



MODELING OF MUSHROOMS (*AGARICUS BISPORUS*) OSMOTIC DEHYDRATION PROCESS IN SUGAR BEET MOLASSES

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Abstract: Mushrooms (*Agaricus bisporus*) were osmotically dehydrated in sugar beet molasses solutions at concentrations of 60%, 70% and 80%_{d.m.}, at operating temperatures of 25 °C, 35 °C and 45 °C during 0.5h, 1h, 1.5h, 2h, 3h, and 5 hours. Moisture content, water activity (a_w), microbiological parameters (total plate counts, *Enterobacteriaceae*, total yeasts and moulds count) and content of mineral elements (potassium, magnesium, iron and calcium) were determined in the osmodehydrated mushroom samples. Response surface methodology and analysis of variance were selected to estimate the main effects of the process variables (temperature, time, concentration) on process performance and selected mushroom attributes (microbiological counts, chemical composition and mineral content). Increase in the values of applied osmotic process parameters led to the significant increase in the content of minerals (for example, an increase in K and Ca content by 269.42% and 939.03%, respectively) and a decrease in a_w values (from 0.941 to 0.811), decrease in microbiological load and relative protein content (decrease by 33.07%), indicating a possibility for prolonged shelf life and suitability for further processing. The osmodehydrated mushrooms could be considered as ingredients for new functional (semi)products due to improved nutritive profile.

Key words: mineral composition, water loss, solid gain, microbiological load, chemical composition

INTRODUCTION

Osmotic dehydration involves the immersion of a substrate (food) in a solution of high concentration, which partially dehydrates the food (Mújica-Paz, Valdez-Fragoso, Lopez-Malo, Palou & Welti-Chanes, 2003; Erle & Schubert, 2001). The driving force for water removal is the concentration gradient that is established on the opposite sides of the cell membrane.

This gradient causes two counter currents: dissolved substances of osmotic solution diffuse into the material being treated whilst water from the material flows into osmotic solution (Qiu, Zhang, Tang, Adhikari & Cao, 2019; Cieurzyńska, Kowalska, Czajkowska & Lenart, 2016; Ahmed, Qazi & Jamal, 2016). Water is removed by capillary forces and diffusion,

while counter current leaching and solute uptake are transmitted by diffusion (Shi & Xue, 2009; Rahman & Perera, 2007). Both flows depend on the cellular structure and membrane permeability (Fernandes, Gallão & Rodrigues, 2009; Amami et al. 2007).

Products with reduced water content are obtained by osmotic dehydration. They are classified as partially preserved (minimally processed) products of high quality with prolonged shelf life (Silva, Fernandes & Mauro, 2014). Intermediate moisture foods (IMF) are gaining in importance in widespread use because their characteristics are similar to fresh food products but shelf life is extended (Qiu, Zhang, Tang, Adhikari & Cao, 2019). If a fresh appearance of a dehydrated product is required, the effect of dehydration must be at least 30%, which makes such products moderately stable and could be further processed (dried, frozen or treated with additives) (Khan, 2012; Phisut, 2012) in the dairy, bakery or confectionery industries.

Choice regarding proper osmotic solution is important factor for successful dehydration, and this decision is mainly influenced by the water loss/solid gain ratio. In the case of osmotic solution with lower concentration - the components penetrate in deeper layers of the treated material (Rodrigues & Mauro, 2004), while higher osmotic solution concentrations lead to faster water loss (Waliszewski, Delgado & Garcia, 2002). The osmotic solution must have a low value of water activity (a_w), an acceptable sensory quality and must achieve food safety requirements. Potential solutions are sucrose, glucose, NaCl, corn syrup, starch concentrates, etc., which are selected according to the dehydrated product properties (Ahmed, Qazi & Jamal, 2016). Alternative osmotic solutions, such as maple syrup, high fructose corn syrup, honey, ethanol, etc., have been attracting more attention due to high dehydration rates, optimal rehydration capacity, and negligible sensory effect on the substrate (Qiu, Zhang, Tang, Adhikari & Cao, 2019).

During osmotic dehydration, simultaneously with the diffusion of water from the tissue into the surrounding solution there is an antidote diffusion of dissolved substances from the osmotic solution into the surface layers of the treated material (Rastogi & Raghavarao, 2004; Chiralt & Fito, 2003). Sugar beet molasses has

been recognized as suitable osmotic solution due to its exceptional and complex chemical and nutritional composition. Molasses is an important by-product of sugar beet/sugar cane refining industry, remaining after no more sugar can be extracted by crystallization from the raw crop (Šarić et al., 2016). Cane and beet molasses are viscous polycomponent systems with a high dry matter content (around 80%) and are significant source of many micronutrients (in the dissolved state), especially potassium, calcium, iron, magnesium and the vitamin B complex (Sauvant, Perez & Tran, 2004). From a nutritional point of view, sugar beet molasses significantly enriches the content that is dehydrated in terms of minerals and vitamins (Cvetković et al., 2019; Lončar et al., 2015; Nićetin et al., 2015a; Nićetin et al., 2015b). Some investigations were conducted using sugar beet molasses as osmotic solution for dehydration of plant origin food (Knežević et al., 2019; Nićetin et al., 2017; Koprivica, Pezo, Čurčić, Lević & Šuput, 2014; Mišljenović, Koprivica, Jevrić & Lević, 2011) and animal origin food (Šuput et al., 2019; Čurčić, Pezo, Filipović, Nićetin & Knežević, 2015; Filipović et al., 2014).

In previous works, mushrooms were osmotically pretreated/treated with different solutions: sucrose, citric acid, but mostly NaCl solution (González-Pérez et al., 2019; Darvishi, Azadbakht & Noralahi, 2018; Gupta, Bhat, Chauhan, Ahmed & Malik, 2015; Doymaz, 2014), at different process parameters (concentration, time, etc.). The aim of the study presented in this paper was to investigate and mathematically model the effects of varying processing parameters applied during the osmotic dehydration of mushrooms in sugar beet molasses on basic osmodehydration responses (water loss, solid gain, dry matter content), microbiological parameters, mineral and chemical composition of treated mushrooms.

MATERIALS AND METHODS

Sample preparation

Fresh mushrooms (*Agaricus bisporus*) were bought at a local greengrocery, after which their basic composition was determined, given in Supplementary material, Tables S1 and S2. Mushrooms were wiped with a damp cloth, cut into 5 mm-slices, after which they were immersed in sugar beet molasses diluted to the concentrations of 60%, 70% and 80% of dry

matter (d.m.). Basic composition of used sugar beet molasses is given in Table 1. The sample (mushroom slices) to osmotic solution (molasses) weight ratio was 1:5. The process was performed in laboratory jars at temperatures of 25, 35 and 45 °C under atmospheric pressure, in a constant temperature chamber (KMF 115 l, Binder, Germany). The samples were stirred every 15 minutes.

Processing conditions regarding stirring, intensity, duration and frequency were the same for all experimental runs, so the results could be comparable. Process duration was varied between process times of 0.5, 1, 1.5, 2, 3, and 5 hours. After dehydration treatment, the samples were rapidly rinsed with running water, absorbed from excess water and further processed for the required tests.

Table 1.
Sugar beet molasses basic composition

Composition	Content (% _{d.m.})
Proteins	24.43
Carbohydrates	26.22
Ash	9.17
	(mg/kg)
K	14 640
Ca	2 050
Mg	2420
Fe	47.2

Moisture content was determined at 105 °C until constant weight was achieved (according to AOAC, 2000).

Water activity values (a_w) were determined on a TESTO 650 water activity tester (Testo, Inc., 40 White Lake Rd, Sparta, NJ, USA) with a special probe with an accuracy of ± 0.001 at 25 °C.

Microbiological counts

Determination of total plate counts (TPC) was performed according to ISO 4833:2013.

The determination of *Enterobacteriaceae* was determined according to ISO 21528-2:2017.

The determination of the total yeasts and moulds count (TYMC) was made according to the ISO 21527-2: 2008.

Content of mineral elements

Content of potassium (K), magnesium (Mg), iron (Fe) and calcium (Ca) was performed according to ISO 6869:2000.

Calculations

Osmotic dehydration process responses of dry matter content (DMC), water loss (WL) and solid gain (SG) were calculated and presented as mean values and standard deviation of three parallel runs:

$$DMC = \frac{m_d}{m_i} \cdot 100 \% \quad (1)$$

$$WL = \frac{m_i z_i - m_f z_f}{m_i} \left[\frac{g}{g_{initialsample(i.s.)}} \right] \quad (2)$$

$$SG = \frac{m_f s_f - m_i s_i}{m_i} \left[\frac{g}{g_{i.s.}} \right] \quad (3)$$

where m_d , m_i and m_f are dry matter, initial and final samples mass (g), respectively; z_i and z_f are the initial and final water fraction mass (g_{water}/g_{sample}), respectively; s_i and s_f are the initial and final total solids fraction mass ($g_{total\ solids}/g_{sample}$), respectively.

Response Surface Methodology

Response Surface Methodology (RSM) and Analysis of Variance (ANOVA) were selected to estimate the main effects of the process variables on osmodehydration process, microbiological, and compositional responses during osmotic dehydration of mushroom samples.

The independent variables were process time (X_1), process temperature (X_2) and concentration of molasses as an osmotic solution (X_3). The dependent variables observed were osmotic dehydration responses: DMC (Y_1), WL (Y_2), SG (Y_3), a_w (Y_4); microbiological responses: TPC (Y_5), TYMC (Y_6); mineral responses: K (Y_7), Mg (Y_8), Ca (Y_9), Fe (Y_{10}) and chemical responses: Proteins (Y_{11}), Sugars (Y_{12}) and Ash (Y_{13}).

Models were fitted to the response surface generated by the experiment. The model used was function of the variables:

$$Y_k = f_k(\text{time, temperature, concentration}) \quad (4)$$

The following second order polynomial (SOP) model was fitted to the data. Thirteen models of the following form were developed to relate thirteen responses (Y) to three process variables (X):

$$Y_k = \beta_{k0} + \sum_{i=1}^3 \beta_{ki} X_i + \sum_{i=1}^3 \beta_{kii} X_i^2 + \sum_{i=1}^2 \sum_{j=i+1}^3 \beta_{kij} X_i X_j, k=1-13; \quad (5)$$

where β_{kij} are constant regression coefficients.

ANOVA and RSM were performed using StatSoft Statistica, for Windows, ver. 12 program. The model was obtained for each dependent variable (or response) where factors were rejected when their significance level was less than 95%.

RESULTS AND DISCUSSION

Analysis of the osmotic dehydration process responses

The untreated, raw mushrooms were characterized by DMC and a_w values of $8.51 \pm 0.31\%$ and 0.941 ± 0.04 , respectively. Supplementary material, Table S1 displays the results obtained for the four osmotic dehydration process responses (DMC, WL, SG, a_w) that adequately represent the osmotic process. The maximal obtained values were: $58.33 \pm 1.11\%$, 0.7953 ± 0.0158 g/g_{i.s.}, 0.1009 ± 0.0016 g/g_{i.s.} and 0.811 ± 0.008 for DMC, WL, SG and a_w , respectively. The osmodehydrated mushroom sample with the highest levels of DMC, WL and SG, and lowest level of a_w , indicating the most intensive mass transfer during the process, was obtained at the highest levels of applied technological parameters (process time of 5 hours, process temperature of 45 °C and molasses concentration of 80%).

By analysing the statistically significant difference between the values of different process time and constant process temperature and molasses concentration, it can be concluded that the effect of the process time had statistically significant influence on all four osmotic dehydration process parameters (for example, comparing significance level of runs no. from 49 to 54, at $p < 0.05$, see in Supplementary material, Table S1). This result harmonises with the findings from other similar studies which reported that the increase in immersion time led to higher moisture loss (Ispir & Toğrul, 2009; Mundada, Hathan & Maske, 2011). Figure 1 shows changes in DMC, WL, SG and a_w during 5-h osmotic dehydration.

During osmodehydration, substrate is in contact with osmotic medium, which has high osmotic pressure and mass transfer is established with respect to time. As time is longer – osmodehydration effect is higher with respect to the

evaluated process parameters (DMC, WL, SG). It was noted that the initial process period is the most important, since mass transfer phenomena are the fastest and have highest impact on further osmodehydration flow. Studies showed that exchange of masses occurred at a fastest rate within the initial 2 h followed by a reduction in drying rate during further processing time (Ramaswamy, 2005).

From the result presented in Supplementary material, Table S1 it can be seen that the temperature statistically significantly affected mass transfer in the process, manifested via statistically significant increase in DMC, WL and SG values and statistically significant decrease of a_w values. Findings related to the osmodehydration of mushrooms in molasses are similar to those from other works which reported that temperature affects the rate of osmotic mass transfer (Tortoe, 2010) and that rise in process temperature accelerates water loss, while solid uptake is less affected (Khan, 2012; Tortoe, 2010). As in cases of the two previously analysed technology parameters, the effect of molasses concentration was also statistically significant on all four osmotic dehydration process responses, where the increase in the concentration of molasses solution significantly raised the values of the three responses (DMC, WL and SG), while a_w significantly decreased. Other studies reported similar findings (Ispir & Toğrul, 2009; Falade, Igbeka & Ayanwuyi, 2007). The higher concentration of osmotic solution leads to greater osmotic pressure gradients, thereby leading to higher solid gain and water loss throughout the osmotic treatment period (Mundada, Hathan & Maske, 2011).

Effect on microbiological characteristics of the treated mushrooms

The fresh mushroom samples were characterized by log₁₀ (CFU/g) values of: $5.54 \pm 1.33 \times 10^{-2}$; $3.36 \pm 1.67 \times 10^{-2}$ and $4.64 \pm 1.11 \times 10^{-2}$ for TPC, TYMC and *Enterobacteriaceae*, respectively, (Supplementary material, Table S2). The highest reduction of present microorganisms and the lowest values of TPC and TYMC (log₁₀ (CFU/g) of $4.25 \pm 1.43 \times 10^{-2}$ and $2.99 \pm 8.82 \times 10^{-2}$, respectively) are obtained at the highest levels of

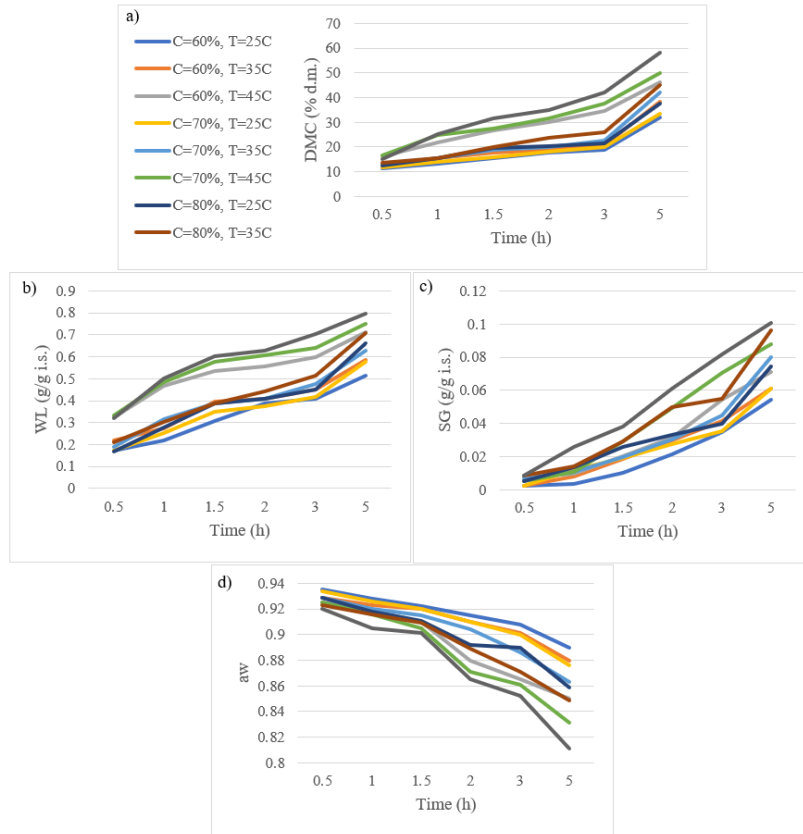


Figure 1. Dry matter content (DMC), water loss (WL), solid gain (SG) and a_w changes in mushrooms during osmotic dehydration in sugar beet molasses

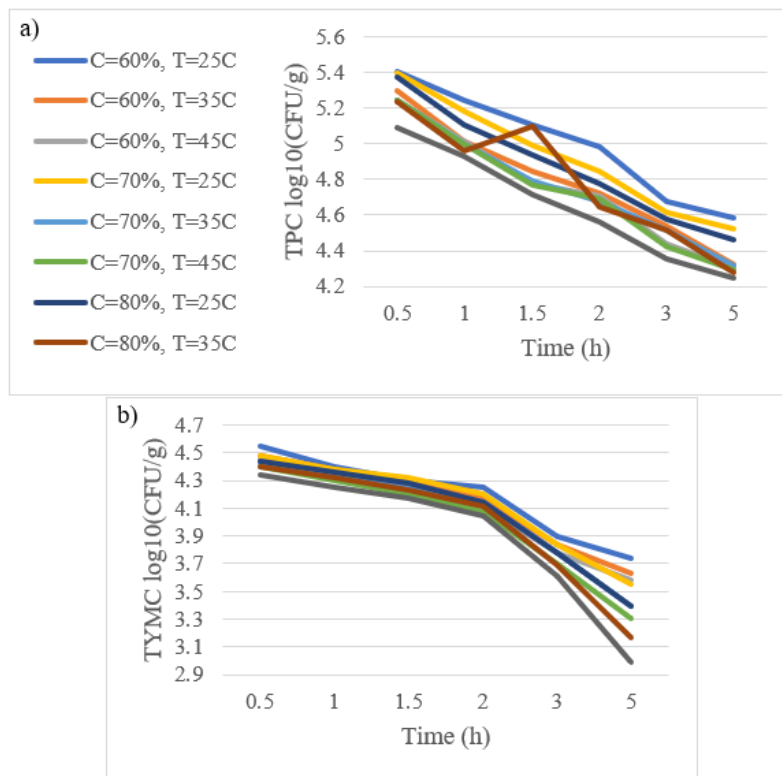


Figure 2. Changes in total plate counts (TPC) and total yeasts and moulds count (TYMC) of mushrooms during osmotic dehydration in sugar beet molasses

applied technological parameters. Values of *Enterobacteriaceae* were reduced to $<1.00 \log_{10}$ (CFU/g) in all osmodehydrated samples, regardless of applied technological parameters. The effect of the process duration had statistically significant influence on the TPC and TYMC \log_{10} (CFU/g) values, where prolonged duration of the osmotic dehydration process led to higher reduction of present microorganisms. An increase in process temperature significantly decreased TPC and TYMC. The effect of molasses concentration exerted also significant effect on both TPC and TYMC in such a way that an increase in the molasses concentration caused a significant decrease in TPC and TYMC. Prolonged duration of osmotic dehydration has led to the longer exposure of selected microorganisms to high osmotic pressure environment of osmotic solutions. Higher values of temperature and molasses concentration has led to the intensified mass transfer of the process, and reduced a_w value. As a consequence, the treated samples provided unfavourable conditions for the growth and development of the tested microorganisms. Studies on the effect of osmotic dehydration parameters on pork and chicken meat microbiological profiles showed similar results (Filipović et al. 2019; Filipović et al., 2012).

Regarding microbiological safety, the osmodehydrated mushrooms are not ready-to-eat products so they are not covered by the ordinance of Commission Regulation (EC) 2073/2005. According to the other legal acts, such as the national regulation on sanitary requirements during food processing and trading (Pravilnik o opštim i posebnim uslovima higijene hrane u bilo kojoj fazi proizvodnje, prerade i prometa (2010)) it could be concluded that the detection of low number of *Enterobacteriaceae* in the mushrooms dehydrated in molasses indicates satisfactory hygiene of the production process.

Effect on the chemical composition and mineral content in the treated mushrooms

The fresh mushroom samples contained 3312.53 ± 79.64 ; 185.36 ± 5.76 ; 90.43 ± 5.46 ; 23.53 ± 0.22 and mg/kg_{d.m.} K, Ca, Mg, and Fe, respectively and 24.43 ± 0.57 ; 26.22 ± 0.35 and 9.17 ± 0.18 %_{d.m.} proteins, sugars and ash, respectively (Supplementary material, Tables S3 and S4).

Osmotic dehydration process, through increasing solid matter of dehydrating samples (Rastogi & Raghavarao, 2004; Chiralt & Fito, 2003), statistically significantly affected the amounts of all tested minerals and chemical parameters. There was a statistically significant increase in K, Ca, Mg, Fe, sugars and ash contents as well as a significant decrease in protein content (comparing the significance level of run no. 0 with any other dehydrated sample, except the samples dehydrated during 0.5h, at $p < 0.05$, Supplementary material, Tables S3 and S4). Figures 3 and 4 depicts the changes in the content of minerals and proximal chemical composition of treated mushrooms during the osmotic dehydration in molasses. Increase in the content of minerals is a direct consequence of solid matter uptake from molasses which is abundant in these components. A decrease in the osmodehydrated mushrooms protein content is a result of non-protein solid matter uptake (molasses is not a protein source), resulting in a relative decrease of dry matter protein content, although absolute quantities of mushrooms protein contents did not change during the osmotic dehydration process.

The concentrations of minerals and chemical parameters in the mushrooms treated at the applied highest levels of processing parameters (5-hour process duration, at 45 °C, in 80% molasses) were the following: 8917.78 ± 152.90 , 1241.23 ± 4.06 , 1105.08 ± 13.182 and 35.02 ± 0.73 mg/kg for K, Mg, Ca and Fe, respectively, and 16.35 ± 0.19 , 38.49 ± 0.34 and 10.39 ± 0.18 % for protein, sugar and ash contents, respectively.

The effects of individual process parameters on mineral and chemical responses are the same as in the case of basic osmotic dehydration process parameters, since process mass transfer mechanisms are leading to compositional changes of the dehydrating samples. Individual increase of process time, temperature and molasses concentration has led to the statistically significant increase of minerals, sugars and ash, and a significant decrease of protein content. These results are in correlation with previously reported results on mineral and chemical composition of osmodehydrated fish (Lončar et al., 2015), pork meat (Nićetin et al., 2015b) and wild garlic (Šobot et al., 2019).

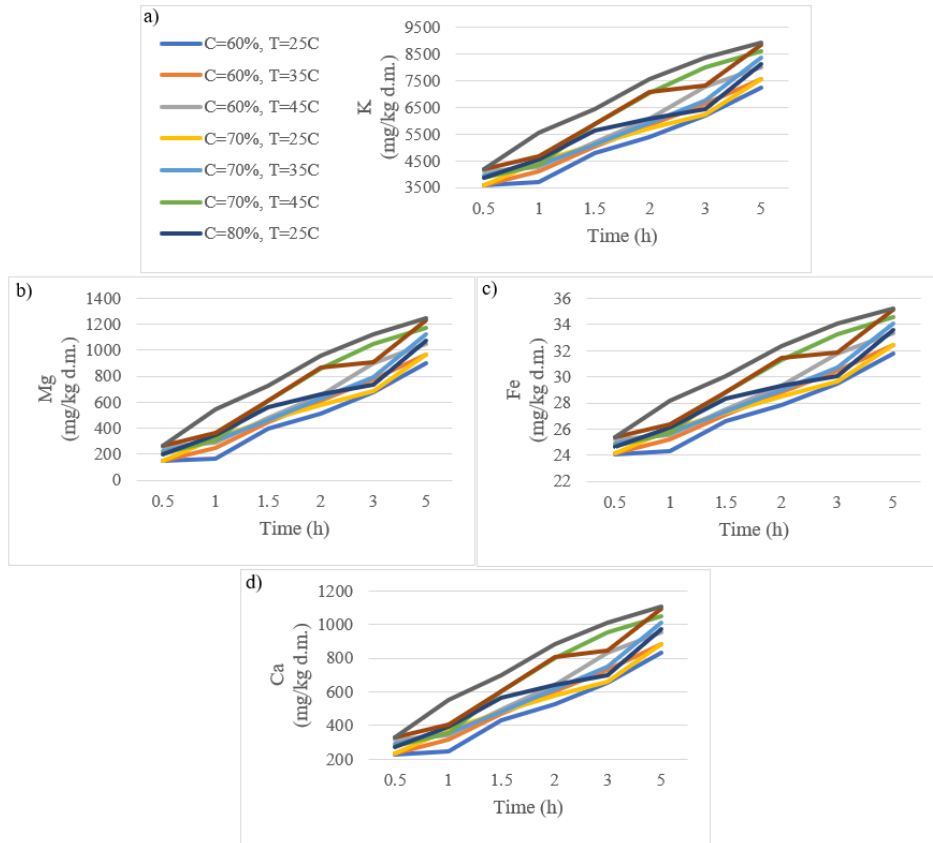


Figure 3. Uptake of minerals (K, Ca, Mg and Fe) in mushrooms during osmotic dehydration in sugar beet molasses

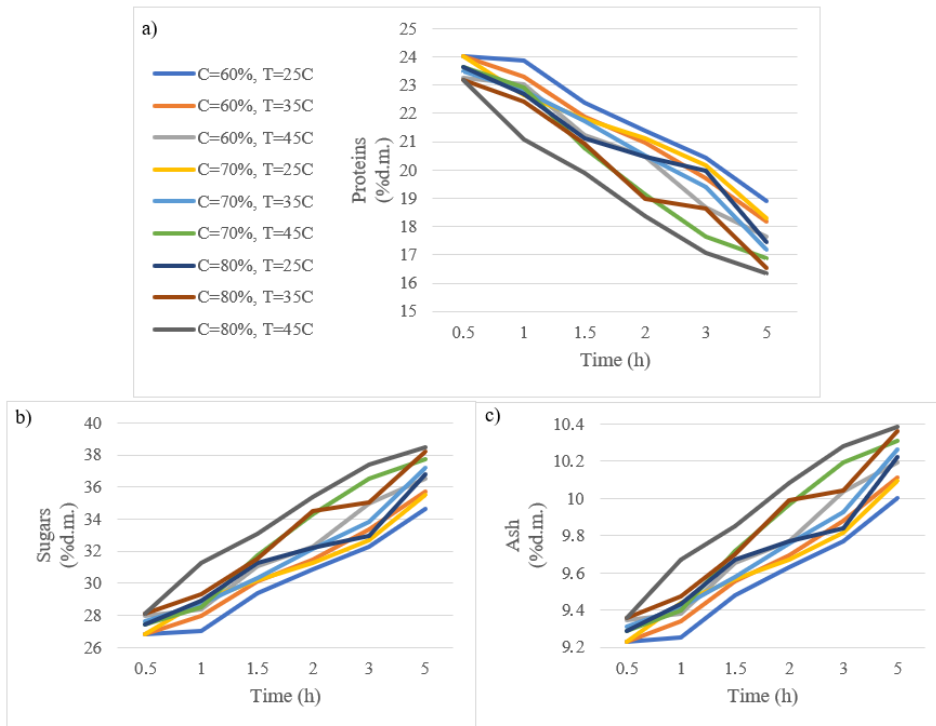


Figure 4. Changes in proximal chemical composition of mushrooms during osmotic dehydration in sugar beet molasses

Table 2.
Variance analysis of the model for the osmotic dehydration process responses

Technological parameters	Term	df ⁺	Sum of squares			
			DMC	WL	SG	a _w
Time	Linear	1	4377.736*	0.900677*	0.031284*	0.031313*
	Quadratic	1	9.752	0.052920*	0.000349*	0.000541*
Temperature	Linear	1	1522.139*	0.310866*	0.003132*	0.007109*
	Quadratic	1	133.521*	0.037826*	0.000000	0.000367*
Concentration	Linear	1	182.165*	0.033919*	0.002897*	0.003183*
	Quadratic	1	3.728	0.000155	0.000003	0.000038
Cross product	Time x Temperature	1	141.004*	0.000372	0.000525*	0.001543*
	Time x Concentration	1	50.149*	0.011242*	0.000422*	0.000732*
	Temperature x Concentration	1	7.611	0.000003	0.000053	0.000001
	Residual variance	44	195.494	0.051955	0.001439	0.001378
	Total sum of squares	53	6494.416	1.421158	0.038857	0.043641
R ²			0.9699	0.9634	0.96296	0.96841

*Statistically significant at significance level of $p < 0.05$
df⁺ - degrees of freedom

Increasing the temperature, process duration and molasses concentration solid gain increases that affects the chemical and nutritional composition of the final product. The driving force for osmotic water removal is the concentration gradient established on opposite sides of the cell membrane. During dehydration, two counter current flows take place: water from the material passes into osmotic solution, while the dissolved substances of the osmotic solution diffuse into the material to be treated (Rodrigues and Mauro, 2004). Molasses concentration, regarding rich chemical and nutrient composition, contributes to substrate enrichment during osmotic dehydration.

Analysis of the mathematical models for mass transfer during osmotic dehydration

Table 2 shows ANOVA results of the response surface models which were calculated from the osmodehydration process responses (DMC, WL, SG, a_w) at different time, temperature and molasses concentration. ANOVA testing showed that all four responses were statistically significantly influenced by all three technological parameters, where the parameter with the highest influence was duration, followed by temperature and molasses concentration. In all four mathematical models of osmodehydration process responses, all three linear terms (for time, temperature and concentration) were statistically significant. Statistically significant model members are marked with * in Table 2. Quadratic term for time statistically significantly contributed to the model forming of WL, SG and a_w, in-

dicating that exchange of masses occurred at a faster rate at the initial phase of the process followed by a reduction in drying rate during further processing time (Ramaswamy, 2005).

In the case of quadratic term for temperature, it was statistically significant for DMC, WL and a_w.

Interaction of time and concentration was significant in cases of all four responses, while the cross product Time x Temperature was significant in cases of: DMC, SG and a_w.

Residual variance was not statistically significant in any of four tested mathematical models, and together with high values of coefficient of correlation (R²) pointed that the applied models adequately represented variation in osmotic process responses within the range of applied technological parameters.

Analysis of the mathematical models for microbiological counts

ANOVA results of the response surface models calculated from the recorded microbiological responses are shown in Table 3. Response for *Enterobacteriaceae* were not modelled, since there was not enough variation between the experimental results. ANOVA testing showed that both modelled responses (TPC and TYMC) were statistically significantly influenced by all three technological parameters, where the most influential parameter was time, followed by temperature and the least influential molasses concentration. The increase in immersion time, pro-

cess temperature and osmotic solution concentration lead to higher and accelerated moisture

loss until equilibrium level is achieved (Mundada et al., 2011; Khan, 2012; Tortoe, 2010).

Table 3.
Variance analysis of the model for changes in the microbiological responses

Technological parameters	Term	df ⁺	Sum of squares	
			TPC	TYMC
Time	Linear	1	4.759147*	6.781457*
	Quadratic	1	0.584806*	0.008988
Temperature	Linear	1	0.401177*	0.193637*
	Quadratic	1	0.022711*	0.000083
Concentration	Linear	1	0.043333*	0.313438*
	Quadratic	1	0.000002	0.000052
Cross product	Time x Temperature	1	0.001275	0.033880*
	Time x Concentration	1	0.000005	0.154575*
	Temperature x Concentration	1	0.001295	0.004181
Linear	Residual variance	44	0.145756	0.162417
	Total sum of squares	53	5.800317	7.504803
R ²			0.97487	0.97836

*Statistically significant at significance level of $p < 0.05$
df⁺ - degrees of freedom

Table 4.
Variance analysis of the model for mineral composition

Technological parameters	Term	df ⁺	Sum of squares			
			K	Mg	Fe	Ca
Time	Linear	1	109780640*	4632787*	484.3570*	2979382*
	Quadratic	1	7593746*	321768*	34.2301*	206338*
Temperature	Linear	1	6848700*	286218*	32,9853*	185128*
	Quadratic	1	17144	721	0.0204	560
Concentration	Linear	1	6039284*	253727*	32.4158*	162932*
	Quadratic	1	59476	2821	0.1135	1666
Cross product	Time · Temperature	1	412475*	17289*	2.1359*	11239*
	Time · Concentration	1	127673	5334	0.6506	3329
	Temperature · Concentration	1	218477	9267	0.4653	5733
Linear	Residual variance	44	3998398	166226	19.6996	109882
	Total sum of squares	53	131522730	5545108	591.0625	3569327
R ²			0.9696	0.97002	0.9666	0.96221

*Statistically significant at significance level of $p < 0.05$
df⁺ - degrees of freedom

Table 5.
Variance analysis of the model for chemical composition responses

Technological parameters	Term	df ⁺	Sum of squares		
			Proteins	Sugars	Ash
Time	Linear	1	225.6559*	520.8845*	5.133447*
	Quadratic	1	15.8561*	36.6009*	0.360711*
Temperature	Linear	1	15.4544*	35.736*	0.351572
	Quadratic	1	0.0351	0.0810	0.000798
Concentration	Linear	1	12.3922*	28.6051*	0.281910*
	Quadratic	1	0.0823	0.1899	0.001872
Cross product	Time x Temperature	1	0.8952*	2.0664*	0.020364*
	Time x Concentration	1	0.3051	0.7043	0.006941
	Temperature x Concentration	1	0.2938	0.6782	0.006684
Linear	Residual variance	44	8.0342	18.5454	0.182770
	Total sum of squares	53	271.4764	626.6526	6.175817
R ²			0.97041	0.9643	0.9743

*Statistically significant at significance level of $p < 0.05$
df⁺ - degrees of freedom

All three linear terms (for time, temperature and concentration) were statistically significant in cases of both microbiological responses. Quadratic terms of time and temperature statistically significantly contributed to the TPC model forming. Cross products Time x Temperature and Time x Concentration were significant in the case of TYMC.

Residual variance was not statistically significant in both tested mathematical models, and together with high R^2 values showed that applied models adequately represented variations of microbiological profile responses.

Analysis of the mathematical models for responses related to mineral and chemical composition

Significant mineral enrichment and chemical composition change in the treated mushrooms is a consequence of previously explained mechanisms of solid gain upgrowth, owing to molasses favourable nutritional composition. Tables 4 and 5 shows the ANOVA results of the response surface models calculated for mineral and chemical composition, respectively.

The presented results show that all seven responses were influenced by all three technological parameters, in the following order of significance: time, temperature, concentration. In cases of all responses, linear terms of all three dehydration parameters were statistically significant. Quadratic term for time, together with cross product of Time x Temperature were also statistically significant in all cases. Residual variance was not statistically significant in any of the tested mathematical models. High R^2 values again indicated on good fit of proposed models to the minerals and chemical responses experimental data.

Mathematical models regression coefficients

Individual coefficients, which can be used for forming thirteen quadratic equations of models for selected responses (mass transfer parameters, microbiological counts, mineral and chemical composition), are shown in Supplementary material, Tables S5 and 6, along with their statistical significance. Using presented equations and knowing technological parameters of the process (time, temperature and molasses concentration), values of all selected responses at the determined process conditions

can be calculated. Data obtained from these models can be used for process and quality control and management of the osmotic dehydration of mushrooms in molasses.

CONCLUSIONS

From the presented results it can be concluded that osmotic dehydration of mushrooms in beet molasses and an increase in its intensity led to the significant increase in mass transfer kinetics, mineral uptake (for example, an increase in K content by 269.42%; and Ca content increase by 939.03%), changes in proximate chemical composition and a decrease in a_w values (from 0.941 to 0.811), microbiological load and relative protein content (33.07% decrease). The obtained osmodehydrated mushroom samples were characterized by high levels of DMC, low a_w values and favourable microbiological profile, indicating a good base for prolonged shelf life and further processing. Improved nutritive profile of osmodehydrated mushrooms owing mostly to prominent mineral enrichment due to transfer of minerals from molasses, suggest a possibility for production of new and functional products. The proposed mathematical models of changes in selected responses (mass transfer parameters, microbiological counts, mineral and chemical composition) were statistically significant, calculated and observed responses corresponded very well, indicating a satisfactory approximation of responses values within the applied technological parameters.

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SUPPORTING INFORMATION

Additional Supplementary material may be found in the online version of this article.

Table S1. Experimental data for osmotic dehydration mass transfer responses

DMC (%) - Dry matter content; WL (g/g_{i.s.}) - Water loss; SG (g/g_{i.s.}) - Solid gain; a_w - Water activity

Table S2. Experimental data for microbiological responses

TPC(log10(CFU/g)) - Total plate count; *Enterobacteriaceae* (log10(CFU/g)); TYMC (log10(CFU/g)) - Total yeasts and moulds count

Table S3. Experimental data for responses related to mineral composition

K, Mg, Ca and Fe content in mg/kg_{d.m.}

Table S4. Experimental data of chemical composition responses

Content of ash, sugars and proteins in %_{d.m.}

Table S5. Regression coefficients of SOP models for osmotic dehydration process and microbiological responses

Table S6. Regression coefficients of SOP models for minerals and chemical responses

МОДЕЛОВАЊЕ ПРОЦЕСА ОСМОТСКЕ ДЕХИДРАТАЦИЈЕ ПЕЧУРАКА (*AGARICUS BISPHORUS*) У МЕЛАСИ ШЕЋЕРНЕ РЕПЕ

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Сажетак: Печурке (*Agaricus bisporus*) су осмотски дехидриране у растворима меласе шећерне репе различитих концентрација (60%, 70% и 80%), на радним температурама од 25, 35 и 45 °C током 0,5, 1, 1,5, 2, 3 и 5 h. Садржај воде, активност воде (a_w), микробиолошки квалитет (укупан број бактерија, ентеробактерије, укупан број квасца и плесни) и садржај минералних материја (садржај калијума, калцијума, магнезијума и гвожђа) одређени су на добијеним узорцима осмотски дехидрираних печурака. Методи одзивних површина и анализе варијансе одабрани су да би се проценили главни ефекти процесних варијабли на микробиолошки квалитет, садржај минералних материја и хемијски састав осмотски дехидрираних печурака. Повећање вредности процесних параметара осмотске дехидратације довело је до значајног повећања садржаја минералних материја (на пример, пораст садржаја К за 269,42% и садржаја Са за 939,03%), а смањења вредности активности воде (са 0,941 на 0,811), микробиолошког оптерећења и релативног садржаја протеина (пад од 33,07%) у дехидрираним узорцима печурака, што указује на могућност продуженог рока трајања и погодности овако обрађених печурака за даљу обраду. Осмотски дехидриране печурке могу се сматрати новим функционалним (полу)производима, узимајући у обзир њихов побољшан нутритивни профил.

Кључне речи: минерални састав, губитак воде, прираст суве материје, микробиолошки квалитет, хемијски састав

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