Study of the coupling of osmotic dehydration and tomato (*Lycopersicum esculentum*) drying by the response surface methodology

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ABSTRACT

In statistics, response surface methodology (RSM) explores the relationships between several explanatory variables and one or more response variables. In this study, it was utilized to study the relationship between osmotic dehydration and *Lycopersicum esculentum* (tomato) drying. The goal of this research was to assess the effect of standard operating parameters (for example, temperature of the osmotic media, the concentration of the osmotic media, the duration of the osmotic treatment, and the drying temperature) on the loss of mass, the duration of the drying, and the final moisture content of tomato during processing. Information obtained will be computed in order to mathematically model this phenomenon and generate optimal operating settings. The concentration of the osmotic solution and the temperature of the osmotic dehydration were found to influence the loss of tomato mass during the coupling process. The concentration of the osmotic solution and the drying temperature had a significant influence on the drying time and the final water content of the tomato. Mathematical models predicting the loss of mass, the duration of drying and the final water content of the tomato according to the three operating parameters are proposed and the conditions for the optimization of the coupling process are determined: a solution of sodium chloride (100 g/L) warmed at 30°C and an osmotic dehydration time of 8 h coupled with drying at 52.5°C were utilized shorten the total drying time to 42 h and yield a maximum tomato mass loss of 96.71% and a final water content of 14.51%.

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INTRODUCTION

Tomato (*Lycopersicon esculentum*) is an annual herb that originated from the tropical highlands of South America. It is cultivated throughout the intertropical zone (Anonymous, 2006). The production of tomato for

processing and canning (industrial tomato) accounts for about half of the production in the European Union, 80% in the United States and about 15% in China (2008) (FAO, 2016).

In developing countries, 20 to 40 percent of food losses occur each year as a result of conservation difficulties. These losses are enormous in the tropical and subtropical regions, where climatic conditions are unfavorable for the conservation of food (Igwe et al.,

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1999).

The tomato is one of the foods that rapidly deteriorate after harvesting in a tropical environment (Naika et al., 2005). Its long-term storage for its subsequent uses will require the development of novel preservation techniques its shelf life. Eggplants and tomato are very perishable and have very short shelf life due to rapid enzymatic browning, tissue softening and water loss which limit commercialization of these products (Ghidelli et al., 2013).

The tomato, one of the most scientifically investigated vegetables because of its commercial importance (Sacilik, 2007). It is low in calories and rich in vitamins A, C, and E and minerals such as calcium, potassium, and phosphorus.

In a rank of 10 vitamins and minerals, tomato is the first in terms of contribution in the diet (Vinson et al., 1998). The thermal drying of the tomato is energy consuming has high water content is very well supplied with water, more than 90% (Igwe et al., 1999).

To avoid the abovementioned problem relating to use of thermal drying, osmotic dehydration can be utilized as an alternative and suitable technique, not only because it minimizes energy expenditure but more importantly preserves the shape, texture, nutritional composition and organoleptic quality of the product. The lowering of the water activity of the food products by adding solute with respect to the microorganism. This technique helps protecting food products of flexible texture for lengthy consumption without rehydration (Bonazzi and Bimbenet, 2003).

The performance of this method depends both on the intrinsic properties of the treated tissues and the operating conditions of the treatment. Among them, the treatment temperature, the composition of the impregnating solution and the treatment time play a key role (Azuara et al., 1998; Uddin et al., 2004).

The hypothesis of this work is based on the fact that, applying selected operating parameters to a hypertonic sodium chloride medium, would induce a high loss of mass, shorten the drying time and reduce the final water content of the treated tomato.

The general objective of this study is to contribute to the development of efficient ways of preservation methods to length shelf life locally produced fresh tomatoes. To this end, we aim to:

- Evaluate the effect of independent operating parameters (Sodium chloride concentration of osmotic solution: 100 - 300 g/L, osmotic dehydration temperature: 30 - 60°C, duration of osmotic dehydration: 1 - 8 h and drying temperature: 40 - 60°C) on weight loss, drying time, and the final water content of the tomato during the coupling process;
- Model these phenomena in order to determine the optimal operating conditions.

MATERIAL AND METHODS

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

Analysis of morphological parameters and water content of fresh tomato

The weight of tomato samples was determined by weighing with a portable digital scale; the height and diameter of samples were determined using a digital caliper; the shape coefficient was calculated by 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 drying (OSC 9500 C) to constant weight.

Preparation of osmotic solutions

Sodium chloride was used to prepare the osmotic dehydration test solution of different concentrations. Using a volumetric flask X ml, the salt of varying weights was individually mixed with x ml distilled water until complete dissolution in a graduated flask of known capacity. After obtaining a homogeneous mixture, the concentrated solution is ready for use.

Coupling osmotic dehydration - tomato drying

Osmotic dehydration of tomato samples was performed in 500 ml glass jars. In a jar containing 300 ml of osmotic solution was placed one tomato sample. Then the jar was closed with the lid and kept in a thermostatically controlled water bath under gentle stirring at the temperatures and treatment times used are shown in Table 1.

The experimental design applied was a factor plan of central type a composite; corresponding to four independent factors (concentration of sodium chloride in the osmotic solution: 100-300 g/L, osmotic dehydration temperature: 30-60°C, duration of osmotic dehydration: 1 - 8 h drying temperature: 40-60°C) and five levels were established using Minitab software 17 (MINITAB, Inc., State College, PA). The coded matrix of the experimental design and the range of variation of the independent variables are presented in Tables 1 and 2. With A, B, C and D independent variables as signified in Table 1.

In order to increase the accuracy of the results obtained, this experimental design was repeated once in order to make the generated data more robust and to allow the tracing of the response surfaces. Seven trials

Table 1. Variable range of independent variables.

Independent variables		-2	-1	0	1	2
Concentration of the osmotic solution	A (g/L)	100	150	200	250	300
Temperature of osmotic dehydration	B (°C)	30	37.5	45	52.5	60
Duration of osmotic dehydration	C (h)	1 h	2 h 45 min	4 h 30 min	6 h 30 min	8 h
Temperature of drying	D (°C)	40	45	50	55	60

Table 2. Coded matrix of the experimental design.

Traitement	A	B	C	D
1	1	-1	1	1
2	0	2	0	0
3	0	0	-2	0
4	-1	1	-1	-1
5	1	-1	-1	1
6	1	1	1	1
7	-2	0	0	0
8	-1	-1	1	-1
9	0	0	0	0
10	1	1	1	-1
11	0	0	0	0
12	1	-1	1	-1
13	1	1	-1	-1
14	0	0	0	0
15	-1	1	-1	1
16	0	0	0	0
17	-1	1	1	-1
18	0	0	0	0
19	0	-2	0	0
20	-1	1	1	1
21	2	0	0	0
22	0	0	0	0
23	1	1	-1	1
24	-1	-1	-1	-1
25	0	0	0	2
26	1	-1	-1	-1
27	0	0	0	-2
28	-1	-1	1	1
29	0	0	2	0
30	-1	-1	-1	1
31	0	0	0	0

were conducted at the center of the experimental domain, in order to assess the repeatability of the measurements. The analysis of the variance was carried out according to the model:

$$R = R_0 + aA + bB + cC + dD$$

A, B, C and D represent independent variables applied, where R is the response studied, R_0 is the mean response, a, b, c and d are model fit constants. This model made it possible to assess the linear contributions as well as the effects of the independent variables on the responses studied. Response surfaces, fit of variation

Table 3. Morphological parameters and moisture content of tomato.

Parameters determined	Valeur ($\pm$ Et)
Average weight (g)	38.89 $\pm$ 3.07
Average diameter (mm)	51.72 $\pm$ 2.18
Average height (mm)	42.06 $\pm$ 2.60
Coefficient of form (D/H)	0.81 $\pm$ 0.07
Number of lobes	4 $\pm$ 0.00
Average water content (%)	95.78 $\pm$ 0.75

Classification of Fagbohoun and Kiki (1999); Cf less than 0.8, flattened shape; Cf greater than 1, elongated shape; Cf between 0.8 and 1, round shape.

models, and search for optima were performed using the Minitab 17 software (MINITAB, Inc., State College, PA).

RESULTS AND DISCUSSION

Morphological parameters and water content of tomato

Table 3 gives the morphological parameters and moisture content of tomato. Table 3 shows the average morphological parameters and the water content of the fruits used in the experiment. Morphological characteristics were determined on about forty fruits in good quality. In this, the number of lobes for each fruit was counted, the average fruit weight calculated, and the shape coefficient (Cf) determined. The shape coefficient was determined by the formula previously applied by Fagbohoun and Kiki (1999). This factor, which is only the ratio between the average diameter and the average height of the tomato, helps characterize cultivar to which belong the fruits used as well as to classify the varieties in three categories, in particular: Cf <0.8 indicates a flattened shape; Cf >1 indicates an elongated shape and 0.8 <Cf <1 indicates a round shape.

The values obtained indicate that the fruits used, in addition to being of the same variety and cultivated under the same conditions, were of similar sizes and shapes. Obtained value of the form factor (0.81 $\pm$ 0.07), according to the classification of Fagbohoun and Kiki (1999) indicates that the fruits used in this study can be considered round and therefore sufficiently close to the spherical geometry.

The Caribbean tomato variety used in this work is high water content, around 95.78%, makes it a very perishable food material of short shelf life.

Results of the coupling of the osmotic dehydration and the drying of the tomato

The effect of operating parameters on the coupling of

osmotic dehydration and drying of tomato is here presented. We studied the effects of the concentration of the osmotic solution, the duration of impregnation of tomatoes in salty environment, the temperature of osmotic dehydration and the temperature of tomato drying on mass loss; as well as the duration of the drying, the ratio of the mass loss over the drying time and the final water content of the tomato. Finally, mathematical models were developed in order to assess both their linear contributions and the effects of the independent variables on the answers studied.

Effect of operating parameters on the loss of tomato mass

Analysis of variance: The analysis of variance relating to the effect of the operating parameters on the loss of tomato mass is provided in Table 4.

The statistical analysis (ANOVA) shows that the experimental model used significantly influenced tomato mass loss during the process (p-value = 0.005). In this ANOVA, as the p-value for the regression is lower than α = 0.05, it is concluded that the mathematical model is valid and can be used for predictive purposes.

This analysis of the variance shows that osmotic dehydration temperature and osmotic solution concentration are variables that significantly influenced mass loss during the coupling process. The range of temperatures used and the concentration of the osmotic solution induced changes resulting in significant tomato mass losses. This implies that a modification of the concentration of the osmotic solution and the temperature of the osmotic treatment induce the change in tomato mass loss. The duration of the osmotic treatment and the temperature of the drying, in turn, did not induce significant changes in the mass losses.

Effect of the concentration of osmotic solution and the temperature of osmotic dehydration on the mass loss: Figure 1 shows the effect of osmotic solution

Figure 1. Surface of response of loss of mass according to the variables concentration and temperature.

Table 4. Variance analysis of process parameters for mass loss.

Source of variation	DF	Adj SS	MS	F-value	p-value
General model	4	26.6737	6.6684	4.76	0.005
Concentration of solution	1	14.0454	14.0454	10.02	0.004
Temperature of osmotic of dehydration	1	11.0704	11.0704	7.90	0.009
Duration of osmotic dehydration	1	0.7512	0.7512	0.54	0.471
Temperature of drying	1	0.8067	0.8067	0.58	0.455
Error	26	36.4449	1.4017		
Lack of Fit	21	34.2200	1.6295	3.66	0.077
Pure error	5	2.2249	0.4450		
Total	30	63.1186			

DF, Degree of freedom; SC, sum of squared deviations; CM, average square of the gaps.

concentration and osmotic treatment temperature on the mass loss. Figure 1 compares the changes induced by the increase in the temperature of the osmotic treatment with that of the concentration of the osmotic solution on the mass loss of the tomato during the process. There is a continuous linear variation in mass loss with these variables.

Mercali et al. (2010) reported the positive dependence of mass loss on temperature and solute concentration. Figure 1 shows how the solute concentration and the osmotic dehydration temperature affect the mass loss during the coupling process of osmotic dehydration and

drying. A general trend of mass loss rate was observed with these two variables. Previously published works have reported a similar trend on dehydrated carrot cubes (Amami et al., 2007; Singh et al., 2007), pumpkin (Mayor et al., 2006), apricot (Ispir and Türk Togrul, 2009) and chestnut (Chenlo et al., 2007).

The influence of salt concentration and dehydration temperature in terms of mass loss was evaluated using an analysis of variance. Summarized in Table 4, the results of the analysis of the variance confirmed that the concentration and temperature of the osmotic solution had a significant ($p < 0.05$) effect on the mass loss during

Figure 2. Main effects of the operating parameters on the loss of mass of the tomato.

Figure 3. Main effects of the operating parameters on the final water content.

the coupling of osmotic dehydration and drying the tomato. The similar results have been obtained by Ganjloo and Bimakr (2015) on the influence of sucrose concentration and temperature on mass transfer during osmotic dehydration of eggplant (*Solanum melongena* L.) cubes. Figure 2 shows the main effects of the operating parameters on the mass loss during coupling.

Figure 3 provides main effects of the operating parameters on the loss of the mass of tomato. Its reveals that the concentration of the osmotic solution and the temperature of the osmotic treatment influenced significantly the mass loss during the coupling osmotic dehydration-drying tomato, while the duration of the osmotic treatment and the temperature of the drying were demonstrated a negligible effect.

In summary, a decrease in the mass loss of tomato was observed while increasing the concentration of the osmotic solution. A similar effect was observed with an increase of the temperature of the osmotic treatment. It was experimentally demonstrated that increasing the temperature of osmotic dehydration resulted in a

decrease in the loss of tomato mass.

As variable, the effect of temperature in the range of 30-60°C on mass transfer during coupling osmotic dehydration and drying process was analyzed. The experimental results revealed that increasing temperature made intense dehydration by increasing water loss. This variable also affected the Mass loss. Mass transfer acceleration caused by higher temperatures can be associated with the increase in membrane permeability promoting swelling and plasticization of the cell membranes (Lazarides et al., 1995). On the other hand, increasing temperature leads to reduction in solution viscosity and reducing external resistance to mass transfer making easier transport of water and solutes (Tonon et al., 2007). In addition, higher temperatures (>50°C) can lead to adverse effects on tissue, color and aroma of product. In contrast, lower temperatures (<30°C) prevent satisfactory mass transfer characteristics due to reduction of the osmotic medium viscosity. Such findings have been reported for osmotic dehydration of carrot (Singh et al., 2007), tomato (Tonon et al., 2007),

Table 5. Variance Analysis of process parameters for drying time.

Source of variation	DF	Adj SS	MS	F-value	p-value
General model	4	2625.33	656.33	4.01	0.011
Concentration of osmotic solution	1	590.04	590.04	3.61	0.069
Temperature of osmotic dehydration	1	45.38	45.38	0.28	0.603
Duration of osmotic dehydration	1	134.87	134.87	0.83	0.372
Temperature of drying	1	1855.04	1855.04	11.35	0.002
Error	26	4250.41	163.48		
Lack of Fit	21	4182.91	199.19	14.75	0.004
Pure error	5	67.50	13.50		
Total	30	6875.74			

Chestnut (Chenlo et al., 2007) and apricot (Ispir and Türk Togrul, 2009).

Modeling tomato mass loss by regression: The regression equation of mass loss can be written as follows:

Mass Loss (%) = 99.81 - 0.01530 Solution Concentration (g/l) - 0.0906 Temperature of osmotic dehydration (°C) - 0.096 Duration of osmotic dehydration (h) + 0.0367 Temperature of drying (°C)

The mathematical model found using Minitab 17 (MINITAB, Inc., State College, PA) shows that the average effect of the selected factors is 99.81% on the mass loss and the main effect of the osmotic dehydration temperature is 0.09% greater than that of the concentration of the osmotic solution (0.015%). This observation matches a previous report. Themelin (1994) with a concluding remark affirmed that the effect of the temperature is essential and superior to that of the concentration. The model developed therefore shows a greater effect of the temperature on the mass loss. It is indeed known that the phenomenon of osmotic dehydration is a phenomenon converging with the temperature towards an asymptotic value. Such convergence assumes a curvilinear appearance of the response as a function of temperature.

Effect of operating parameters on the drying time of the tomato

Analysis of variance: Table 5 gives the analysis of the variance related to the process parameters for the drying time. The analysis of the variance analysis in Table 5 shows that the general model implemented significantly influenced the drying time during the coupling of osmotic dehydration and tomato drying (p-value = 0.011 and less than $\alpha = 0.05$).

Only the drying temperature of the tomato proved to be an operating variable that significantly influenced the drying time, its p-value being equal to 0.002, less than $\alpha = 0.05$. Even statistically not significant (p-value = 0.069), the concentration of the osmotic solution impacted the tomato drying time as well.

Experimentally, there were observed significant linear changes in tomato mass losses due to the increase of the concentration of the osmotic solution.

Effect of drying temperature and concentration of osmotic solution on drying time during coupling:

Figure 4 shows the effect of the drying temperature and the concentration of the osmotic dehydration solution on the drying time of the tomato. Figure 4 shows how the concentration of the osmotic solution and the drying temperature affect the drying time of the tomato.

Sacilik (2007) observed that temperature influences the change in the moisture content during drying and that the influence of temperature on drying kinetics is important. An increase in the temperature induces a decrease in the water content. These exchanges are less and less important as the drying is done.

Bimbenet et al. (2002) reported that the drying time is not the same for different temperatures and that the drying time decreases with increasing temperature. Figure 4 show that the temperature rise from 40 to 60°C which causes a decrease in the drying time. This influence is due to the increase of the osmotic pressure of the water inside the product which accelerated water migration from the product toward the external layer. The variation of the drying time as affected by the temperature is also explained by the fact that the rise in temperature leads to an increase in the intensity of the heat transfer (Bimbenet et al., 2002).

During the conventional air drying, setting heat and mass transfer results in the removal of moisture by thermal flow with the help of heated air, which flows across the fruit surface. Drying time is shorter with increasing temperatures.

Figure 4. Response surface of the drying time as a function of the osmotic solution concentration and drying temperature variables.

Likewise, the temperature influences the process, and also affects the kinetics of each food type (Pokharkar et al., 1997). Thus, increasing temperatures reduce the drying time in all cases and this time is decreased further when the drying pressure reduces. The same observations have been reported by Correia et al. (2015) on the effect of temperature, time, and material thickness on the dehydration process of tomato.

Concerning the effect of the concentration of the osmotic solution on the drying time, Figure 4 shows that the increase in the concentration of the osmotic solution from 100 to 200 g/L shortens the drying time. This is due to a significant water loss occurring during the osmotic dehydration of tomato proceeding the drying step.

In fact, increasing the concentration of the osmotic solution resulted in an increase in the osmotic pressure gradient salt the interface between the external layer of the tomato and the osmotic solution. As a result for the tomato samples, this led to a higher water losses and solute gains during the osmotic dehydration. Similar results have been reported by Azoubel and Murr (2004). Renzo et al. (2007) who observed that increasing the concentration of the osmotic solution accelerates the flow of water loss. Figure 5 shows the main effects of the operating parameters on the drying time during the tomato coupling process.

Based on the review of the results presented in Figure 5, there were observed the effect of operating parameters on the drying time. Statistically speaking, among studied

variables, the temperature of drying exhibited the major effect, followed by the concentration of the osmotic solution. The temperature and osmotic dehydration time, on the contrary, showed a minor effect on the drying time (see the analysis of the variance in Table 5).

As the concentration of the osmotic solution increases, the drying time of the tomato also increases. This shows that only the use of low concentrations positively impacts the drying time. The increase in the drying temperature, in turn, presented a shortening effect on the drying time. The increase in the osmotic dehydration temperature, although less remarkable, but led to an increase in the duration whereas the increase in the duration of osmotic dehydration leads to a decrease in the drying time.

Modeling tomato mass loss by regression: The regression equation for the mass loss can be written as follows:

$$\text{Drying time (h)} = 129,2 + 0,0992 \text{ Solution concentration (g/L)} + 0,183 T^{\circ} \text{ of the OD } (^{\circ}\text{C}) - 1,29 \text{ Duration of the OD (h)} - 1,758 T^{\circ} \text{ of the drying } (^{\circ}\text{C})$$

The modeling equation of the drying time of the mass loss using the linear regression of the tomato shows that the average effect of the factors is 129.2% on the drying time, the main effects of both the dehydration temperature osmotic and the concentration of the osmotic solution are respectively 0.183 and 0.0992%. On the

Figure 5. Main effects of the operating parameters on the drying time of the tomato.

Table 6. Variance analysis of process parameters for final water content of tomato.

Source of variation	DF	AdjSS	MS	F-value	p-value
General model	4	410.46	102.614	2.21	0.096
Concentration of osmotic solution	1	219.25	219.252	4.71	0.039
Temperature of osmotic dehydration	1	1.16	1.162	0.02	0.876
Duration of osmotic dehydration	1	0.42	0.425	0.01	0.925
Temperature of drying	1	189.62	189.619	4.08	0.054
Error	26	1209.43	46.517		
Lack of Fit	21	1075.09	51.195	1.91	0.245
Pure error	5	134.34	26.867		
Total	30	1619.89			

other hand, those of both the duration of osmotic dehydration and the drying temperature were 1.29 and 1.758% respectively. Among parameters studied in this work, the drying temperature demonstrated the major effect on the drying time.

The model developed therefore revealed by singling out the drying temperature as the major parameter influencing the shortening of the drying time during the coupling osmotic dehydration- drying of the tomato.

Study of the effect of the operating parameters on the final water content of the tomato

Analysis of variance: Table 6 gives the analysis of the variance of the process parameters for the final water content of the dried tomato. In this ANOVA, since the p-value for the regression is much higher (p-value = 0.096) than the threshold at a significant level of 5%, it is

concluded that the mathematical model is not valid and cannot be used at all predictive purposes.

Nevertheless, the variable concentration of the osmotic solution is significantly influential on the final water content of the tomato. Indeed, the range of concentrations used can statistically induce significant variations in the final water content; its p-value being 0.039 and lower than the threshold $\alpha = 0.05$. The drying temperature variable, meanwhile also induces changes in the temperature range used in this work but its influence is less than that of the osmotic solution concentration variable.

Effect of drying temperature and concentration of the osmotic solution on the final water content of the dried tomato: Figure 6 shows the response surface of the final water content of the tomato as a function of the drying temperature and the concentration of the osmotic dehydration.

Surface Plot of final water content vs conc. of osmotic; Drying temperature

Figure 6. Influence of final tomato moisture content as a function of drying temperature and concentration of osmotic dehydration.

The Figure 6 shows how the water loss is dependent on both the drying temperature and the concentration of the osmotic solution. This variation is due to the loss of water during the osmotic dehydration and the drying of the tomato. Mercali et al. (2010) confirmed the positive dependence of water loss on temperature and concentration. The results presented in Figure 6 confirmed that obtained by Kouame et al. (2012) who showed that the greatest loss of water was recorded at high temperatures.

Depending on the final moisture content, dried tomatoes can be divided into 4 categories according to their texture (CEE-ONU, 2007). This is the soft and collapsible textured category (25-50%), the firm but foldable category (18-25%), the very firm category (12-18%) and the hard and brittle category (6-12%). Figure 3 gives the main effects of the operating parameters on the final water content.

The review of obtained results as illustrated in Figure 3 shows that the concentration of the osmotic solution and the drying temperature influence the final water content of the tomato. The concentration of the osmotic solution was statistically more influential than the drying temperature. The increase of these two variables led to the increase of the final water content of the dried tomato. On the other hand, the variables temperature and duration of the osmotic dehydration were not significant. Their variations did not induce any change in the final water content of the dried tomato.

Modeling of the final water content by regression:

The final water content regression equation can be written as follows:

$$\text{Final water (\%)} = -22.5 + 0.0605 \text{ Solution concentration (g/L)} + 0.029 \text{ Temperature of osmotic dehydration (°C)} + 0.072 \text{ Duration of osmotic dehydration (h)} + 0.562 \text{ Temperature of osmotic dehydration (°C) drying (°C)}$$

The experimental data were used to adapt a mathematical model presented previously. The regression equation of the water content of dried tomato shows that the average effect of the factors is 22.5% and the main effect of the temperature of the osmotic dehydration is 0.029%, that of the concentration of the solution osmotic is 0.0605%. On the other hand, that of the duration is 0.072% and that of the drying temperature is 0.562%.

The effect of the concentration of the osmotic solution proved to be essential and superior to those of the other operating parameters studied in this work. The model developed thus shows a greater effect of the concentration of the osmotic solution on the final water content of the dried tomato. The regression equation of the ratio mass loss over drying time shows that the average effect of the factors is 0.356% and the main effect of the temperature of the osmotic dehydration is 0.00394%, that of the concentration of the solution

Figure 7. Optimization of the responses studied according to the operating variables.

osmotic is 0.00263%. On the other hand, that of the duration is 0.00263% and that of the drying temperature is 0.0352%.

The effect of the drying temperature was still essential and superior to those of the other operating parameters studied in this work. The model developed thus shows a greater contribution of the drying temperature on the ratio mass loss over drying time during the coupling osmotic dehydration-drying of the tomato.

Optimization of the answers obtained

In order to optimize our experimental operating conditions, a combinatorial multi-criteria approach was carried out, which consisted in choosing from the set of multiple combinations the optimal conditions. The later were determined by applied the methodology of the response surfaces (RSM) by comparing and generating the best combination with optimal conditions.

This optimization consists in finding the optimal values of the operating variables to achieve optimal mass loss by, concomitantly shortening the drying time with a lowered final water content of the tomato. The studied

optimization method is a mathematical/numerical approach based on the partial nulls cancellation of the global quadratic model. The optimal values determined using the Minitab V.17 software are shown in Figure 7.

Figure 7 allows us to determine the optimal operating conditions for the coupling of dehydration and drying of the tomato and the optimal values of the responses obtained. Thus, it emerges from these results, on the optimization of the responses studied as a function of the operating variables, that the solution is all the more interesting in the experimental conditions of the study that it corresponds to working using a chloride solution. At a concentration of 100 g/L, an osmotic solution (made of 100 g/L solution chloride) warmed at 30°C was used to undergo an osmotic dehydration during 8 h, followed by a drying at 52.5°C during 42 h, which induced a tomato mass loss evaluated at 96.71% with 14.51% of the final water content.

Conclusion

The present work aimed specifically at evaluating the effect of the following operating parameters: temperature

(30-60°C), concentration of the osmotic solution (100-300 g of cooking salt per liter), the duration of the treatment (1-8 h) and drying temperature (40-60°C) on mass loss, drying time, mass loss ratio over drying time and final water content of the tomato during the coupling process and to model this phenomenon in order to select the optimal operating conditions.

Conducted variance analyzes showed that sodium chloride is an important osmotic dehydrating agent. The mass losses, the drying time, the final water content of the tomato are, in general, as a logical sequence dependent on these operating parameters. The concentration of the osmotic solution and the temperature of the osmotic dehydration are the parameters that influence tomato mass loss during the coupling process. The concentration of the osmotic solution and the drying temperature are the key parameters influencing the drying time of the tomato. The final water content of the dried tomato is similarly influenced by the two abovementioned operating parameters.

Mathematical models to predict the mass loss, the drying time, and the final water content of tomato, based on the 3 operating parameters, are proposed in this work. These models also help to define optimal treatment conditions based on the constraints of these processes. An efficient set of operating parameters have been determined. In particular a 100 g/L of sodium chloride solution warmed at 30°C and a duration of the osmotic dehydration of 8 h coupled with a drying at 52.5°C. This serial process resulted in a total drying time of 42 h with a maximum tomato mass loss of 96.71% and a final water content of 14.51%.

REFERENCES

- Amami E., Fersi A., Vorobiev E. & Kechaou N. (2007). Osmotic dehydration of carrot tissue enhanced by pulsed electric field, salt and centrifugal force. *J. Food Eng.* 83:605-613.
- Anonyme (2006). *Mémento de l'agronome*. Inra, France.
- Azoubel P. M. & Murr F. E. X. (2004). Mass transfer kinetics of osmotic dehydration of cherry tomato. *J. Food Eng.* 61:291-295.
- Azuara E., Beristain C. I. & Crustorrez G. M. (1998). A method for continuous chemists Arlington. Food Research International.
- Bimbenet J. J., Duquenoy A. & Trystram G. (2002). *Génie des procédés alimentaires : des bases aux applications*; Dunod: Paris.
- Bonazzi C. & Bimbenet J. J. (2003). *Séchage des produits alimentaires*. Principes. Technique de l'ingénieur F3000, vol agroalimentaire.
- CEE-ONU (2007). Norme CEE-ONU DDP- 19 concernant la commercialisation et le contrôle de la qualité commerciale des tomates séchées. Version 200. New York, Genève. 8p.
- Chenlo F., Moreira R., Fernández-Herrero C. & Vázquez G. (2007). Osmotic dehydration of chestnut with sucrose: Mass transfer processes and global kinetics modelling. *J. Food Eng.* 78:765-774.
- Correia A. F. K., Loro A. C., Zanatta S., Spoto M. H. F. & Vieira T. M. F. S. (2015). Effect of temperature, time, and material thickness on the dehydration process of tomato. *Int. J. Food Sci.* Article ID: 970724. 7p.
- Fagbohoun O. & Kiki D. (1999). Aperçu sur les principales variétés de tomate locales cultivées dans le sud du Bénin. *Bulletin de la Recherche Agronomique du Bénin*. 24: 10-21.
- FAO (2016). Production mondiale de tomates. Planetoscope.
- Ganjloo A. & Bimakr M. (2015). Influence of sucrose solution concentration and temperature on mass exchange during osmotic dehydration of eggplant (*Solanum melongena* L.) cubes. *Int. Food Res. J.* 22(2):807-811.
- Ghidelli C., Mateos M., Rojas-argudo C. & Pérezgago M. B. (2013). Effect of antioxidants on enzymatic browning of eggplant extract and fresh-cut tissue.
- Igwe E. C. & Isonguyo E. N. in Kapseu and Kayem, (1999). International workshop on drying and improvement of shea and canarium. Presses universitaires de Yaoundé, Cameroun. Pp. 213-220.
- Ispir A. & Türk Togrul I. (2009). Osmotic dehydration of apricot: Kinetics and the effect of process parameters. *Chem. Eng. Res. Design.* 87:166180.
- Kouame P., Assidjo N. & N'goran S. (2012). Etude de l'influence des paramètres de la déshydratation osmotique sur la perte en eau des fruits tropicaux: essais avec la papaye (*Carica papaya*) et mangue (*Mangifera indica*). *J. Appl. Biosci.* 59:4330-4339.
- Lazarides H. N., Katsanidis E. & Nikolaidis A. (1995). Mass transfer kinetics during osmotic preconcentration aiming at minimal solid uptake. *J. Food Eng.* 25:151-166.
- Mayor L., Moreira R., Chenlo F. & Sereno A. M. (2006). Kinetics of osmotic dehydration of pumpkin with sodium chloride solutions. *J. Food Eng.* 74:253-262.
- Mercali G. D., Ferreira Marczak L. D., Tessaro I. C. & Zapata Norena C. P. (2010). Evaluation of water, sucrose and NaCl effective diffusivities during osmotic dehydration of banana (*Musa sapientum*, shum). *LWT- Food Science and Technology* in Press.
- Naika S., Lidt de Jeude J. van, Goffau M. de, Hilmi M., Dam B. van (2005). *Culture de la tomate: production, transformation et Commercialisation*. Didigrafi, Wageningen, Pay-bas.
- Pokharkar S. M., Prasad S. & Das H. (1997). A model for osmotic concentration of banana slices. *J. Food Sci. Technol.* 34(3):230-232.
- Renzo M., Fernandez R. M., Norena C. P. Z. & Brandelli A. (2007). Osmotic dehydration of Muskmelon (CUCUMIS MELO): Influence of blanching and syrup concentration. *J. Food Process. Preserv.* 31(4):392-405.
- Sacilik K. (2007). The thin-layer modeling of tomato drying process. *Agriculturae Conspectus Scientificus.* 72(4):343-349.
- Singh B., Kumar A. & Gupta A. K. (2007). Study of mass transfer kinetics and effective diffusivity during osmotic dehydration of carrot cubes. *J. Food Eng.* 79:471-480.
- Themelin A. (1994). Optimisation des procédés combinés de déshydratation par immersion dans les solutions concentrées et de change par entraînement à l'air chaud. Thèse de doctorat, ENSIAA, Massy.
- Tonon R. V., Baroni A. F. & Hubinger M. D. (2007). Osmotic dehydration of tomato in ternary solutions: Influence of process variables on mass transfer kinetics and an evaluation of the retention of carotenoids. *J. Food Eng.* 82:509-517.
- Uddin M. B., Ainsworth P. & Ibanoglu S. (2004). Evaluation of mass exchange during osmotic dehydration of carrots using response surface methodology. *J. Food Eng.* 65:473-47.
- Vinson J. A., Hao Y., Su X. & Zubik L. (1998). Phenol antioxidant quantity and quality in foods: vegetables. *J. Agric. Food Chem.* 46(9):3630-3634.