EFFECTS OF TEMPERATURE AND IMMERSION TIME ON REHYDRATION OF OSMOTICALLY DEHYDRATED PORK MEAT

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ABSTRACT

The aim of this work was to study the changes in osmotically dehydrated (OD) pork meat during rehydration. Meat samples (1x1x1cm cubes) were osmotically treated in two solutions: (1) solution with 350g of NaCl and 1200g of sucrose diluted in 1 l of distilled water and (2) sugar beet molasses (80 ^{0}Brix) solution at 23±2°C for 1, 2, 3 and 4 hours. In both cases, the solution to sample mass ratio was 10:1 to avoid significant dilution of the medium by water removal. After being osmotically dehydrated, meat samples were rehydrated by immersing meat cubes in water bath at constant temperature (20, 40 and 60 ^{0}C). The samples were removed after different immersion periods (15, 30, 45 and 60 min) and examined for mass and volume gain and rehydration percentage was calculated. After relatively short time (15 min), significant weight and volume gains were observed for both treatments. Process temperature was the most significant variable affecting final dry matter content and rehydration kinetics. At the end of rehydration process, conducted at 20 ^{0}C and 40 ^{0}C, a significant recovery in mass was observed, although the values were lower than for fresh meat. Ruptured and shrunken meat tissue produced as the result of OD had reduced its ability to absorb water. Rehydration percentage at 20 ^{0}C for molasses solution was 24.11%, and for sucrose-salt solution was 26.19%. However, rehydration at 40^0 C brings higher mass gain in case of molasses as a solution (11.33%) compared with sucrose-salt solution (7.88%). Results obtained at 60 ^{0}C were negative which means that rehydration didn't take place. The best conditions for meat rehydration were obtained using a temperature of 20 ^{0}C and time of 60 min. Volume of samples increased almost linearly with weight increment.

1. INTRODUCTION

The technique of dehydration is probably the oldest method of food preservation practiced by mankind (*Afzal, Abe, & Hikida, 1999*). Osmotic dehydration (OD) is a non-thermal process that consists in the immersion of a food material in a hypertonic solution. The difference of the chemical potential between the material and the solution promotes two main fluxes: the outcome of water from the material to the osmotic solution, and the income of soluble solids from the osmotic solution to the material. As osmotic agents are often used sugars (sucrose or glucose) and salts (sodium chloride).

In dehydration processes, heat and mass transfer flows can modify physicochemical properties of the material such as chemical composition (*McLaughlin and Magee 1998*), mechanical properties (*Lewicki and Lukaszuk, 2000*), volume and porosity. The quality of the dehydrated product depends on the extension of these changes. Regarding to the changes in volume and porosity, high shrinkage and low porosity lead to products with poor rehydration capability (*McMinn and Magee, 1997*). Furthermore, the changes in volume and dimensions must be considered for mass transfer modelling during dehydration (*Khalloufi et al., 2009*).

Volume changes during OD are mainly due to compositional changes and mechanical stresses associated to mass fluxes. These changes have been analyzed as variations in the volumes of solid, liquid and gas phases of the food material during the process (*Barat et al., 2001*), and have been correlated with changes in moisture content and WR (*Moreira and Sereno, 2003*), or with WL (*Nieto et al., 2004*).

Structural parameters such as sample volume, specific dimensions and porosity are closely related not only to food behaviour in mass transfer processes but also to other aspects such as food sensory and physical properties.

Dehydrated products need to be rehydrated before consumption or further processing (*Oliveira and Ilincanu, 1999*). During rehydration, absorption of water into the tissue results in an increase in the mass. Simultaneously, leaching out of solute (sugars, acids, minerals, vitamins) also occurs and both phenomena are influenced by the nature of the product and conditions employed for rehydration (*Krokida and Marinos-Kouris, 2003*). A study of rehydration kinetics can be used to ascertain the net extent of injuries sustained by any material during rehydration and any other processing step prior to it (*Lewicki, 1998a*). Rehydration is influenced by several factors, grouped as intrinsic factors such as product chemical composition, predrying treatment, product formulation, drying techniques and conditions and post drying procedure and extrinsic factors such as composition of immersion media, temperature and hydrodynamic conditions (*Oliveira and Ilincanu, 1999*).

The literature is inconsistent on rehydration characteristics with regard to food-to-water ratio, temperature of rehydration, level of agitation and procedure for the determination of moisture content (*Lewicki, 1998a*).

Rehydration can be considered as a measure of the injury to the material caused by drying and treatment preceeding dehydration (*Okos, Narishman, Singh and Weitnauer, 1992*).

It has been shown (*Steffe and Singh, 1980*) that the volume changes (swelling) of biological materials are often proportional to the amount of absorbed water. It is generally accepted that the degree of rehydration is dependent on the degree of cellular and structural disruption.

In some studies which consider food structure in the process modelling, changes in sample volume have been explained in terms of water loss throughout the process (*Andreotti, Tomassicchio and Macchiavelli, 1983*).

The time needed to reach the minimum volume was determined with a proposed equation (*Barat et al., 2001*). The initial shrinkage period was observed to be followed by a swelling period.

Response surface methodology (RSM) is an effective tool for optimizing a variety of food processes including rehydration (*Azoubel and Murr, 2003*). 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.

The objectives of here presented article were to investigate the effects of temperature and processing time on the mass transfer phenomena during rehydration of pork meat cubes, that were osmotically dehydrated in sugar beet molasses or sucrose solutions, to model rehydration percent (R) and volume changes (dV), as a function of the process variables.

2. MATERIALS AND METHODS

Sample preparation

Fresh pork (Musculus brachii) was bought in local butcher store and transported to the laboratory where it was held at about 4°C for 1–2 h. The muscles were trimmed of external fat and connective tissues and manually cut into approximately 1x1x1 cm (1cm^3) cubes with shark sterile knives.

Osmotic dehydration (OD)

Meat samples were osmotically treated in
solution of sugar beet molasses (soluble solid content = 80 ^{0}Brix);
sucrose-salt solution in distilled water (solution with 350g of NaCl and 1200g of sucrose diluted in 1 l of distilled water)
at 23±2°C for 5 hours.

The solution to sample mass ratio was 10:1 to avoid significant dilution of the medium by water removal, which would lead to local reduction of the osmotic driving force during process (*Medina-Vivanco et al., 2002; Antonio et al., 2008*). Meat cubes were fully immersed and held in the solutions using wire mesh. Experiment was carried out using laboratory glasses (V=500 ml each). On every 5 minutes meat samples in osmotic solutions were mixed with hand-held agitator in order to induce sample - solution contact and provide better homogenization of the osmotic solution. After being removed from the osmotic solution, samples were gently blotted with a tissue paper in order to remove excessive solution from the surface and then analyzed.

Rehydration (R)

OD treated meat samples were rehydrated by immersing meat cubes in water bath at constant temperature (20^{0}C, 40^{0}C and 60^{0}C). The samples were taken from the bath at different immersion periods (15, 30, 45 and 60 min) and were weighted after being blotted with tissue paper in order to remove the excess water. Finally, rehydration percentage was calculated.

Rehydration was calculated as:

$$R(\%) = \frac{100 \cdot (M_t - M_0)}{M_0} \qquad (1)$$

where M_t and M_o are the sample`s mass at time *t* (rehydrated samples) and zero (dried samples), respectively.
Dry matter content of the fresh and treated samples was determined by drying the material at 105 °C for 24h in a heat chamber (Instrumentaria Sutjeska, Serbia).

Volume changes (dV) were calculated as:

$$dV(\%) = \frac{100 \cdot (V_t - V_0)}{V_0} \qquad (2)$$

where V_t and V_o are the sample`s volume at time *t* (rehydrated samples) and zero (dried samples), respectively.
Sample dimensions of meat cubes were measured before and after rehydration using digital caliper.
Measured results are presented in Table 1.

Table 1. Experimental design and data for the response surface analysis

Run No	Temp. (X_1)	Time (X_2)	R of sugar beet molasses trated samples (Y_1)	R of NaCl+ Sucrose trated samples (Y_2)	dV of sugar beet molasses treated samples (Y_3)	dV of NaCl+ Sucrose terated samples (Y_4)
1	20	15	11.072	9.272	3.592	4.565
2	20	30	20.012	17.389	6.049	5.413
3	20	45	20.196	23.159	4.089	7.287
4	20	60	24.114	26.186	14.914	9.597
5	40	15	5.536	2.010	3.681	10.078
6	40	30	8.599	4.430	16.099	22.615
7	40	45	12.679	5.447	16.218	15.953
8	40	60	11.331	7.887	16.336	9.291
9	60	15	-7.416	-8.022	16.138	9.056
10	60	30	-7.901	-8.830	8.524	18.947
11	60	45	-9.442	-11.087	-0.719	5.774
12	60	60	-10.952	-11.998	-9.962	-7.399

Response surface methodology

The RSM method was selected to estimate the main effect of solution type (sugar beet molasses or NaCl+sucrose) on mass transfer variables during the rehydration of pork meat cubes. The accepted experimental design was taken from *Box et al. (1960)*. The independent variables were rehydration time (X_1) of 1, 3 and 5h and temperature (X_2) of 40, 50 and 60°C, and the dependent variable observed were responces: rehydrations of sugar beet molasses solution treated samples (Y_1), rehydration of NaCl+sucrose solution treated samples (Y_2), samples volume changes of sugar beet molasses solution treated samples (Y_3), and samples volume changes of NaCl+sucrose solution treated samples (Y_4). The accepted experimental design included 12 experiments.

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

$$Y_k = f_k(temp., time) \quad (3)$$

The following second order polynomial (SOP) model was fitted to the data. Two models of the following form were developed to relate two responses (Y):

$$Y_k = \beta_{k0} + \beta_{k1}X_1 + \beta_{k2}X_2 + \beta_{k11}X_1^2 + \beta_{k22}X_2^2 + \beta_{k12}X_1X_2 \quad (4)$$

where: β_{kn} are constant regression coefficients; Y, either rehydrations of sugar beet molasses solution treated samples (Y_1), and rehydration of NaCl+sucrose solution treated samples (Y_2); X either rehydration time (X_1), and temperature (X_2). The significant terms in the model were found by analysis of variance (ANOVA) for each response.

Statistical analysis and verification of the experiments

Analysis of variance (ANOVA) and response surface regression method (RSM) were performed using StatSoft Statistica, for Windows, ver. 10 program. The model was obtained for each dependent variable (or response) where factors were rejected when their significance level was less than 90%. The same program was used for generation of graphs and contour plots.

The graphs of the responses with significant parameters were superimposed to determine optimum drying conditions, plotted on optimization graphic. After the optimum conditions were established, separate experiments were performed for model validations of the models.

3. RESULTS AND DISCUSSION

The study was conducted to determine the rehydration conditions (rehydration ratio and volume changes) for pork meat cubes. The experimental data used for the analysis were derived from the Box and Behnken's 2 level-2 parameter design. Tab. 1 shows the response variables as a function of independent variables for the analysis.

The analysis of variance (ANOVA) tables exhibits the significant independent variables as well as interactions of these variables. In this article, ANOVA showed the significant effects of independent variables to the responses and which of responses were significantly affected by the varying treatment combinations (Table 2). It shows the ANOVA calculation regarding response models developed when the experimental data was fitted to a response surface. The response surface used a second order polynomial in the form of eq. (4) in order to predict the function f_k , eq. (3) for all dependent variables.

Sugar beet molasses treated samples were significantly affected by all process variables, temperature and treatment time, at 95% confidence level. It was noticed that rehydration was most affected by linear term of processing temperature. The impact of temperature was dominant, as seen by temperature's quadratic term, and also the cross-product term, which were more influential then both rehydration time linear and quadratic term. The rehydration time quadratic term is significant at 90% confidence level.

NaCl+sucrose treated meat samples rehydration were most affected by linear term of processing temperature (significant at 95% confidence level). The quadratic terms for both temperature and rehydration time were found statisticaly insignificant, while cross product of rehydration time and temperature was found more influential then the linear term of rehydration time. Both of these terms were significant at 95% confidence level.

Sugar beet molasses treated samples volume change were significantly affected by cross product of temperature and processing time, and quadratic term of temperature, significantly at 90% level, while linear term affects volume change statistically significant at 90% level. All other sources were statistically insignificant. The temperture terms were found dominant, but mostly non-linear, which can be observed on the contour plots.

NaCl+sucrose treated meat samples volume change were most affected by linear and quadratic terms of processing time (significant at 90 and 95% confidence level, respectively). The quadratic term of temperature and cross product term was found statisticaly significant at 95% level, while all others terms were found statistically insignificnt.

Table 2. ANOVA table

Term	Source	R of sugar beet molasses trated samples	R of NaCl+ Sucrose trated samples	dV of sugar beet molasses treated samples	dV of NaCl+ Sucrose terated samples
Linear	Temp	1543.020*	1680.341*	26.873 **	0.029 ns
	t	39.412*	61.962*	5.074 ns	49.671**
Quadratic	Temp	55.845*	0.504ns	160.379*	163.464 *
	t	9.117**	2.231 ns	2.576 ns	138.729*
Cross product	Temp x t	66.196*	124.950*	357.289*	158.027*
Lack of fit	Error	14.324 ns	5.256 ns	30.459 ns	8.300 ns
r^2		99.171	99.720	91.467	93.665

*Significant at 95% confidence level, **Significant at 90% confidence level, nsNot significant

The analysis revealed that the linear terms for rehydration contributed substantially in all cases to generate a significant SOP model. The SOP models for all variables were found to be statistically significant and the response surfaces were fitted to these models. The linear terms of SOP model were found significant, at 95% confidence level, and their influence were found most important in model calculation. On the other hand, non-linear terms in the SOP model for volume changes were found dominant, which is due to complexity of observed system.

Also shown in Table 2 is the residual variance where the lack of fit variation represents other contributions except for the first and second order terms. A significant lack of fit generally shows that the model failed to represent the data in the experimental domain at which points were not included in the regression. All SOP models had insignificant lack of fit tests, which means that all the models represented the data satisfactorily.

The coefficient of determination, r^2, is defined as the ratio of the explained variation to the total variation and is explained by its magnitude (*Madamba P. S, et. al., 2002*). It is also the proportion of the variability in the response variable, which is accounted for by the regression analysis (*Madamba P. S, et. al., 2002*). A high r^2 is indicative that the variation was accounted and that the data fitted satisfactorily to the proposed model (SOP in this case). The r^2 values for rehydration of sugar beet molasses treated sample (99.171) and rehydration of NaCl+sucrose treated sample (99.720) were very satisfactory and show the good fitting of the model to experimental results. Volume changes of sugar beet molasses treated sample (91.467) and NaCl+sucrose treated sample (93.665) showed less confident model results, but also the good fitting of the model and the experimental results.

Table 3 shows the regression coefficients for the response SOP models of rehydration and volume changes of sugar beet molasses and NaCl+sucrose treated samples, used by eq. (4) for predicting the values. The contour plots developed from the approximating function rehydration and volume change, of sugar beet molasses and NaCl+sucrose treated samples are shown on Fig. 1 and 2, respectively. Both rehydration of sugar beet molasses and NaCl+sucrose treated samples contour plot showed a saddle point configuration, and its value minimized to the upper right corner of the plot, with the increase of all process variables, temperature an treatment time. Volume changes of sugar beet molasses treated samples showed minimum configuration and NaCl+sucrose treated samples contour plot showed a maximum point configuration.

Table 3. Regression coefficients

Term	Source	R of sugar beet molasses trated samples	R of NaCl+ Sucrose trated samples	dV of sugar beet molasses treated samples	dV of NaCl+ Sucrose terated samples
Interchange		-2,27±4,83^{ns}	7,28±2,92*	-45,02±18,93**	-49,04±14,99*
Linear	Temp	0,54±0,20*	-0,20±0,12^{ns}	2,21±0,79*	2,06±0,62*
	t	0,74±0,16*	0,75±0,10*	0,91±0,65^{ns}	1,54±0,51*
Quadratic	Temp	-0,01±0,00*	-0,00±0,00^{ns}	-0,02±0,01**	-0,02±0,01*
	t	-0,01±0,00^{ns}	-0,00±0,00^{ns}	-0,00±0,01^{ns}	-0,02±0,01*
Interaction	Temp x t	-0,01±0,00*	-0,01±0,00*	-0,02±0,01*	-0,01±0,01*

*Significant at 95% confidence level, **Significant at 90% confidence level, ^{ns}Not significant

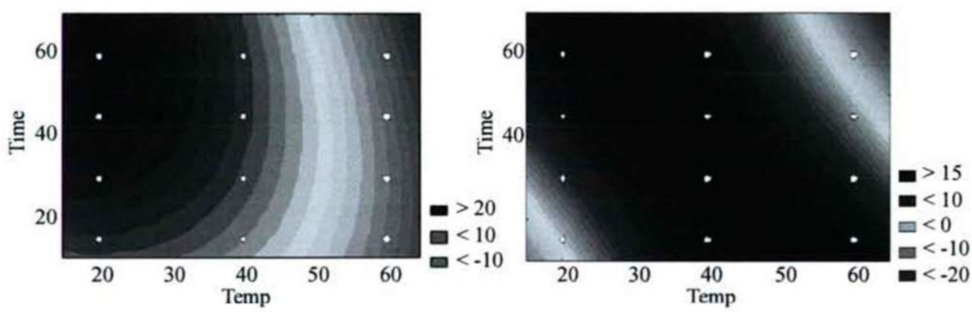
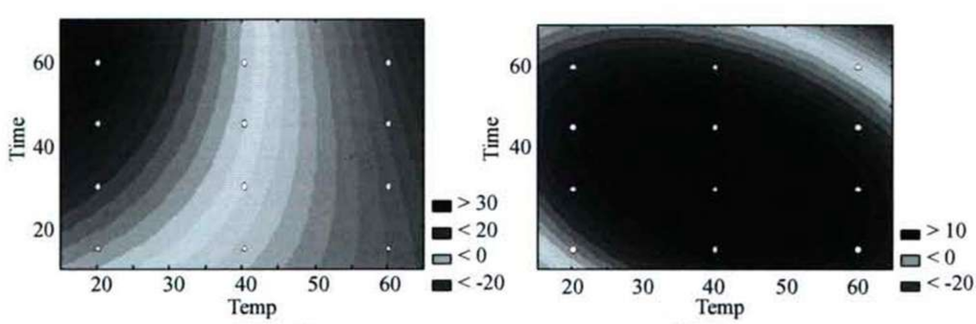


Figure 1. Contour plots for rehydration and volume changes of sugar beet molasses solution treated pork meat Figure 1. Contour plots for rehydration a) and volume changes b) of sugar beet molasses solution treated pork meat cubes as function of temperature and time



a) b)

Figure 2. Contour plots for rehydration a) and volume changes b) of NaCl + sucrose solution treated pork meat cubes as function of temperature and time

Maximum rehydration is achieved when processing time rises, while temperature is relatively low, for both sugar beet molasses and NaCl + sucrose treated meat cubes, while volume changes seem to gain their maximum with mild temperatures and relatively low processing time, close to the center of contour plot. It seems that the upper left corner of contour plots showed on Fig.1 and 2, could produce an processing optimum, concerning low energy consumtion, with long processing time, but also good rehydration percentage, and increase of sample volume. Upper right processing conditions should be avoided, due to high energy cost, and also degradation of pork meat cubes structure. The rehydration results were also unexeptable, as seen from Table 1.

To determine the adequacy of the SOP models, independent experiments were performed at chosen processing condition (rehydration temperature 40°C and processing time 45 minutes) for validation (*Madamba P. S, et. al., 2002*). Table 4 shows the model validation results. As shown in the previous ANOVA tables, the predicted values were comparable to the actual values in the experiment. Very good coefficients of variation (CV) of less than 10% for all process variables were calculated. CV values higher than 15% for response variables show great influence to the statistically minor significance of its SOP model (*Madamba P. S, et. al., 2002*). The low CV values for response variables for rehydration of sugar beet molasses and NaCl+sucrose indicated the adequacy of these models.

Table 4. Predicted and observed responses at optimum conditions

Rehydration	Predicted	Observed	Standard deviation	Coeff. of variation
R, sugar beet molasses	12.542	12.679	0.041	0.323
R, NaCl+ Sucrose	5.432	5.447	0.263	4.826
dV, sugar beet molasses	16.218	15.989	0.694	4.340
dV, NaCl+ Sucrose	15.953	16.013	0.563	3.515

4. CONCLUSION

The wide variety of dehydrated foods, which today are available to the consumer (snacks, dry mixes and soups, dried fruits, etc.) and the interesting concern for meeting quality specifications and conserving energy, emphasize the need for a thorough understanding of the operation and the problems related to the design and operation of dehydration and rehydration plants. The knowledge of physicochemical properties of food materials is important for an adequate design of food operations as well as for the control and improvement of the quality of the final product.

Food shape is one of the main quality attributes perceived by the consumer. Drying not only causes volume changes but also may cause changes in shape. In this sense, product deformation is not fully described by the evaluation of volumetric shrinkage. Mathematical models of dehydration and rehydration operations are important in the design and optimisation of those operations.

The RSM algorithm was used to model the rehydration and volume change of pork meat cubes after osmotic dehydration in sugar beet molasses and NaCl+sucrose solutions.

SOP models for all system responses were statistically significant while predicted and observed responses correspond very well.

Sugar beet molasses treated samples were significantly affected by all process variables, temperature and treatment time whereas the NaCl+sucrose treated meat samples rehydration were most affected by linear term of processing temperature. In terms of volume change, in case of sugar beet molasses treatment, volume changes were significantly affected by cross product of temperature and processing time, and quadratic term of temperature; while NaCl+sucrose treated meat samples volume changes were most affected by linear and quadratic terms of processing time.

Rehydration is most effective with the time increase at relatively low temperatures, for both cases of dehydration in sugar beet molasses and NaCl+sucrose solution. Volume change has its maximum at mild temperatures and at relatively low processing time.

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