TITLE: The effects of technological parameters on chicken meat osmotic dehydration process efficiency

AUTHORS: Ivana Filipović, Biljana Ćurčić, Vladimir Filipović, Milica Nićetin, Jelena Filipović, Violeta Knežević

NOTICE: This is the author's version of a work that was accepted for publication in *Journal of Food Processing and Preservation.* Changes resulting from the publishing process, such as peer review, editing, corrections, structural formatting, and other quality control mechanisms may not be reflected in this document. Changes may have been made to this work since it was submitted for publication. A definitive version was subsequently published in *Journal of Food Processing and Preservation*, Volume 41, Issue 1, 3rd of February 2017, Pages 1–7. DOI: 10.1111/jfpp.13116

THE EFFECTS OF TECHNOLOGICAL PARAMETERS ON CHICKEN MEAT OSMOTIC DEHYDRATION PROCESS EFFICIENCY

IVANA FILIPOVIĆ[1], BILJANA ĆURČIĆ[2], VLADIMIR FILIPOVIĆ[2,4], MILICA NIĆETIN[2], JELENA FILIPOVIĆ[3] and VIOLETA KNEŽEVIĆ[2]

[1]SP Laboratory, Indistrijska 3, Bečej 21220, Serbia
[2]University of Novi Sad, Faculty of Technology, Bul. Cara Lazara 1, Novi Sad 21000, Serbia
[3]University of Novi Sad, Institute for Food Technology, Bul. cara Lazara 1, Novi Sad 21000, Serbia

[4]Corresponding author.
TEL: +381214853708;
FAX: +38121450413;
EMAIL: vladaf@uns.ac.rs

Received for Publication January 15, 2016
Accepted for Publication May 18, 2016

doi:10.1111/jfpp.13116

ABSTRACT

Osmotic dehydration is important food preservation method because of many advantages considering mild processing temperature, base waste material and low energy requirements. The goal of this research was to investigate the effects of the process temperaute, time and osmotic solution concentration on the effectiveness of the chicken meat osmotic dehydration process in osmotic solution of sodium chloride and sucrose. Developed mathematical models had good fit with experimental data, while maximal obtained values of process responses of: dry matter content: 58.30 ± 0.22%; water loss: 0.4791 ± 0.0014 $g/g_{i.s.}$; solid gain: 0.1579 ± 0.0024 $g/g_{i.s.}$ and water activity: 0.800 ± 0.001; indicated on good dehydration levels and that applied osmotic solution is very good osmotic medium. Application of principal component analysis has provided better visualization in differentiation of the samples, while score analysis was used to point at optimal combination of technological parameters in effort to obtain best osmotic dehydration process results.

PRACTICAL APPLICATIONS

Process of osmotic dehydration is commonly used technique for food processing since its low energy requirements for water removal, minimal waste material and possibility of producing new types of food products from animal and plant raw matterials. This study investigates the effects of applied technological parameters on the process of osmotic dehydration of chicken meat. Developed mathematical models in this research can be considered as precise for process parameters prediction and optimization in experimental and industrial applications. The analysis of the osmotic dehydration process efficiency points at the optimal combination of applied technological parameters in effort to obtain best osmotic dehydration process results.

INTRODUCTION

The production of chicken meat has undergone remarkable growth in recent years and as a result of the growth in demand, meat producers began to diversify their products with a view to increasing the value and an increase in shelf life (Volpato *et al.* 2007).

Process of osmotic dehydration has been successfully used to remove water from food material and increase their storage stability. During osmotic dehydration process food samples are being placed in hypertonic solution, which creates a concentration gradient between the solution and the intracellular fluid. This driving force results in the removal of water from the food through semipermeable cellular membranes (Ozdemir *et al.* 2008; Knežević *et al.* 2013).

Osmotic dehydration is recognized as a pre-treatment step to meat drying processes such as air-drying, microwave or freeze-drying, to improve the nutritional, sensorial and functional properties of meats, reduce heat damage and minimize their color and flavor changes (Rastogi *et al.* 2002).

Osmotic dehydration is important food preservation method in food processing industry because of many advantages considering mild processing temperature, base waste material and low energy requirements (El-Aouar *et al.* 2006).

Many factors (the solute cost, organoleptic compatibility with the end product, additional preservation by the solutes) are considered when it comes to choosing the most suitable osmotic solution for the specific food material (Tortoe 2010). The most often used osmotic solutions are concentrated water solutions of sugar (sucrose, glucose, fructose and corn syrup) or sodium chloride (NaCl) (Singh *et al.* 2008; Ispir and Toğrul 2009). In comparison with the binary solution (water/NaCl), ternary solutions with added sugar to the NaCl and water have enchanced mass transfer potential and enable quick processing and high product dehydration. Due to its higher molecular weight, sugar diffusion is much slower than salt diffusion throught the product (Qi 1998; Collignan *et al.* 2001).

Response surface methodology (RSM) is an effective tool for optimizing a variety of food processes including osmotic dehydration (Azoubel and Murr 2008; Ozdemir *et al.* 2008; Singh *et al.* 2010).

The main advantage of RSM is reduced number of experimental runs that provide sufficient information for statistically valid results. The RSM equations describe effects of the test variables on the observed responses, determine test variables interrelationships and represent the combined effect of all test variables in the observed responses, enabling the experimenter to make efficient exploration of the process (Mišljenović *et al.* 2012).

The goal of this research was to investigate the effects of the process temperature, process time and osmotic solution concentration on the effectiveness of the chicken meat osmotic dehydration process. Measured responce values which were used to describe total efficiency of the osmotic process were: dry matter content (DMC), water loss (WL), solid gain (SG) and water activity.

MATERIALS AND METHODS

Raw skinless chicken breast was purchased at the lokal shop in Novi Sad, just before use. Before the osmotic treatment, whole muscle (24-h postmortem, with removed fat tissue) was cut into cubes, dimension 1 × 1 × 1 cm, and then homogenized before the samples were taken for the process.

Osmotic solution of sodium chloride and sucrose was made from commercial sucrose and NaCl in the quantities of 1,200 and 350 g/kg of distilled water, respectively (Qi 1998; Collignan *et al.* 2001).

Distilled water was used for dilution of osmotic solutions. The diluded osmotic solution concentrations were 45, 52.5 and 60% w/w. The sample to osmotic solution ratio was 1:5 (w/w). The process was performed in laboratory jars at the temperature of 20, 32 and 44C under atmospheric pressure, in constant temperature chamber (KMF 115 l, Binder, Germany). Meat samples were stirred every 15 min. Processing conditions regarding stirring, intesity, duration and frequency were the same for all concentrations of osmotic solutions at all temperatures, so the results could be comparable.

After 1, 3 and 5 h, the samples were taken out from osmotic solutions to be lightly washed with water and gently blotted to remove excessive water. DMCs of the fresh and treated samples, and osmotic solution were determined by drying at 105C in a heat chamber until constant mass was achived (Instrumentaria Sutjeska, Srbija). All analytical measurements were carried out in accordance to AOAC (2000).

Water activity (a_w) of the osmotic dehydrated samples was measured using a water activity measurement device (TESTO 650, Germany) with an accuracy of ±0.001 at 25C.

In order to describe the effectiveness of the mass transfer of the osmotic dehydration process, DMC, WL and SG were calculated for different temperatures, processing times and concentration of osmotic solutions and presented as mean values and standard deviation of three parallel runs:

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

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

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

where m_i and m_f are the initial and final mass (g) of the samples, respectively; z_i and z_f are the initial and final mass fraction of water (g water/g sample), respectively; s_i and s_f are the initial and final mass fraction of total solids (g total solids/g sample), respectively (Filipović *et al.* 2014a).

Response Surface Methodology

RSM and ANOVA were selected to estimate the main effect of the process variables on mass transfer variables during the osmotic dehydration of chicken meat samples. The accepted experimental design was according to Box and Behnken (1960). The independent variables were temperature (X_1) of 20, 32 and 44C, osmotic time (X_2) of 1, 3 and 5 h and concentration of osmotic solution (X_3) of 45%, 52.5% and 60%. The dependent variables observed were the responses: DMC (Y_1), WL (Y_2), SG (Y_3) and a_w (Y_4). A model was fitted to the response surface generated by the experiment. The model used was function of the variables:

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

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

$$Y_k = \beta_{k0} + \sum_{i=1}^{3} \beta_{ki} X_i + \sum_{i=1}^{3} \beta_{kii} X_i^2 + \sum_{i=1}^{2} \sum_{j=i+1}^{3} \beta_{kij} X_i X_j,\ k=1\text{–}4; \quad (5)$$

where β_{kij} are constant regression coefficients; Y, either DMC (Y_1), WL (Y_2), SG (Y_3) or a_w (Y_4); X_1, temperature, of the process; X_2, time of the process; X_3, concentration of the osmotic solution.

Analysis of variance (ANOVA) and RSM were performed using StatSoft Statistica, for Windows, ver. 10 program (Statistica 2010). The model was obtained for each dependent variable (or response) where factors were rejected when their significance level was less than 95%.

Principal component analysis (PCA), used as the pattern recognition technique, was applied within assay descriptors to characterize and differentiate various analyzed samples. The evaluations of ANOVA and PCA analyses of the obtained results were performed using StatSoft Statistica, ver. 10 software (Statistica 2010).

Score Analysis

Score analysis uses min-max normalization of osmotic dehydration responses and transfer them from their unit system in new dimensionless system which allows further mathematical calculation of different types of responses (Jayalakshmi and Santhakumaran 2011). Maximum value of normalized score present optimal values of responses (DMC, WL, SG and a_w), and point at optimal combination of used technological parameters of time and temperature of the process (Filipović *et al.* 2014b):

$$S_{1i} = \frac{(\text{DMC}_i - \text{DMC}_{\min})}{(\text{DMC}_{\max} - \text{DMC}_{\min})} \quad (6)$$

$$S_{2i} = \frac{(\text{WL}_i - \text{WL}_{\min})}{(\text{WL}_{\max} - \text{WL}_{\min})} \quad (7)$$

$$S_{3i} = 1 - \frac{(\text{SG}_i - \text{SG}_{\min})}{(\text{SG}_{\max} - \text{SG}_{\min})} \quad (8)$$

$$S_{4i} = 1 - \frac{(a_{wi} - a_{w\min})}{(a_{w\max} - a_{w\min})} \quad (9)$$

$$S_i = \frac{(S_{1i} + S_{2i} + S_{3i} + S_{4i})}{4} \quad (10)$$

$$\max[S_i] \rightarrow \textbf{optimum} \quad (11)$$

RESULTS AND DISCUSSION

In Table 1, mean values and standard deviations of the DMC, WL, SG and a_w as responses of the chicken meat osmotic dehydration process are shown. Temperature of the process was 20, 32 and 44C, time of the process ranged from 1 to 5 h, while concentration of the osmotic solution was set to 45%, 52.5% and 60%.

The highest values of DMC ($58.30 \pm 0.22\%$), WL (0.4791 ± 0.0014 g/g$_{\text{initial sample (i.s.)}}$), SG ($0.1579 \pm 0.0024$ g/g$_{\text{i.s.}}$) and the lowest a_w value (0.800 ± 0.001) were achieved at the end of 5-h process, at the highest temperature of 44C.

Osmotically dehydrated chicken meat have achieved similar process response values in comparison to the other osmotically dehydrated raw material of animal origin subjected to the similar process conditions (5-h process at 50C in the same osmotic solution of maximal concentration of 60%). Osmotically dehydrated chicken had achieved slightly better process response values than osmotically dehydrated silver crucian carp, with DMC of $52.907 \pm 0.355\%$; WL of 0.470 ± 0.004 g/g$_{\text{i.s.}}$; SG of 0.127 ± 0.000 g/g$_{\text{i.s.}}$ and a_w value of 0.887 ± 0.010 (Ćurčić *et al.* 2015; Lončar 2015). While, in comparison to the osmotically dehydrated pork meat, dehydrated chicken had achieved slightly lower process response values, since dehydrated pork meat had achieved DMC of $62.16 \pm 0.44\%$; WL of 0.4950 ± 0.0029 g/g$_{\text{i.s.}}$; SG of 0.1616 ± 0.0152 g/g$_{\text{i.s.}}$ and a_w value of 0.805 ± 0.016 (Filipović 2013).

The PCA allows a considerable reduction in a number of variables and the detection of structure in the relationship between measuring parameters and different osmodehydrated chicken meat samples that give complementary information (Otto 1999 and Fongaro and Kvaal 2013). The full auto scaled data matrix consisting of osmodehydrated chicken meat samples processed at temperatures of 20, 32 and 44C, during 1, 3 and 5 h of the process and in concentrations of osmotic solutions of 45%, 52.5% and 60% was submitted to PCA. For visualizing the data trends and for the discriminating efficiency of the used descriptors a scatter plot of samples using the first two principal components (PCs) from PCA of the data matrix was obtained (Fig. 1).

As can be seen, there was a neat separation of the 27 samples of osmotically dehydrated chicken meat at different technological parameters, according to osmotic dehydration process response values (DMC, WL, SG and a_w). Samples

TABLE 1. RESPONCE VALUES OF CHICKEN MEAT OSMOTIC DEHYDRATION PROCESS

Sample number	Temp. (C)	Time (h)	Conc. (% d.m.)	DMC (%)	WL ($g/g_{i.s.}$)	SG ($g/g_{i.s.}$)	a_w
1	20	1	45	35.92 ± 0.49^{a}	0.1845 ± 0.0098^{a}	0.0870 ± 0.0026^{ab}	0.910 ± 0.010^{d}
2	20	3	45	42.97 ± 0.31^{cd}	0.2780 ± 0.0026^{ef}	$0.1184 \pm 0.0036^{fghij}$	0.891 ± 0.007^{bcd}
3	20	5	45	45.88 ± 0.14^{ef}	0.3099 ± 0.0011^{gf}	0.1140 ± 0.0044^{egh}	0.875 ± 0.003^{bcd}
4	32	1	45	39.05 ± 0.81^{b}	0.2260 ± 0.0070^{b}	$0.1007 \pm 0.0050^{bcdef}$	0.908 ± 0.009^{d}
5	32	3	45	44.24 ± 1.05^{de}	0.3003 ± 0.0143^{fg}	$0.1122 \pm 0.0104^{defgh}$	0.890 ± 0.008^{bcd}
6	32	5	45	48.70 ± 0.66^{gh}	0.3359 ± 0.0054^{hi}	0.1210 ± 0.0074^{ghij}	0.870 ± 0.011^{bcd}
7	44	1	45	41.05 ± 1.21^{bc}	0.2454 ± 0.010^{bc}	0.0882 ± 0.0100^{abc}	0.905 ± 0.005^{cd}
8	44	3	45	49.12 ± 0.33^{gh}	0.3618 ± 0.0033^{jk}	0.1348 ± 0.0025^{ijk}	0.878 ± 0.007^{bcd}
9	44	5	45	50.13 ± 0.43^{gh}	0.3670 ± 0.0025^{jk}	0.1365 ± 0.0033^{jkl}	0.875 ± 0.002^{bcd}
10	20	1	52.5	39.44 ± 0.23^{b}	0.2376 ± 0.0020^{bc}	0.0853 ± 0.0040^{ab}	0.905 ± 0.003^{cd}
11	20	3	52.5	44.58 ± 0.45^{de}	0.3198 ± 0.0082^{gh}	0.1213 ± 0.0062^{ghij}	0.875 ± 0.004^{bcd}
12	20	5	52.5	48.21 ± 0.18^{g}	0.3464 ± 0.0015^{ij}	0.1215 ± 0.0034^{ghij}	0.860 ± 0.006^{abcd}
13	32	1	52.5	39.96 ± 1.04^{b}	0.2529 ± 0.0088^{cd}	0.0935 ± 0.0078^{abcd}	0.903 ± 0.007^{cd}
14	32	3	52.5	50.48 ± 0.02^{h}	0.3737 ± 0.0001^{kl}	$0.1068 \pm 0.0011^{cdefg}$	0.870 ± 0.011^{bcd}
15	32	5	52.5	53.10 ± 0.02^{ij}	0.3993 ± 0.0001^{m}	0.1289 ± 0.0031^{hijk}	0.852 ± 0.05^{abcd}
16	44	1	52.5	43.13 ± 1.37^{cd}	0.3003 ± 0.0116^{fg}	0.0956 ± 0.0096^{bcde}	0.884 ± 0.09^{bcd}
17	44	3	52.5	52.84 ± 1.48^{ij}	0.4125 ± 0.0112^{m}	$0.1174 \pm 0.0012^{fghij}$	0.858 ± 0.012^{abcd}
18	44	5	52.5	56.13 ± 0.13^{klm}	0.4539 ± 0.0009^{no}	0.1547 ± 0.0049^{lm}	0.851 ± 0.007^{abcd}
19	20	1	60	40.68 ± 0.28^{b}	0.2734 ± 0.0023^{de}	0.0762 ± 0.0029^{a}	0.879 ± 0.006^{bcd}
20	20	3	60	49.96 ± 0.60^{gh}	0.3929 ± 0.0189^{lm}	0.1160 ± 0.0087^{fghi}	0.846 ± 0.004^{abcd}
21	20	5	60	50.91 ± 0.55^{hi}	0.4107 ± 0.0038^{m}	0.1341 ± 0.0048^{ijk}	0.839 ± 0.009^{abc}
22	32	1	60	44.62 ± 0.74^{de}	0.3436 ± 0.0115^{hij}	0.0958 ± 0.0084^{bcde}	0.872 ± 0.004^{bcd}
23	32	3	60	54.71 ± 0.68^{jk}	0.4423 ± 0.0047^{n}	0.1133 ± 0.0059^{efgh}	0.841 ± 0.003^{abc}
24	32	5	60	57.11 ± 0.08^{lm}	0.4702 ± 0.0041^{op}	0.1336 ± 0.0051^{ijk}	0.835 ± 0.008^{ab}
25	44	1	60	47.97 ± 1.19^{fg}	0.3520 ± 0.0121^{ijk}	0.0908 ± 0.0100^{abc}	0.867 ± 0.009^{bcd}
26	44	3	60	55.95 ± 0.76^{kl}	0.4590 ± 0.0050^{nop}	0.1457 ± 0.0054^{klm}	0.855 ± 0.002^{abcd}
27	44	5	60	58.30 ± 0.22^{m}	0.4791 ± 0.0014^{p}	0.1597 ± 0.0024^{m}	0.800 ± 0.001^{a}

Different letters in the superscript in the same column of the table indicate on statistical significant difference between values at the level of significance of $P < 0.05$ (based on post-hoc Tukey HSD test).

were grouped according to process temperature and concentration of osmotic solution (samples that were subjected to the same process temperature and concentration of osmotic solution and different process time (1, 3 and 5 h) are connected with tin lines). Sample numbering is noted in Table 1.

With increasing process time samples were positioned from left to the right side of the graphic. The increase of the process temperature has also characterized samples at the left side of the graphic, while the increased osmotic solution concentration has characterized samples at the lower part of the graphic. Samples located in lower right quadrant had high levels of response values of DMC and WL (sample numbers 23, 24, 27). Samples located in upper left quadrant were characterized by high adversely high aw values (sample numbers 1, 4, 2, 5, 11), while the most favorable low a_w values characterized samples in lower right quadrant (sample numbers 23, 24, 27). Samples located in lower right quadrant were characterized by high SG values (sample numbers 8, 9, 18, 26).

Quality results showed that the first two PCs, account for 94.24% of the total variance and could be considered sufficient for data representation. Process response values of DMC contributed with 27.05%, WL contributed with 26.89% and a_w contributed with 24.67% to the first factor calculation. Process response value of SG contributed with 73.26% to the second factor calculation.

Table 2 shows the results of ANOVA of the RSM models which were developed on the basis of the experimental results provided in Table 1. In the method, SOP in form of Eq. (5), for the prediction of the function (4) of technological parameters of process temperature, process time and osmotic solution concentration was used.

Values of DMC were statistically significantly influenced by all three technological parameters, where the time was the most influential, than concentration, while the least statistically significantly parameter was temperature. Linear SOP terms for temperature, time and concentration and also quadratic term for temperature statistically significantly contributed to forming of the model. Residual variance was not statistically significant, indicating that applied model for DMC was adequate for the process of osmotic dehydration of chicken meat, with high level of determination coefficient R^2 (0.9773), which indicated good fitting of SOP model with obtained experimental values.

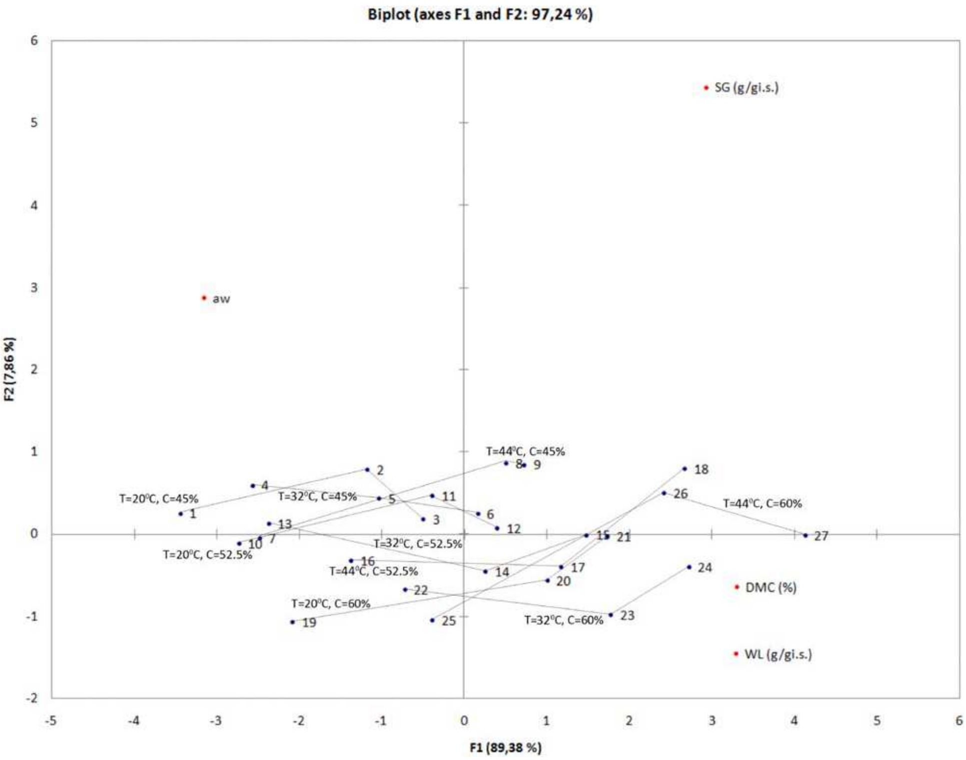

FIG. 1. BIPLOT DIAGRAM OF OSMODEHYDRATED CHICKEN MEAT SAMPLES

ANOVA test showed that values of WL were statistically significantly influenced by all three technological parameters, as in case of DMC, with also the same levels of significance. Quadratic and linear terms of the SOP for time and linear terms of the SOP for concentration and temperature contributed statistically significantly to the forming of the model of the process. High value of R^2 (0.9832) and insignificant residual variance, indicated good fitting capabilities of the proposed mathematical model for WL with experimental data.

In case of process response values of SG, ANOVA showed that process time and temperature affected values of SG at statistically significant level, while osmotic solution

TABLE 2. ANOVA OF THE RESPONSES OF THE MODEL OF THE CHICKEN MEAT OSMOTIC DEHYDRATION PROCESS

Technological parameters	Term	df[+]	Sum of squares DMC	WL	SG	a_w
Temperature	Linear	1	174.7239*	0.025522*	0.001245*	0.000636*
	Quadratic	1	2.1519^{ns}	0.000200^{ns}	0.000135^{ns}	0.000016^{ns}
Time	Linear	1	518.9699*	0.074324*	0.008496*	0.007854*
	Quadratic	1	45.1600*	0.008873*	0.000444*	0.000125^{ns}
Concentration	Linear	1	221.7904*	0.057185*	0.000153^{ns}	0.007524*
	Quadratic	1	0.0424^{ns}	0.000028^{ns}	0.000015^{ns}	0.000119^{ns}
Cross product	Temp. · Time	1	0.9936^{ns}	0.000079^{ns}	0.000255^{ns}	0.000008^{ns}
	Temp. · Conc.	1	2.1992^{ns}	0.000011^{ns}	0.000074^{ns}	0.000048^{ns}
	Time · Conc.	1	1.5838^{ns}	0.000096^{ns}	0.000396*	0.000140^{ns}
Linear	Residual variance	26	22.5145^{ns}	0.002835^{ns}	0.001174^{ns}	0.001041^{ns}
	Total sum of squares	35	990.1295	0.169153	0.001174	0.017509
R^2			0.9773	0.98324	0.90525	0.94057

*Statistically significant at level of significance of $P < 0.05$.

^{ns}Not statistically significant.

[1]df – degrees of freedom.

TABLE 3. REGRESSION COEFFICIENTS OF SOP MODELS FOR FOUR CHICKEN MEAT OSMOTIC DEHYDRATION PROCESS RESPONSES

	Y1/DMC	*Y2/WL*	*Y3/SG*	*Y4/a_w*
β_0	15.47948^{ns}	−0.181884^{ns}	0.257667^{ns}	0.765918*
β_1	0.24010^{ns}	0.004835^{ns}	−0.003446^{ns}	0.001492^{ns}
β_{11}	−0.00416^{ns}	−0.000040^{ns}	0.000033^{ns}	−0.000011^{ns}
β_2	5.14478*	0.076487*	−0.002472^{ns}	−0.004208^{ns}
β_{22}	−0.68587*	−0.009614*	−0.002151*	0.001139^{ns}
β_3	0.08633^{ns}	0.002577^{ns}	−0.004571^{ns}	0.006965^{ns}
β_{33}	0.00149^{ns}	0.000038^{ns}	0.000028^{ns}	−0.000079^{ns}
β_{12}	0.01199^{ns}	0.000107^{ns}	0.000192^{ns}	−0.000035^{ns}
β_{13}	0.00476^{ns}	0.000010^{ns}	0.000028^{ns}	−0.000022^{ns}
β_{23}	0.02422^{ns}	0.000189^{ns}	0.000383*	−0.000228^{ns}

*Statistically significant at level of significance of $P < 0.05$.
^{ns}Not statistically significant.

concentration did not have statistically significant influence on SG values. Quadratic and linear terms of time, linear term of temperature and cross product of time and concentration of the SOP were statistically significant to the forming of the model. As well as the previous responses, residual variance was not significant, while R^2 was high (0.9053), which indicated a good fitting of proposed model for SG with experimental data.

The statistical significance of quadratic terms of time in SOP models indicates that values of DMC, WL and SG are affected by quadratic dependence with time, as the consequence of reducing mass transfer rates with time of the process. By lowering the content of water in dehydrating chicken meat and simultaneously increasing SG by entering solutes into the chicken meat, concentration gradient between chicken meat and osmotic solution, which is drive force of the process, is reduced.

ANOVA of the a_w response showed that, as in the case of the responses DMC and WL, all three technological parameters statistically significantly affected a_w values with the same levels of significance. Linear SOP terms for temperature, time and concentration statistically significantly contributed to forming of the model. Residual variance was not significant, as in previous cases, while R^2 was high (0.9406) pointing at good fit of proposed model for a_w with experimental data.

Table 3 shows regression coefficients of SOP models for the four responses of chicken meat osmotic dehydration process, indicating good fitting capabilities for all SOP models to experimental data.

Score analysis quantifies different responses of process of osmotic dehydration in dimensionless values that represent score values which are comparable between different processes of osmotic dehydrations. In that way score values allow the possibility of comparing total efficiency of different processes of osmotic dehydration and optimization of each processes (Filipović *et al.* 2014b).

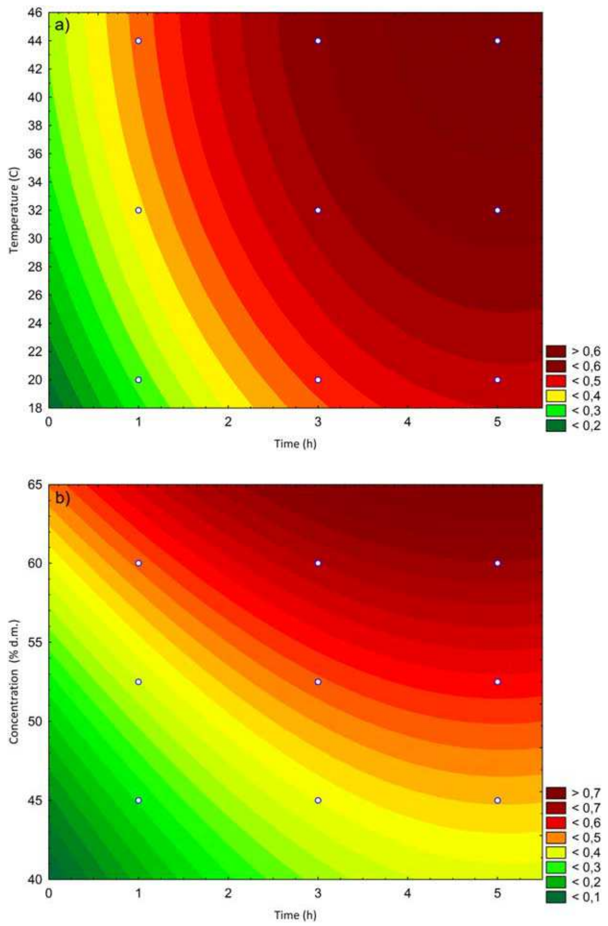

FIG. 2. (a) SCORE VALUES CONTOUR PLOTS OF OSMODEHYDRATED CHICKEN MEAT SAMPLES AT DIFFERENT TIME AND TEMPERATURE OF THE PROCESS. (b) SCORE VALUES CONTOUR PLOTS OF OSMODEHYDRATED CHICKEN MEAT SAMPLES AT DIFFERENT TIME OF THE PROCESS AND CONCENTRATION OF THE OSMOTIC SOLUTION

In Fig. 2a, b, score values countour plots of osmodehydrated chicken meat samples at different process time, process temperature and osmotic solution concentration are shown.

From Fig. 2a, it can be seen that the increase of process time and process temperature have influenced the increase of the score value or total efficiency of the process. From Fig. 2b, it can be seen that the increase of osmotic solution concentration has also increased the score value, hence the total efficiency of the process. The influence of technological parameters on score values, which represents combined process responses, is also in accordance with the influences of technological parameters on individual process responses, Tables 1 and 2.

Maximum obtained value of score for osmotic dehydration process at 44C, during 5 h in 60% concentration of osmotic solution was 0.75 of maximal 1.

CONCLUSION

Based on presented it can be concluded that:

- Maximal obtained values of process responses of: DMC: 58.30 ± 0.22%; WL: 0.4791 ± 0.0014 g/$g_{i.s.}$; SG: 0.1579 ± 0.0024 g/$g_{i.s.}$ and a_w: 0.800 ± 0.001; indicated on good dehydration levels at technological parameters of 44C and 5 h treatment in osmotic solution concentration of 60%, and indicated that applied osmotic solution is very good osmotic medium, providing high dehydration levels of chicken meat.
- Application of PCA, as the multivariate method of analysis, has provided better visualization in differentiation of the samples. DMC, WL and a_w are the dominant variable in the first principle component, while the SG was the most dominant variable in the second principle component, indicating on the effects of applied technological parameters.
- The RSM well described mathematical models for all four responses, which were statistically significant, while predicted and observed responses corresponded very well, allowing good prediction of process response values based on applied technological parameters.
- Score analysis was used to calculate total process efficiency in correlation with applied technological parameters and to point at their optimal combination in effort to obtain best osmotic dehydration process results.

REFERENCES

AOAC. 2000. *Official Methods of Analysis*, Association of Analytical Communities, Washington, DC.

AZOUBEL, P. M and MURR, F. E. X. 2008. Optimization of the osmotic dehydration of cashew apple (*Anacardium occidentale L.*) in sugar solutions. Food Sci. Technol. Int. *9*, 427–433.

BOX, G. E. P. and BEHNKEN, D. W. 1960. Some new three level designs for the study of quantitative variables. Technometrics *2*, 455–475.

COLLIGNAN, A., BOHUON, P., DEUMIER, F. I. and POLIGNE, I. 2001. Osmotic treatment of fish and meat products. J. Food Eng. *49*, 153–162.

ĆURČIĆ, B., PEZO, L., FILIPOVIĆ, V., NIĆETIN, M. and KNEŽEVIĆ, V. 2015. Osmotic treatment of fish in two different solutions-artificial neural network model. J. Food Process. Presv. *39*, 671–680

EL-AOUAR, A. A., AZOUBEL, M. P., BARBOSA, L. J. R. J. and MURR, F. E. X. 2006. Influence of the osmotic agent on the osmotic dehydration of papaya (*Carica Papaya L.*). J. Food Eng. *75*, 267–274.

FILIPOVIĆ, V. 2013. The effect of the osmotic dehydration process on mass transfer and pork meat quality. PhD Thesis, pp. 54–55, Faculty of Technology, University of Novi Sad, Serbia.

FILIPOVIĆ, V., LEVIĆ, L. J., ĆURČIĆ, B., NIĆETIN, M., PEZO, L. and MIŠLJENOVIĆ, N. 2014a. Optimisation of mass transfer kinetics during osmotic dehydration of pork meat cubes in complex osmotic solution. Chem. Ind. Chem. Eng. Q. *20*, 305–314.

FILIPOVIĆ, V., LONČAR, B., NICETIN, M., KNEŽEVIĆ, V., FILIPOVIĆ, I. and PEZO, L. 2014b. Modeling counter-current osmotic dehydration process of pork meat in molasses. J. Food Process Eng. *37*, 533–542.

FONGARO L. and KVAAL K. 2013. Surface texture characterization of an italian pasta by means of univariate and multivariate feature extraction from their texture images. Food Res. Int. *51*, 693–705.

ISPIR, A and TOĞRUL, T. 2009. The influence of application of pretreatment on the osmotic dehydration of apricots. J. Food Process. Presv *33*, 58–74.

JAYALAKSHMI, T. and SANTHAKUMARAN, A. 2011. Statistical normalization and back propagation for classification. IJCTE *3*, 89–93.

KNEŽEVIĆ, V., ĆURČIĆ, B., FILIPOVIĆ, V., NIĆETIN, M., LEVIĆ, L. J., KULJANIN, T. and GUBIĆ, J. 2013. Influence of osmotic dehydration on color and texture of pork meat. J. Process. Energy Agric. *17*, 39–42.

LONČAR, B. 2015. Chemometric approach to the analysis of osmotic dehydration of silver crucian carp (*Carassius gibelio*). PhD Thesis, pp. 63–64, Faculty of Technology, University of Novi Sad, Serbia.

MIŠLJENOVIĆ, N., KOPRIVICA, G., PEZO, L., LEVIĆ, L. J., ĆURČIĆ, B., FILIPOVIĆ, V. and NAD NIĆETIN, M. 2012. Optimization of the osmotic dehydration of carrot cubes in sugar beet molasses. Therm. Sci. *16*, 43–52.

OTTO, M. 1999. *Chemometrics Statistics and Computer Application in Analytical Chemistry*, pp. 28–29, Wiley-VCH, Weinheim, Germany.

OZDEMIR, M., OZEN, B. F., DOCK, L. L and FLOROS, J. D. 2008. Optimization of the osmotic dehydration of diced green peppers by response surface methodology. Lwt *41*, 2044–2050.

QI, H., LEMAGUER, M. and SHARMA, S. K. 1998. Design and selection of processing conditions of a pilot scale contactor for continuous osmotic dehydration of carrots. J. Food Process Eng. *21*, 75–88.

RASTOGI, N. K., RAGHAVARAO, K. S. M. S., NIRANJAN, K. and KNORR, D. 2002. Recent developments in osmotic dehydration: Methods to enhance mass transfer. Trends Food Sci. Technol. *13*, 48–59.

SINGH, B., PANESAR, P. S. and NANDA, V. 2008. Optimization of osmotic dehydration process of carrot cubes in sucrose solution. J. Food Process Eng. *31*, 1–20.

SINGH, B., PANESAR, P. S., GUPTA, A. K. and KENNEDY, J. F. 2010. Optimisation of osmotic dehydration process of carrot cubes in mixtures of sucrose and sodium chloride solutions. Food Chem. *123*, 590–600.

STATISTICA. 2010. *Data Analysis Software System*, v. 10, StatSoft, Tulsa, OK.

TORTOE, C. 2010. A review of osmodehydration for food industry. Afr. J. Food Sci. *4*, 303–324.

VOLPATO, G., MICHIELIN, E. M. Z., FERREIRA, S. R. S. and PETRUS, J. C. C. 2007. Kinetics of the diffusion of sodium chloride in chicken breast (pectoralis major) during curing. J. Food Eng. *79*, 779–785.