0.2675 ± 0.0291^{c}	0.5199 ± 0.0147^{d}	1.9432 ± 0.1571^{g}

^{abcdefghj} Different letters in the superscript in the same column indicate significant statistical difference between the values at a level of significance $p < 0.05$.

The values of the SG parameter were slightly higher when the process was performed without agitation (the lowest value after five hours was 0.2713 ± 0.0017 g/g i.s.w. for samples dehydrated in solution 1).

ANOVA showed that there was a significant statistical difference between the values of SG of the meat dehydrated in solutions 1, 2 and 3. Also, there was a significant statistical difference between the values of SG of the meat samples dehydrated for 1, 3 and 5 hours. However, there was no significant statistical difference between the values of SG in meat when the process was performed with and without agitation, except for meat samples dehydrated in solution 3 for 1 and 3 hours with agitation. This indicates that time and the nature of the osmotic solution have a significant influence on the SG of the meat samples while agitation does not have a significant influence. The amount of the solute penetration from the osmotic solution into the sample can be reduced by applying starch edible coatings (*Mišljenović et al.*, 2009). Increasing the dehydration time causes a greater water loss of the meat samples. The highest WL values were noticed in samples dehydrated for 5 hrs in solution 3 (with agitation 0.5199 ± 0.0147 g/g i.s.w. and without agitation 0.4651 ± 0.0035 g/g i.s.w.). The value of EI (WL/SG ratio) is the most important indicator of the effectiveness of the OD process (*Lević et al.*, 2007). In general, the increased concentration of the osmotic medium favours the diffusion of solids into the sample, which leads to decline in the value of EI. This ratio is considered to best predict the efficiency of the osmotic treatment. High EI ratios point to intensive water removal from the samples accompanied with minimal solid gain. In contrast, low EI are associated with an increased diffusion of solute to the sample with minimal water removal, which is unacceptable considering the purpose of the dehydration process. By changing the process variables (temperature, concentration and time), one tends towards finding the optimal conditions under which the process is most efficient (maximum EI). According to results in tables 1 and 2, OD treatment is more effective when the process is performed with agitation. The highest value of EI (2.4175 ± 0.0867) was achieved by using sugar beet molasses as osmotic solution after 3 hrs of treatment performed with agitation.

ANOVA showed that process time, the type of osmotic solution and agitation have a significant influence on the EI of the meat samples.

Tables 2 and 3 show the mass transfer rate during the osmotic dehydration with and without agitation, respectively, as a function of the immersion time and type of osmotic solution. According to the obtained results, osmotic dehydration was the most intensive at the beginning of the process.

Table 2: Mass transfer rate during the osmotic dehydration of pork meat without agitation

Type of osmotic solution	Time (h)	RWL g/(gi.s.w.·s)·10^5	RSG (gi.s.w.·s)·10^5	RWR (gi.s.w.·s)·10^5
	1	7.1817	6.0748	4.2181
Solution 1	3	3.6835	2.4636	2.4927
	5	2.2639	1.5070	1.5297
	1	7.9395	5.7310	4.9703
Solution 2	3	3.7155	2.5625	2.4783
	5	2.5642	1.8458	1.6703
	1	7.9793	5.5729	5.2992
Solution 3	3	3.7906	2.5845	2.5536
	5	2.5842	1.5487	1.8175

Table 3: Mass transfer rate during the osmotic dehydration of pork meat with agitation

Type of osmotic solution	Time (h)	RWL g/(gi.s.w.·s)·10^5	RSG (gi.s.w.·s)·10^5	RWR (gi.s.w.·s)·10^5
	1	7.9550	5.9957	5.0047
Solution 1	3	3.8014	1.9923	2.7735
	5	2.6283	1.6076	1.8449
	1	8.5612	5.9399	5.7134
Solution 2	3	4.0752	1.9632	3.0799
	5	2.8380	1.4675	2.1119
	1	8.0705	4.8576	5.5745
Solution 3	3	4.0584	1.6788	3.1876
	5	2.8882	1.4863	2.1788

Higher values of mass transfer rate were obtained when the process was performed with agitation, due to the already mentioned recovering of the thick diffusion layer of water. In this way, the forming of the concentration gradient in solution is avoided. The rate of mass reduction, the rate of water loss and the rate of solid gain were the highest during the first hour of the process. Mass transfer rate decreased continuously from the first to the third hour and, after the third hour, it showed a tendency of slowing down. The mass transfer rate was slightly more intensive when meat samples were immersed in solution 3, due to greater difference between the osmotic pressures of the hypertonic medium and the animal tissue.

Based upon the presented results, it can be concluded that all three solutions are satisfying osmotic mediums. The process was more efficient when it was performed with agitation due to the better homogenization of the osmotic medium. The best results regarding dry matter content were achieved using solutions 2 and 3. At the end of the treatment, the solid gain values were the lowest in samples immersed in solutions 1 and 2. However, the best results considering water loss, weight reduction and dehydration efficiency index were achieved using sugar beet molasses as osmotic agent, which is economical, considering that molasses is a by-product of sugar industry. During the osmotic dehydration of pork meat, in all three osmotic solutions, the water removing process was the most intensive at the beginning and, after 3 hours, it had a tendency of slowing down; therefore, processing time can be limited to 3 hours.

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References

[1] AOAC (2000). Official Methods of Analysis. Washington, USA.

[2] J. Barat, M. Alino, A. Fuentes, R. Grau, J. B. Romero, Measurement of pork meat brining. *J. Food Eng.*, 93. (2009) 108–113.

[3] A. N. Bellary, H. B. Sowbhagya, N. K. Rastogi, Osmotic dehydration assisted impregnation of curcuminoids in coconut slices. *J. Food Eng.*, 105. 3 (2011) 453–459.

[4] J. L. G., Corrêa, L. M., Pereira, G. S., Vieira, M. D., Hubinger. Mass transfer kinetics of pulsed vacuum osmotic dehydration of guavas. *J. Food Eng.*, 96. (2010) 498–504.

[5] J. L. Damez, S. Clerjon, Meat quality assessment using biophysical methods related to meat structure. *Meat Sci.*, 80. (2008) 132–149.

[6] A. A. El-Aouar, P. M. Azoubel, Jr. J. L. Barbosa, F. E. X. Murr, Influence of the osmotic agent on the osmotic dehydration of papaya (*Carica Papaya L.*). *J. Food Eng.* 75. (2006) 267–274.

[7] C. C. Ferrari, J. R. Arballo, R. H. Mascheroni, M. D. Hubinge, Modelling of mass transfer and texture evaluation during osmotic dehydration of melon under vacuum. *Int. J. Food Sci.* Tech., 46. (2011) 436–443.

[8] V. S. Filipović, B. Lj. Ćurčsić, M. R. Nićetin, D. V. Plavšić, G. B. Koprivica, N. M. Mišljenović, Mass transfer and microbiological profile of pork meat dehydrated in two different osmotic solutions. *Hem. Ind.*, 66. 5. (2012) 743–748.

[9] G. Koprivca, N. Mišljenović, Lj. Lević, L. Jevrić, Mass transfer kinetics during osmotic dehydration of plum in sugar beet molasses. *PTEP*. 14. (2010) 27–31.

[10] G. Koprivca, N. Mišljenović, Lj. Lević, V. Pribiš, Changes in nutritive and textural quality of apple osmodehydrated in sugar beet molasses and saccharose solutions, *APTEFF*. 40. (2009) 35–46.

[11] H. Kowalska, A. Lenart, Mass transfer during osmotic dehydration of plant tissue. In: Proceedings of the IX seminar, Properties of Water in Food, (1998) 131–142.

[12] Lj. Lević, V. Filipović, T. Kuljanin, Osmotski tretman oblikovanog korena mrkve u saharozi i melasi. *PTEP*. 11. 3. (2007) 131–142.

[13] P. Manivannan, M. Rajasimman, Optimization of process parameters for the osmotic dehydration of beet root in sugar solution. *J. Food Eng.*, 34. (2011) 804–825.

[14] E. N. Mavroudis, V. Gekas, I. Sjöholm, Osmotic dehydration of apples – effects of agitation and raw material characteristics. *J. Food Eng.*, 35. (1998) 191–209.

[15] G. D. Mercali, I. C. Tessaro, C. P. Z. Noren, L. D. F. Marczak, Original article mass transfer kinetics during osmotic dehydration of bananas (*Musa sapientum, shum*). *Int. J. Food Sci. Tech.*, 45. (2010) 2281–2289.

[16] N. Mišljenović, G. Koprivica, Lj. Lević, B. Filipčev, T. Kuljanin, Osmotic dehydration of red cabbage in sugar beet molasses-mass transfer kinetics. *APTEFF*, 40. (2009) 145–154.

[17] N. Mišljenović, G. Koprivica, L. Pezo, T. Kuljanin, M. Bodroža-Solarov, B. Filipčev, Application of Peleg model to study mass transfer during osmotic dehydration of apple in sugar beet molasses. *APTEFF*, 42. (2011) 91–100.

[18] R. Moreira, F. Chenlo, N. Vallejo, L. Gerbet, Mass transfer analysis during osmotic dehydration of eggplant using binary solutions of sucrose and sodium chloride, *Defect Diffus. Forum*, 273–276. (2008) 413–418.

[19] J. Moreno, R. Simpson, M. Sayas, I. Segira, O. Aldana, S. Almonacid, Influence of ohmic heating and vacuum impregnation on the osmotic dehydration kinetics and microstructure of pears (cv. Packham's Triumph), *J. Food Eng.*, 104. 4. (2011) 621–627.

[20] S. J. Santchurn, A. Collignan, G. Trystram, Impact of solute molecular mass and molality, and solution viscosity on mass transfer during immersion of meat in a complex solution. *J. Food Eng.*, 78. 4. (2007) 1188–1201.

[21] F. C. Schmidt, B. A. M. Carciofi, J. B. Laurindo, Application of diffusive and empirical models to hydration, dehydration and salt gain during osmotic treatment of chicken breast cuts. *J. Food Eng.*, 91. (2009) 553–559.

[22] M. S. A. Silva, Z. E. Silva, V. C. Mariani, S. Darche, Mass transfer during the osmotic dehydration of West Indian cherry. *Food Sci. Technol.*, 45. (2012) 246–252.

[23] S. Šušić, V. Sinobad, Istraživanja u cilju unapredenja industrije šećera Jugoslavije. *Hem. Ind.*, 43. 1–2. (1989) 10–21.

[24] G. S. Vieira, L. M. Pereira, M. D. Hubinger, Optimization of osmotic dehydration process of guavas by response surface methodology and desirability function. *Int. J. Food Sci. Tech.*, 47. (2012) 132–140.