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Evaluation and modeling of effects of parameters of osmotic dehydration of tomatoes (*Lycopersicon esculentum*)

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ABSTRACT

The purpose of the current study was to evaluate the influence of osmotic solution concentration, duration and temperature of the osmotic solution as process variables on mass transfer during osmotic dehydration of tomato (*Lycopersicum esculentum*). The experiments were performed using sodium chloride salt as osmotic agent, varying the concentration of the osmotic solution (100-300 g/l), temperature (30-60°C) and contact time (1-8 h). The results obtained show that mass transfer in terms of solid gain and water loss was influenced by the increase in time and temperature over the course of treatment. The solid gain was also influenced by the concentration of the osmotic solution and the duration of treatment. It has been found that the optimum area for maximizing water loss is that defined by immersion time equal to or greater than 7:30 and an immersion solution temperature equal to or greater than 58°C and the optimum working area minimization of salt gain during osmotic dehydration of tomatoes ranges from 100 to 150 g/l for the concentration of the salt solution and from 1 to 2 h for the duration of impregnation of tomatoes in the hypertonic solution of salt.

INTRODUCTION

Tomato (*Lycopersicon esculentum*) is an important crop which is produced in many tropical and temperate regions of the world. Tomato is a vital vegetable, which is consumed raw or served as ingredients for pizzas, pasta sauces, soups, stews, and many dishes and sauces. In the diet of the people, tomato plays an important role; it provides the diet with colour, flavour, vitamins, and lycopene. The average tomato composition is: water (94.5/100 g), carbohydrate (3.9/100 g), sugar (2.6/100 g), dietary fibre (1.2/100 g), fats (0.2/100 g), proteins (0.9/100 g), vitamins (mainly vitamin C: 0.014/100 g). Fresh tomatoes contain more than 90% water (Igwe et al., 1999).

Tomatoes and tomato derived products are rich in nutrients and sanitary components, because they are good sources of carotenoids (in particular, lycopene), ascorbic acid (vitamin C), vitamin E, flavonoids and potassium. In developing countries such as Democratic Republic of Congo, tomato is a seasonal product. In addition, it is highly perishable and records huge losses during the period of maximum production (Manashi et al., 2011).

In order to make it available on the market as long as possible after harvest, the products are most often subjected to the drying process. So, the most important

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problem in the tomato industry in our country is the lack of adequate means of processing and preservation tomatoes in peasant environments. In this work, we want to put in place an easy and suitable way to reduce post-harvest losses of tomatoes.

Therefore, simple and inexpensive processes are needed to offer a way to make this fruit available out of the normal season and for the regions away from production zones. Osmotic dehydration (OD) is one of most important complementary treatment and food preservation techniques in the processing of dehydrated foods, since it presents some benefits such as reducing the damage of heat to the flavor, color, inhibiting the browning of enzymes and decreasing the energy costs (Alakali et al., 2006; Torres et al., 2006). Osmotic dehydration is an inexpensive process due to the fact that there is no phase change of water from liquid to vapour state (Arballo et al., 2012).

Osmotic dehydration is a partial water removal process through immersion of cellular materials in a hypertonic solution of one or more soluble solutes. The concentration gradient between the food and the osmotic medium is the driving force for dehydration (Alves et al., 2005). Despite traditional drying (for example, sun drying, hot air drying) which is usually a long process requiring high temperatures; osmotic dehydration is effective even at ambient temperature leading that preserve the functional, nutritional and sensorial properties of the product.

Mass transfer during osmosis process takes place through simultaneous processes of water and solute transfer in opposite directions (Lazarides, 1994; Panades et al., 2006). The influence of process variables such as concentration and composition of osmotic solution, temperature, contact time, agitation, nature of food and its geometry, solution to sample ratio on the rate of mass transfer have been described extensively in scientific literature (Kaymak-Ertekin and Sultanoglu, 2000; Singh et al., 2007; Tonon et al., 2007).

The provision to consumers of products that have been osmotically dehydrated at the start also requires knowledge of the fraction of the solute that entered the system in order to have an idea about the product to be delivered to users for later use. The optimal combination of factors that maximizes water loss and minimizes solute gain should be kept in mind. Hence there is a need to evaluate the water loss as well as the gain in tomato solids after osmotic dehydration and to model the process to deduce an optimal treatment to apply to the product.

Despite of numerous researches which have investigated the effects of these variables on the mass transfer during osmotic dehydration of different products, no information is available in the literature regarding the modeling of osmotic dehydration of tomato.

Therefore, the objective of the present current work was to evaluate and model parameters of osmotic dehydration of tomato fruit.

MATERIALS AND METHODS

Fresh and ripe *L. esculentum* var Caribbean; from the Seed Production Center, were used in this study. Additionally the sodium chloride salt (NaCl) was used as osmotic agent.

Morphological parameters and moisture content

- The weight of the tomato samples was determined by weighing with a portable digital scale;
- The height and diameter of the samples were determined using a digital caliper;
- The shape coefficient was determined by making the ratio between the average diameter and the average height of the fruit;
- The water content was determined by putting a sample in the oven (OSC 9500 C) to constant weight.

Preparation of solutions

Solutions were prepared with distilled water as solvent according to the retained NaCl salt concentrations: 100, 200 and 300 g/l of solution. For each of the solutions, the quantity of weighed solute was transferred to a 1 liter volumetric flask, and then dissolved in distilled water before being carried to the gauge mark with the same water.

Osmotic dehydration treatment

Fresh and ripe tomatoes were immersed in salt solution which was prepared by mixing NaCl salt and distilled water on weight-to-weight basis at 100, 200 and 300 g/l. The solution concentration throughout each experiment was monitored by portable refractometer (VWR Handheld Refractometer). Experiments were performed at three temperature levels (30, 45 and 60°C) using an agitated water bath (Versa-Bath S) maintained at the selected temperatures. Temperature was monitored by means of digital thermometer (DURAC Digital Thermometer).

Osmotic dehydration of tomato samples was carried out in glass jars with a capacity of 500 ml. Each jar contains a sample of tomato and 300 ml of the osmotic solution concerned. Sampling was performed in time intervals of 1, 4.5 and 8 h and then the samples were quickly rinsed with distilled water to eliminate the solution from the surface and carefully blotted with tissue paper to remove the excess surface water. All experiments were repeated three times.

Table 1. Experimental design.

Treatment	Temperature	Time	Concentration
1	-1	-1	-1
2	1	0	0
3	-1	1	1
4	0	0	-1
5	-1	-1	1
6	0	0	0
7	0	0	1
8	1	-1	-1
9	0	0	0
10	-1	1	-1
11	0	0	0
12	1	1	1
13	0	-1	0
14	0	0	0
15	-1	0	0
16	1	1	-1
17	0	1	0
18	1	-1	1
19	0	0	0
20	0	0	0

Mass transfer determination

In order to determine mass change, all samples were weighed before and after treatment using an analytical balance (Sartorius).

Loss water: Resulted from the balance between its initial concentration (X_0) and the final concentration (X_t) after a given time (t) of dehydration. The following expression was used:

$$\text{Water loss: } X_1\left(X_0 - \frac{Xt \times Pt}{P_0}\right) \times 100$$

Where: X_1 is the percentage of water loss in tomato simples; X_0, initial content of water of the sample (g/g); Xt, water content in the sample after t hours of treatment (g/g).

Po is the initial mass of the sample (g), and Pt the mass of the sample after t hours of treatment (g).

Solute gain: It was evaluated by difference in concentration between the osmotically dehydrated tomatoes and the control (that is, tomato sample that did not undergo osmotic dehydration).The NaCl in the tomato samples was assayed by argentimetry (Volhard Carpenter Method).

Experimental design and statistical analysis

The experimental design applied was a factorial plan of central type a composite; corresponding to three salt concentrations, three temperatures and three time intervals. MINITAB version 17 (MINITAB, Inc., State College, PA) software was used for statistical and significance level was 95%. Matrix of the experimental plan is presented according to the code given in Table 1. The ranges of variables selected are summarized in Table 2.

This experimental design was repeated a second time, in order to make the generated data more robust and to allow the tracing of a response surface. The central points were repeated several times to appreciate the repeatability of the measurements.The analysis of variance was carried out according to the model.

$$R = R_0 + aX + bY + cZ + dX^2 + eY^2 + fZ^2 + gXY + hXZ + iZY + jXYZ + \varepsilon$$

X, Y, Z representing the independent variable level applied, R being the response, R_0 an average response, a, b, c, d, e, f, g, h, i, j being model fit constants and ε a standard adjustment error.

This model allowed us to appreciate both the linear and curvilinear contributions of the independent variables on the response, as well as the interactions that may exist between the effects of the different variables. Response

Table 2. Variation range of independent variables.

Variable		Encodage		
		-1	**0**	**1**
Temperature (°C)	X	30	45	60
Time (h)	Y	1	4.5	8
Concentration (g/l)	Z	100	200	300

Table 3. Morphological characteristics of tomato fruits.

Variable	Moyenne	Ecart-type	Coefficient de variation (%)
Diameter (mm)	48.3385	2.54	5.25
Height (mm)	40.6625	3.17	7.79
Coefficient of forme (Cf)	0.841203	1.24031	1.48

S.D, Standard deviation; C.V, coefficient of variation.

surfaces, adjustment of variation models and optima search were performed using Minitab 17 (MINITAB, Inc., State College, PA).

RESULTS AND DISCUSSION

Morphological characteristics of study material

Table 3 shows the average morphological parameters of the 40 fruits used in the experiment and their variability. The values obtained indicate that the fruits used, from the same variety and cultivated under the same conditions, were similar in their sizes and shapes. In kinetic experiments, only the coefficients of variation greater than 25% are considered sufficiently dispersed.

According to Statcan (2010), the coefficient of variation is excellent, when ranging from 0 to 4.9%, very good from 5.0 to 9.9%, good from 10.0 to 14.9%, and acceptable from 15.0 to 24.9%. Cf less than 0.8 refers to a flattened shape; Cf greater than 1to an elongated shape and Cf between 0.8 and 1 to a round shape(Fagbohounand Kiki, 1999). The tomato fruits used in this study had a round shape (Cf= 0.8). And therefore sufficiently close to the spherical geometry. Depending on the coefficients of variation, the tomato samples are not statistically dispersed in this work.

Water content

Table 4 gives the water content of the tomato samples of the Caribbean variety used in this work. The tomato of the Caribbean variety contains a very high water content, around 95.27%, which makes it very perishable, as are other varieties. This is in agreement with the literature that fresh tomato contains more than 90% water (Igwe et al., 1999).

Effects of temperature, concentration and impregnation time of salted tomatoes on osmotic dehydration

Here, we study the effects of temperature, concentration and impregnation time of salted tomatoes on osmotic dehydration. A mathematical model will be developed that predicts the quantity of water extracted and to meet different constraints of this process.

Study of water loss

Analysis of variance

Table 5 gives the analysis of variance of osmotic process parameters of tomato and the regression model of the loss of water in salty medium. The analysis of the variance presented in Table 5 shows that the experimental model used has a highly significant influence on the dehydration of tomatoes (*p*-value = 0 of the general model).

In addition to the significant linear changes in tomato water losses with temperature and duration of treatment, the regression model analyzed showed significant interactions between these two parameters. The interaction between temperature and treatment time is

Table 4. Initial water content of tomato samples of the Caribbean variety.

Treatment	Weight of tomato (g)		Water	
	Fresh	Oven-dried	Weight(g)	%
Essai 1	32.97	1.48	31.49	95.51
Essai 2	44.1	1.95	42.15	95.58
Essai 3	36.06	1.89	34.16	94.76
Average	37.71	1.77	35.93	95.27
Standard deviation	-	-	-	0.32165

Table 5. Analysis of variance for water loss during osmotic dehydration of tomato using salt solution.

Source of variation	Value	DF	Adj SS	MS	F-Value	P-value α = 0.05
General model		9	1873.73	08.193	9.62	0.000
Overall linear effect		3	1241.1	13.700	19.11	0.000
Intercept (Ro)	28.6					
a	0.997	1	492.74	92.738	22.77	0.000
b	3.58	1	696.23	96.229	32.17	0.000
c	0.0996	1	52.13	52.134	2.41	0.131
Quadratic effect		3	95.24	31.747	1.47	0.243
d	0.00895	1	22.31	22.305	1.03	0.318
e	0.337	1	89.59	89.589	4.14	0.051
f	0.000057	1	1.80	1.797	0.08	0.775
Interaction of two factors		3	517.54	72.515	7.97	0.000
g	0.0861	1	328.39	328.394	15.17	0.001
h	0.001241	1	55.45	55.448	2.56	0.120
I	0.00824	1	133.70	33.703	6.18	0.120
Error		30	649.28	21.643		
Lack of fit		5	254.39	50.878	3.22	0.022
Pure error		25	394.89	15.796		
Total		39	2523.0			

DF, Degree of freedom; SS, Somme square; MS, Moyen Somme.

the one with the most important effect of all interactions on the water loss of tomato during osmotic dehydration, thus the most significant of all interactions because it has the highest value of *F*-value. Figure 1 illustrates the iso-response curve of the water loss as a function of immersion time and temperature of the hypertonic salt solution.

The analysis of the iso-response curve shows that the linear increase in the time of impregnation of tomatoes in the sodium chloride solution and the temperature of hypertonic solution of this salt increases proportionally to the loss of water. The interaction of the maximum duration of impregnation of tomatoes in the salt solution and the maximum temperature of the hypertonic solution considered in the experiment results in a significant water loss in the tomato samples. The most interesting working area optimizing water loss is defined as an immersion time of 7h30s or more and an immersion bath temperature of 58°C or higher. This is in agreement with the previous general observations of Rastogi (2004) who found that water loss, mass reduction and solute gain generally increase with processing time.

Lenart and Lewicki (1989) confirmed that after treatment, the duration of treatment is an important factor to consider. Whatever the products processed the kinetics of material transfers can be decomposed into two exponential phases. In the first phase, most of the water and solute transfers occur and in a second, transport intensity decreases sharply for water transfers, while solute inflows continue to increase steadily.

Modeling regression response

The regression equation can be rewritten by replacing the variables by x, y and z.Let (R) be the water loss in %;

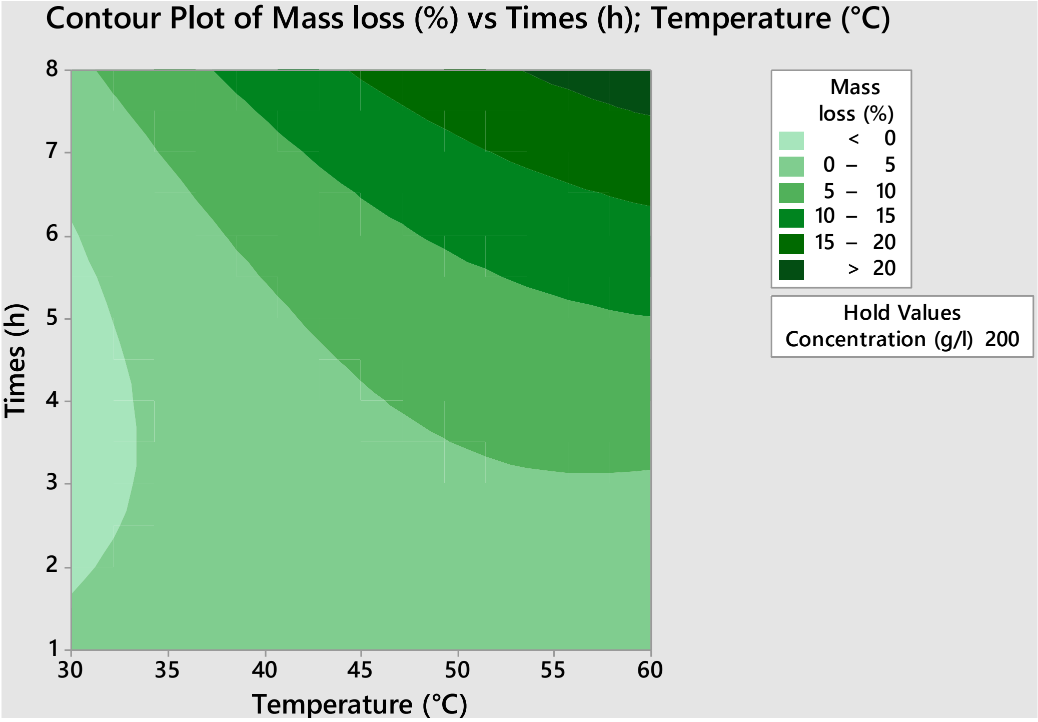

Figure 1. Iso-response curves of water loss as a function of time and temperature.

Temperatures (x); Time (y); Concentration (z). The fitting of the model (1) to the experimental results gives the following equation:

$$R(\%) = -28.6+0.997x - 3.58y+ 0.0996z - 0.00895x^2+ 0.337y^2- 0.000057z^2+ 0.0861xy - 0.001241xz - 0.00824yz \quad (1)$$

The mathematical model found using Minitab 17 (MINITAB, Inc., State College, PA) shows that the average effect of the selected factors is R_0 = 28.6% on water loss and the main effect of temperature is particularly a = 0.997% lower than time, the coefficient being b = 3, 58% and greater than the concentration for which the coefficient c = 0.0996%. The quadratic effect for the temperature is: d = 0.00895, that of the duration is: e = 0.337; the quadratic effect of the concentration is: f = 0.000057.

According to Themelin (1994), the effect of temperature is essential and superior to that of concentration. The model developed shows a greater contribution of time to the quadratic variation of water loss compared to the contribution to the quadratic variation effect of the other two study variables. It is indeed known that the phenomenon of dehydration is a phenomenon convergent in time towards an asymptotic value. Such a convergence implies a curvilinear appearance of the response as a function of time.

For interactions of order 2, we found that the time-temperature interaction is the strongest of the interactions with the coefficient g = 0.0861%. The other interactions are weaker, h = 0.001241% for temperature-concentration, and i = time-concentration = 0.00824%.

The *p*-values (0.000) for the temperature; (0.000) for the duration and (0.131) for the concentration indicate that immersion time and immersion bath temperature factors have a significant influence on water loss. On the other hand, salt concentration did not significantly affect water loss. This is consistent with the work by Vial et al. (1990), who observed that the salt concentration increased the rate of dehydration but slightly affected the final water loss.

The *p*-values of the quadratic effect (0.318) for the temperature; (0.051) for the duration; (0.775) for concentration indicate that the tomato immersion time factor has a significant influence on response. On the other hand, the concentration factors of the salt solution and the temperature of the hypertonic solution of salt did not influence the water loss.

The *p*-value (0.001) shows that the interaction of time-temperature factors significantly influences water loss. However, the interactions of time-concentration, temperature-concentration factors have no significant influence on water loss since their *p*-values are 0.120 and 0.120.

Table 6. Analysis of variance of the solid gain in salty medium.

Source de variation	values	DF	Adj SS	MS	*F*-Value	*p*-value ɑ̣ = 0.05
General model		9	505.255	56.139	4.09	0.019
Overall linear effect		3	291.421	97.140	7.08	0.008
Intercept (R0)	-34.3					
a	1.334	1	42.195	42.195	3.08	0.110
b	-1.48	1	158.496	158.496	11.55	0.007
c	0.1012	1	90.730	90.730	6.61	0.028
Quadratic effect		3	89.283	29.761	2.17	0.155
e	-0.012	1	20.691	20.691	1.51	0.248
f	0.458	1	86.609	86.609	6.31	0.031
g	0.0001	1	3.947	3.947	0.29	0.603
Interaction of two factors		3	124.550	41.517	3.03	0.080
h	0.0134	1	3.967	3.967	0.29	0.603
i	-0.00079	1	11.480	11.480	0.84	0.382
j	-0.01055	1	109.102	109.102	7.95	0.018
Error		10	137.183	13.718		0.382
Lack-of-fit		5	122.775	24.555	8.52	0.017
Pure error		5	14.408	2.882		
Total		19	642.438			

By refining the initial water loss model with respect to the *p*-values of the coefficients at the significance level (ɑ̣ = 5%), we obtain the following equation:

Water loss (%) = - 28. 6 + 0.997 x – 3.58 y+0.337y^2- + 0. 0861xy

Study of solid gain during osmotic dehydration of tomato in a salty medium

Analysis of variance

Table 6 gives the analysis of variance for solid gain during osmotic dehydration of tomato using salt solution. Previous studies on far-infrared radiation (FIR) drying have reported several advantages over the conventional hot air drying: high heat transfer coefficients, high energy efficiency, lower air flow through the food material, short process time, and low cost of energy (Togrul, 2005; Sharma et al., 2005). Chua et al.(2004) applied intermittent FIR heating and concluded that the color degradation can be favourably offset by a significant reduction in drying time. Shortened drying time with improved product quality was reported by other researchers, when occasional FIR heating was applied. Since most food materials subjected to drying contain large amounts of water, the absorption of infrared energy by water is an important variable which affects drying kinetics. It is commonly reported that solid materials absorb infrared radiation in a thin surface layer.

The analysis of Figure 2 shows that the optimum area of work for the minimization of salt gain during the osmotic dehydration of tomatoes ranges from 100 to 150 g/l for the concentration of the salt and 1 to 2 h for the duration of impregnation of tomatoes in the hypertonic salt solution. Vial et al. (1990) have shown that increasing the solute concentration affects less solute transfers, although this increases the rate of water transfer.

Modeling regression response

The regression equation can be rewritten by replacing the variables by x, y, and z.Let (R) be the Solid gain loss in%; Temperature (x); Time (y); Concentration (z). The fitting of the model (2) to the experimental results gives the following equation:

R% = -34.3-1.48y+0.1012z+0.458y^2-0.01055yz (2)

R is the response in question (solid gain), and y and z are coded independent variables (time and concentration, respectively).

Conclusion

The objective of this work was ways to conserve and valorize locally produced fresh tomatoes. This study specifically aimed to evaluate the effect of operating parameters (temperature, concentration of osmotic

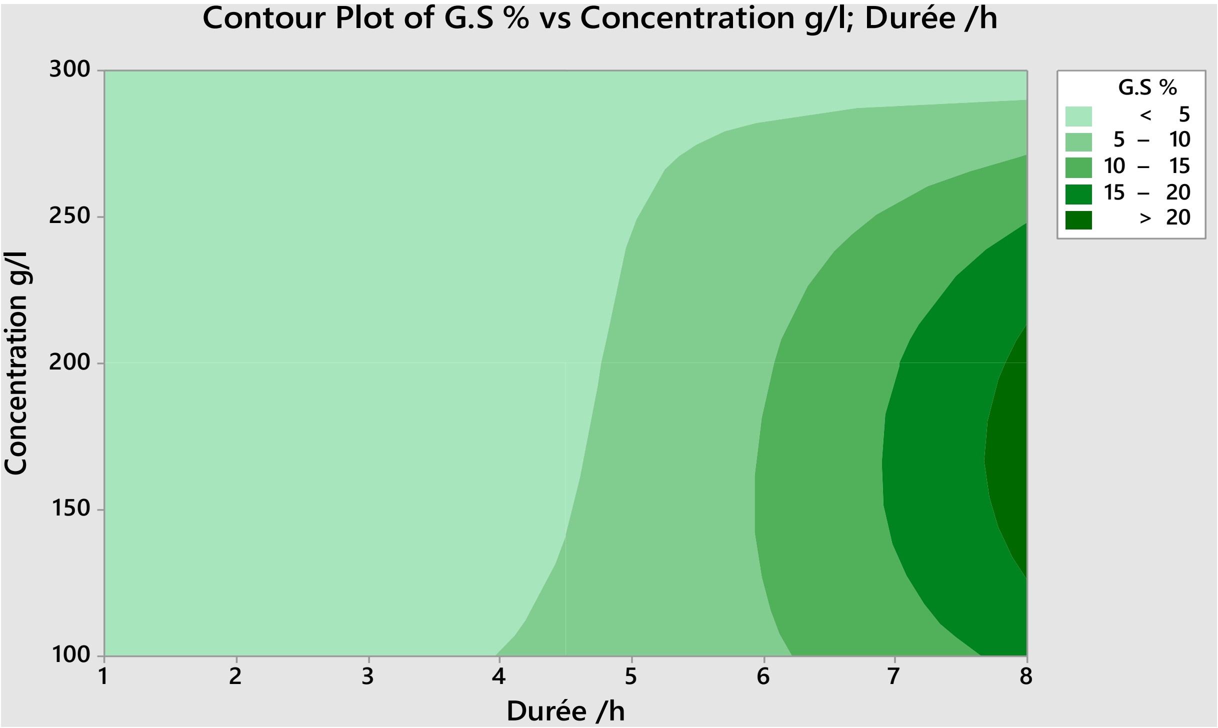

Figure 2. Iso-response curves of solid gain as a function of concentration and time.

solution and duration of treatment) on water loss and solute gain during osmotic dehydration of tomato and to model this phenomenon in order to deduce the optimal operating conditions.

The modeling of this phenomenon made it possible to deduce the optimal dehydration conditions to follow, in order to achieve the expected results.The mathematical model obtained will allow us to analyze real phenomena and to predict results to obtain when we change working conditions.

According to the *p*-values, it has been shown that the interaction of time-temperature significantly influences water loss. However, the interactions of time-concentration factors and temperature-concentration factors have no significant influence on mass loss. There is also a significant influence according to the *p*-values of interaction of time-concentration factors on salt gain. Moreover, the interaction of time-temperature and temperature-concentration factors has no significant influence on salt gain.

The refinement of initial mathematical models of water loss and solute gain relative to the *p*-values of the coefficients at the 5% significance level made the equations simpler by eliminating terms that do not influence the response variable.

At the end of the statistical analyzes of the results obtained, it turned out that the optimal zone maximizing the water loss is the one defined by an immersion time equal to or greater than 7 h 30 s and a temperature of immersion solution equal to or greater than 58°C. It has been found that the optimum area of work minimizing salt gain during osmotic dehydration of tomatoes ranges from 100 to 150 g/l for the concentration of the salt solution and from 1 to 2 h for the duration of impregnation of tomatoes in the hypertonic salt solution.

The results obtained in this study will enable farmers in the DRC to improve the conservation technique of their product; thus reducing the post-harvest losses of the tomato produced.

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