

## FOAM MAT DRYING OF TOMATO PULP

### SECAGEM DE POLPA DE TOMATE PELO MÉTODO DE CAMADA DE ESPUMA

**Regiane Victória de Barros FERNANDES<sup>1</sup>; Fabiana QUEIROZ<sup>2</sup>; Diego Alvarenga BOTREL<sup>3</sup>; Vitangela Vieira ROCHA<sup>4</sup>; Carla Ferreira de LIMA<sup>5</sup>; Vívian Raquel de SOUZA<sup>4</sup>**

1. Engenheira de Alimentos, Mestre, Universidade Federal de Lavras - UFLA, Departamento de Ciência dos Alimentos, Lavras, MG, Brasil. [regiane.fernandes@ufv.br](mailto:regiane.fernandes@ufv.br); 2. Engenheira de Alimentos, Doutora, Departamento de Ciência dos Alimentos - UFLA, Lavras, MG, Brasil; 3. Engenheiro de Alimentos, Doutor, Universidade Federal de Viçosa - UFV, Rio Paranaíba, MG, Brasil; 4. Química, Especialista, UFV, Rio Paranaíba, Minas Gerais, Brasil; 5. Bacharel em Ciência e Tecnologia de Laticínios, Especialista, UFV, Rio Paranaíba, Minas Gerais, Brasil.

**ABSTRACT:** The purpose of this study was to optimize the formulation of tomato pulp foam and to evaluate the drying process using the foam mat method at temperatures of 60°C and 80°C. The optimization was conducted by analyzing the effect of the albumin concentration (expressed in %) and whipping time (expressed in minutes) in relation to the response variables of foam density and thermal stability of the foam based on the volume of remaining foam. The drying curves (moisture versus drying time ratio) for the control treatment (CT; no albumin addition) and optimized treatment (OT) were obtained. The results showed that only the whipping time variable (linear and quadratic effects) had significant influence ( $p < 0.05$ ) on the foam density values. The foam stability was significantly influenced by the whipping time ( $p < 0.10$ ) and albumin concentration ( $p < 0.10$ ). The optimum foam formation conditions considering higher foam stability and lower density included a 4.5% albumin concentration and a 4.5 minutes of whipping time. The results of the drying curves showed that the foam formation with albumin significantly reduced ( $p < 0.05$ ) the time necessary to reach moisture equilibrium during drying. The moisture equilibrium values were not significantly different ( $p > 0.05$ ) among the treatments with foam application at the studied temperatures, but they were lower than the treatments without foam application.

**KEYWORDS:** Dehydration. Albumin. Response surface methodology. Optimization.

### INTRODUCTION

The interest for tomato-based products has been increasing due to their consumption being correlated to the decreased risk of some cancer types and cardiovascular diseases (GIOVANNUCCI et al., 2002; TAPIERO et al., 2004) as well as their practicality in culinary dishes (LENUCCI et al., 2006).

Drying is one of the most used processes to improve food stability because it considerably reduces the water activity of the material, reduces the microbiological activity and minimizes physical and chemical alterations during storage (MAYOR; SERENO, 2004). Drying by foam is a process in which a liquid is beaten by various means to form a stable foam that is then dehydrated by evaporation of the water in the form of a thin layer (LEWICKI, 2006). The main advantages of foam drying are lower temperatures and shorter drying times compared to drying non-foamed materials in the same dryer type (THUWAPANICHAYANAN et al., 2012). Foam has these advantages because it increases the surface area by the incorporation of air/gas, increases the heat and mass transfer and forms a porous structure that provides an instantaneous dry product with high quality and properties (PRAKOTMAK et al., 2010).

Furthermore, the capillarity via the foam pores facilitates moisture loss, which makes the foam mat drying approximately three times faster than the drying of a similar layer of liquid (FRANCIS, 2000).

Foaming properties include the capacity of formation of an air in water dispersion, which is due to the volume expansion of the dispersion promoted by an emulsifier with incorporation of air through whipping, agitation or aeration techniques (THUWAPANICHAYANAN et al., 2012). The structure, expansion and stability of the foam provide an important function in the movement of the moisture during drying and, consequently, in the food quality (BAG et al., 2011; THUWAPANICHAYANAN et al., 2011). Thermally stable foam retains its porous structure, which aids in its rebuilding. In contrast, the collapse of foam increases the drying time, reduces the rehydration and deteriorates the color, texture, flavor and nutritional value of the food (RATTI; KUDRA, 2006).

Various products are used to aid in foam formation, such as protein and monoglycerides, as well as in the stabilization of the emulsions formed, such as gums, methylcellulose and jellies. Egg albumin is an example of an efficient foaming agent that has been used in various studies (FALADE et

al., 2003; RAHARITSIFA et al., 2006; KADAM et al., 2012).

Foam drying allows for the processing of biomaterials that are difficult to dry, such as tomato paste and also allows for the production of materials that can easily rehydrate and retain several quality indicators, such as color, aroma, texture and nutritional values. The main objectives of this study were to optimize the albumin concentration and whipping time in the formation of stable foam and to evaluate the efficiency of tomato pulp drying by the foam mat method at two temperatures (60°C and 80°C).

## MATERIAL AND METHODS

Italian tomatoes (Saladete) were acquired in the local commerce of the city of Carmo do Paranaíba-MG at the commercial maturation stage. The tomatoes were washed under running water and sanitized with a 200 mg/kg solution of sodium hypochlorite (Sumaveg) and the excess sanitizing solution was removed with a 3 mg/kg solution of sodium hypochlorite. The samples were then subjected to pulp extraction. The tomatoes were sliced in four pieces and submitted to trituration for 30 seconds using a blender. After this process, the pulp was filtered using a nylon sieve to separate the seeds and peel. The pH and moisture of the tomato pulp were determined according to methodology described by the Instituto Adolfo Lutz (2005) and the total titratable acidity was determined according to methodology recommended by the AOAC (2002) for colored samples. The soluble solids were

determined by refractometry (Atago portable refractometer) with direct reading expressed in °Brix. After weighing, the tomato pulp and powdered albumin were mixed and homogenized in a blender for 30 seconds. The incorporation of air was performed by the use of a mixer at maximum rotation (Arno Ciranda Chrome Automatic).

The effect of the albumin concentration (expressed in %; m/m) and whipping time (expressed in minutes) on the stability of the formed foam was studied. In the present study, a rotatable central composite design (CCD) was adopted ( $2^2$ ) with 4 axial points and 3 central points with a total of 11 assays (Table 1) (MONTGOMERY, 2001). The optimum condition of the foam formation was determined evaluating the results of the two response variables: foam density (expressed in  $\text{g}\cdot\text{cm}^{-3}$ ) and thermal stability of the foam (expressed in %;  $100 \times \text{volume of remaining foam} / \text{initial foam volume}$ ). The density was determined filling a 50mL graduated cylinder with the foam produced followed by measurement of the corresponding mass (KARIM; WAI, 1999a; SANKAT; CASTAIGNE, 2004). The stability was determined by measuring the volume of the remaining foam in a 50mL graduated cylinder that was initially full after being heated in an oven at 70°C for 60 minutes (SANKAT; CASTAIGNE, 2004). The foams were mounted on slides with distilled water and covered by coverslips and the morphological characteristics of the foams were visualized using an *Olympus* CX31 optical microscope.

**Table 1.** Rotatable central composite design for foam formulation.

Assay	Coded variables		Process variables	
	$x_1$	$x_2$	Albumin concentration (%)	Whipping time (minutes)
1	-1	-1	1.5	1.5
2	-1	1	1.5	7.5
3	1	-1	7.5	1.5
4	1	1	7.5	7.5
5	-1.41	0	0.3	4.5
6	1.41	0	8.7	4.5
7	0	-1.41	4.5	0.3
8	0	1.41	4.5	8.7
9	0	0	4.5	4.5
10	0	0	4.5	4.5
11	0	0	4.5	4.5

For the determination of the optimum albumin concentration value and whipping time, the combination of these variables that provided the lowest density and the highest foam stability (higher remaining volume) was considered ideal. This

determination was performed using the *Response Desirability Profiling* function of the Statistica software (StatSoft v.8) according to methodology described by Derringer and Suich (1980).

The drying of the foam was conducted in an oven with forced air circulation and a digital thermometer (Cienlab, Brazil). The foam was deposited evenly in aluminum trays (flat circular trays measuring 40cm in diameter and 4mm high) by filling the trays with a 2mm high foam mass to occupy the entire surface of the drying tray. The foam drying processes of the control treatment (CT) (tomato pulp without albumin addition) and the optimized treatments (OTs) with albumin addition were compared at two drying temperatures (60°C and 80°C). These experiments were repeated three times. To obtain the drying curves, each tray with foam was weighed at 15 minute intervals for 1 hour and every 30 minutes after until a constant weight was reached with a mass variation of less than 0.2% (m/m), i.e., when the moisture equilibrium was reached at the temperature of the drying air. The drying curve using the moisture ratio (MR) was built plotting a moisture level versus drying time

graph for all of the treatments (CT and OT). The MR values were calculated using Equation 1 as follows:

$$MR = \frac{(M_t - M_{eq})}{(M_i - M_{eq})} \quad (1)$$

where  $M_t$  is the dry basis moisture at the study time;  $M_{eq}$  is the dry basis moisture equilibrium; and  $M_i$  is the initial dry basis moisture. The moisture values were determined according to methods described by the Instituto Adolfo Lutz (2005) and the moisture values were expressed as dry basis moisture ( $M_{bs}$ ).

## RESULTS AND DISCUSSION

The results of the physicochemical analysis of *in natura* tomato pulp are shown in Table 2. Similar values were found by Thyboa et al. (2006) and Pinela et al. (2012).

**Table 2.** Mean values and standard deviation of the physicochemical characteristics of *in natura* tomato pulp.

Variables	Mean ± SD
pH	4.16 ± 0.02
Acidity (g/100g)	0.34 ± 0.02
Moisture (wet basis) (%)	95.93 ± 0.07
Soluble solids (°Brix)	4.0 ± 0.1

SD = Standard deviation

The study of the effect of whipping time and albumin concentration for the preparation of foams was based on evaluating the foam density and foam structure stability by determining the remaining volume. According to Bates (1964), who studied the drying of foamed tropical fruits from concentrate, juice, nectar and purée in an oven at 71°C, foams that do not collapse during the first minutes can be considered structurally stable for the entire drying period. Thermally stable foams maintain their

porous structure, which aids in their rebuilding. In contrast, the collapse of the foam increases the drying time, reduces the rehydration and deteriorates the color, texture, flavor and nutritional value (RATTI; KUDRA, 2006).

For the statistical analysis of the foam formulation optimization, the linear and quadratic effects of the albumin concentration and whipping time as well as the interaction with the response variables were analyzed (Table 3).

**Table 3.** Response variable averages for the different treatments.

Assay	Process variables		Results	
	Albumin concentration (%)	Whipping time (minutes)	Foam density (g.cm <sup>-3</sup> )	Foam stability (%)
1	1.5	1.5	0.406	42.0
2	1.5	7.5	0.303	28.0
3	7.5	1.5	0.435	77.0
4	7.5	7.5	0.266	24.0
5	0.3	4.5	0.401	24.0
6	8.7	4.5	0.307	31.0
7	4.5	0.3	0.507	48.0
8	4.5	8.7	0.330	48.0
9	4.5	4.5	0.311	54.0
10	4.5	4.5	0.318	58.0
11	4.5	4.5	0.323	45.0

For foam density, only the whipping time with linear and quadratic effects was significant at a 5% level of probability. The  $R^2$  value was 83.74%, which indicated good correlation between the obtained data and model (Table 4). The linear effect of the whipping time was negative and the quadratic effect of the whipping time was positive, thereby

indicating the existence of a value or a range of whipping time values that provided a minimum density. A lower whipping time resulted in a more significant increase in the foam density. The albumin concentration did not significantly influence the density of the material.

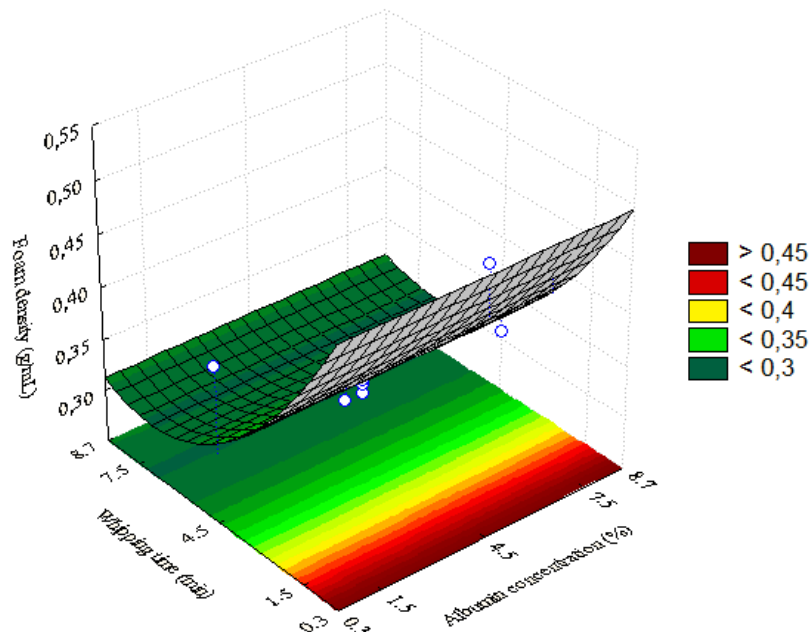
**Table 4.** Analysis of the effects of each factor in the described model for variables coded for foam density.

Factor	Effects	Standard error	t(7)	P
Mean	0.327	0.014	23.924	0.000
Whipping time (L)	-0.131	0.023	-5.680	0.001
Whipping time (Q)	0.078	0.026	2.990	0.017

The encoded mathematical model for foam density ( $\text{g}\cdot\text{cm}^{-3}$ ) is represented by Equation 2 with an  $R^2$  value of 83.74% as follows:

$$\text{Foam density} = 0.327 - 0.065x_2 + 0.039x_2^2 \quad (2)$$

Analysis of the response surface graph (Figure 1) indicated that whipping times of approximately 7.0 minutes resulted in lower density values (approximately  $0.30\text{g}\cdot\text{cm}^{-3}$ , which is of interest when dealing with dry foam.



**Figure 1.** Graph of foam density ( $\text{g}\cdot\text{cm}^{-3}$ ) response surface in function of whipping time and albumin concentration.

Foam density is a factor commonly used to evaluate whipping properties. Higher amounts of air incorporated during whipping results in lower foam densities with more air present within the foam (FALADE et al., 2003; THUWAPANICHAYANAN et al., 2012). The foam density decreased with increased whipping time. After the initial decrease, however, a slight increase in the density was noticed after 7.0 minutes of whipping. Raharitsifa et al. (2006) studied the

foam drying of apple juice using egg white and methylcellulose as foaming agents and they reported similar behavior of the density variation with increased whipping times in which longer times may have caused excessive whipping and led to the collapse of the structure. Higher degrees of aeration result in the liquid between the bubbles being thinner and mechanical deformation can cause the foam to rupture (FALADE et al., 2003).

Lower density values provide a greater contact surface area and greater contact surface area exposed to the drying air accelerates water removal (THUWAPANICHAYANAN et al., 2012). However, other studies have pointed to capillarity as the main moisture movement during foam drying (SANKAT; CASTAIGNE, 2004). The foam densities obtained in the present work varied between  $0.27\text{g}\cdot\text{cm}^{-3}$  and  $0.51\text{g}\cdot\text{cm}^{-3}$ . These values were close to the range of values recommended for the foam drying process ( $0.3$  to  $0.6\text{g}\cdot\text{cm}^{-3}$ ) according to Ratti and Kudra (2006), except for the 7.5% albumin and 7.5 minute whipping time treatment, which formed foam with a density of  $0.27\text{g}\cdot\text{cm}^{-3}$ . The average density obtained for the *in natura* tomato pulp was  $0.94\text{g}\cdot\text{cm}^{-3}$ . Lower densities indicate more air retained in the foam structure (THUWAPANICHAYANAN et al., 2012). Thus, low density values can lead to the collapse of the structure and, consequently, low stability of the foam.

The stability directly characterizes the water retention capacity of the foam. A way of

determining the stability of the foam is to evaluate the amount of liquid that drains from its structure (KAMPF et al., 2003). The drainage is accompanied by a progressive thinning in the lamella and can increase the probability of the film collapse (DURIAN; WEITZ, 1994), which is also evidenced by the reduction of the foam volume over the course of time. In the present study, the quadratic factor of albumin concentration significantly influenced the foam stability at a probability level of 10% and the  $R^2$  value was 71.29% (Table 5). The quadratic effect of the albumin concentration was negative, indicating that the albumin concentration values that provided a higher stability resulted in a higher remaining volume. The linear factor of the whipping time was also significant ( $p < 0.10$ ). An increase in whipping time resulted in a reduction in the stability of the foam, which mainly occurred in higher albumin concentration ranges. Although non-significant, several factors were maintained in the regression model due to the reduction of the determination coefficient.

**Table 5.** Analysis of the effects of each factor in the model described for the coded variables for foam stability.

Factor	Effects	Standard error	t(6)	p
Mean	51,480	4,730	10,883	0,000
Albumin concentration (L)	10,248	7,967	1,286	0,246
Albumin concentration (Q)	-21,884	9,094	-2,407	0,053
Whipping time (L)	-16,800	7,967	-2,109	0,080
Albumin concentration x Whipping time	-19,500	11,250	-1,733	0,134

The coded mathematical model for foam stability (% of remaining foam volume) is represented by equation 3 with an  $R^2$  value of 71.29% as follows:

$$\text{Foam stability} = 51.48 + 5.12x_1 - 10.94x_1^2 - 8.40x_2 - 9.75x_1x_2 \quad (3)$$

Analysis of the response surface graph (Figure 2) indicated that albumin concentration values greater than 4.5% provided higher remaining volumes reaching estimated values approximately 70%. Shorter whipping times resulted in higher foam stability and whipping times less than 1.0 minute provided the highest foam stability. Two regions in the graph presented extremely low foam stability. The combinations of low whipping time and albumin concentration levels as well as high whipping time and albumin concentration levels led to foam formation with low stability where the estimated remaining volume was less than 20%.

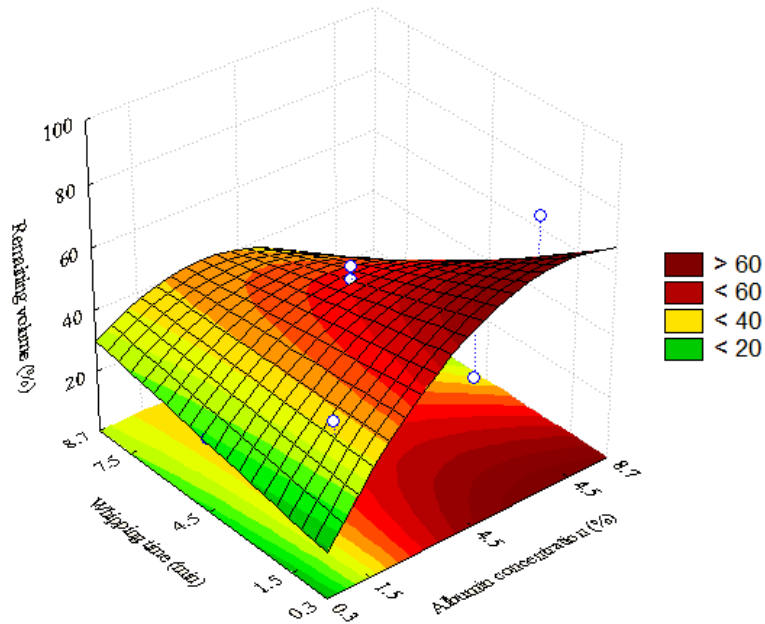
Higher foam stabilities result in the porous structures being maintained for a longer time during the drying process, thereby contributing to faster

water evaporation from the product. If the foam is broken or the drainage is excessive, the drying time is increased, which reduces the product quality (BAG et al., 2011). According to Ratti and Kudra (2006), foams that do not collapse for at least one hour are considered mechanically stable. Thermal stability (stability in the oven) is critical for foam drying. The addition of foam stabilizing agents (usually high molecular weight and water soluble biopolymers) can help prevent the collapse of the structure during drying by changing the rheological properties of the product. For example, the inclusion of glyceryl monostearate contributes to the formation of more stable foam in banana pulp (FALADE; OKOCHA, 2010).

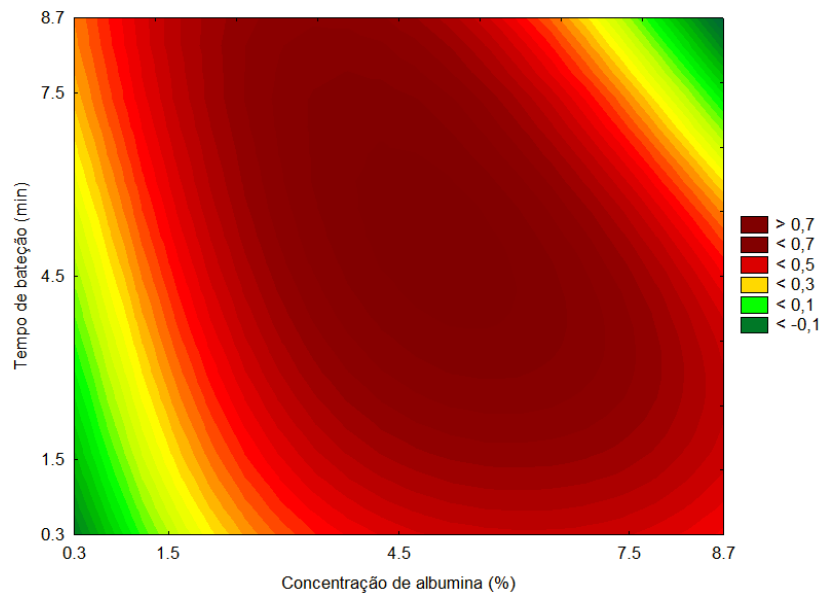
A combination of the independent variables that supplied the best foam formation values was suggested based on previous results and on the optimization process. One of the conditions that provided low foam density values and high foam stability values was selected as the optimal combination, which included 4.5% albumin and a whipping time of 4.5 minutes, because it had a

desirability value of 0.80. This formulation was used in the drying process study as compared to a control formulation (without albumin addition). The

contour graph for the desirability function indicating the optimized area is illustrated in Figure 3.



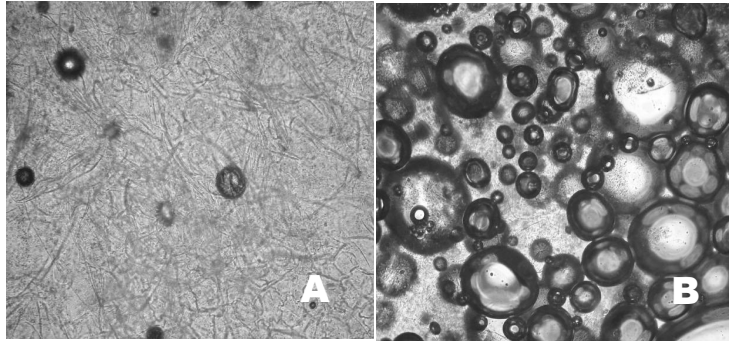
**Figure 2.** Response surface graph for foam stability measured by the remaining foam volume (%) produced in function of whipping time and albumin concentration.



**Figure 3.** Contour curve of the desirability function for whipping time (minutes) and albumin concentration (%) and variables

The structure of the pulp with and without albumin addition after whipping as visualized under the optical microscope is shown in Figure 4. In general, an efficient incorporation of air was observed when albumin was used at a concentration

of 4.5% and a whipping time of 4.5 minutes. Moreover, whipping for 4.5 minutes without albumin addition was not enough to form foam with the tomato pulp.



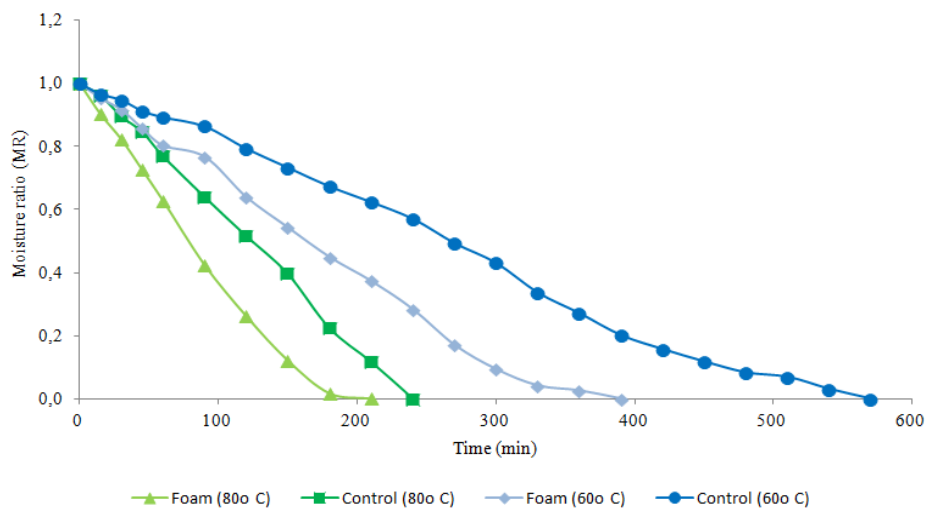
**Figure 4.** Treatment without albumin addition (A) and with addition of 4.5% albumin (B) after whipping for 4.5 minutes.

The effect of the temperature (60°C and 80°C) was studied on the tomato pulp drying process with (4.5%) or without (Control; CT) albumin in addition to a whipping time of 4.5 minutes. Drying temperatures in the range of 60-80°C does not significantly affect the textural properties and shrinkage of foams (THUWAPANICHAYANAN et al., 2008).

Figure 5 shows the variation of the moisture ratio (Equation 1) in function of the drying time for the conducted treatments. The occurrence of foam formation caused reduction in the time to the moisture equilibrium to be reached during drying at

both studied temperatures. The drying times to reach moisture equilibrium at 60°C were 400 and 590 minutes for the treatments with and without foam formation, respectively. The drying times to reach moisture equilibrium at 80°C were less than those at 60°C with drying times of 180 and 240 minutes for the treatments with and without foam formation, respectively.

In general, the drying of foamed materials is faster when compared to materials lacking foaming agents, which has been demonstrated for the drying of star fruit (KARIM; WAI, 1999b) and bananas (SANKAT; CASTAIGNE, 2004).



**Figure 5.** Drying kinetics at 60°C and 80°C for tomato pulp with and without albumin addition on a dry basis.

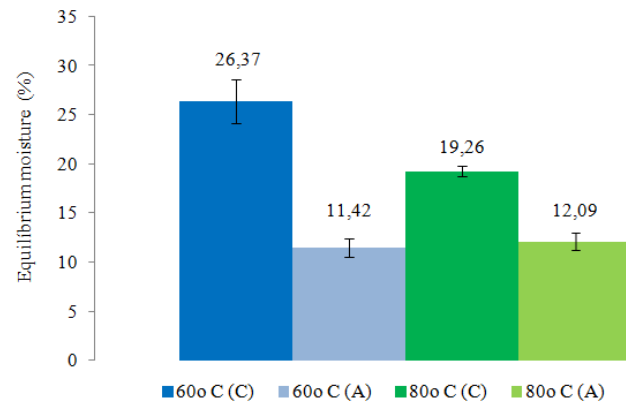
In addition to accelerating the transport of liquid water to the evaporation front, studies have repeatedly pointed to the increase of the foam interface area as the main factor responsible for the reduction in the drying time (KUDRA; RATTI, 2006).

In addition to favoring a higher water removal speed, the drying processes for foam at the

two studied temperatures provided the lowest moisture equilibrium values (Figure 6). The moisture equilibrium values did not present a significant difference ( $p > 0.05$ ) among the foam treatments at 60°C and 80°C with values remaining close to 12%. However, the moisture equilibrium values were significantly different ( $p < 0.05$ ) among the treatments without albumin addition with higher

moisture values at 60°C as compared to 80°C. At 60°C and 80°C, the treatments with and without albumin addition were significantly different ( $p <$

0.05) with the treatments lacking albumin addition having the highest moisture values.



C = control without albumin addition; (A) = addition of 4.5 % albumin

**Figure 6.** The moisture (on a wet basis) at the end of the drying process at 60°C and 80°C for tomato pulp with and without albumin addition.

In general, the tomato pulp powder produced without albumin addition presented a dark red color with small particle sizes and rubbery characteristics, which negatively affected the reconstitution of the powders. In contrast, the powders with albumin addition presented an orange color and the structure was porous with free drainage particles without the occurrence of aggregation, which is an important factor when reconstituting powder.

## CONCLUSIONS

The foam formation in tomato pulp was optimized based on high stability values and low

density values of the produced foam, therefore providing stable foam with great expansion.

The values of the response variables were predicted through second-order polynomial models. A 4.5% albumin concentration with a 4.5 minute whipping time resulted in foam with better quality. With this combination, the values of stability (expressed in remaining volume) and foam density were 53.55% and  $0.32\text{g}\cdot\text{cm}^{-3}$ , respectively.

In addition to less drying time, the drying of the tomato pulp via the foam mat method with albumin addition provided lower moisture equilibrium values as compared to pulp without albumin addition. The temperature increase reduced the drying time for the pulps with and without albumin addition.

**RESUMO:** Este trabalho foi realizado com o objetivo de otimizar a formulação de espuma da polpa de tomate e avaliar o processo de secagem através do método de camada de espuma, nas temperaturas de 60°C e 80°C. A otimização foi realizada analisando-se o efeito da concentração de albumina expressa em % e tempo de bateção expresso em minutos em relação às variáveis respostas densidade da espuma e estabilidade térmica da espuma, baseado no volume de espuma remanescente. Obteve-se a curva de secagem (razão de umidade versus tempo de secagem) para o tratamento controle (TC), sem adição de albumina, e o tratamento otimizado (TO). Os resultados mostraram que somente a variável tempo de bateção (efeito linear e quadrático) teve influência significativa ( $p < 0,05$ ) nos valores de densidade de espuma. A estabilidade da espuma foi influenciada significativamente pelo tempo de bateção ( $p < 0,10$ ) e concentração de albumina ( $p < 0,10$ ). As condições ótimas de formação de espuma encontradas foram concentração de albumina de 4,5% e tempo de bateção de 4,5 minutos, considerando maior estabilidade de espuma e menor densidade. Os resultados das curvas de secagem mostraram que a formação de espuma com o uso de albumina reduziu significativamente ( $p < 0,05$ ) o tempo para que se atingisse a umidade de equilíbrio durante a secagem. Os valores de umidade de equilíbrio não apresentaram diferença significativa ( $p > 0,05$ ) entre os tratamentos com aplicação de espuma nas temperaturas estudadas, porém foram menores que os tratamentos sem aplicação de espuma.

**PALAVRAS-CHAVE:** Desidratação. Albumina. Metodologia de superfície de resposta. Otimização.



**REFERENCES**

- ADOLFO LUTZ. **Métodos físico-químicos para análise de alimentos** 4 ed. Brasília: Ministério da Saúde, 2005.
- AOAC. **Official methods of analysis** 17th ed. Gaithersburg, MD: Association of Official Analytical Chemists, 2002.
- BAG, S. K.; SRIVASTAV, P. P.; MISHRA, H. N. Optimization of process parameters for foaming of bael (*Aegle marmelos* L.) fruit pulp. **Food and Bioprocess Technology**, v. 4, n. 8, p. 1450-1458, 2011.
- BATES, R. P. Factors affecting foam production and stabilization of tropical fruit products. **Food Technology**, Chicago, v. 18, n. 1, p. 93-96, 1964.
- DERRINGER, G.; SUICH, R. Simultaneous optimization of several response variables. **Journal of Quality Technology**, Milwaukee, v. 12, n. 4, p. 214-219, 1980.
- DURIAN, D. J.; WEITZ, D.A. In M. H. Grant (Ed.). **Encyclopedia of chemical technology**. New York: Wiley, 1994.
- FALADE, K. O.; OKOCHA, J. O. Foam-mat drying of plantain and cooking banana (*Musa* spp.). **Food and Bioprocess Technology**, v. 5, n. 4, p. 1173-1180, 2010.
- FALADE, K. O.; ADEYANJU, K. I.; UZO-PETERS, P. I. Foam-mat drying of cowpea (*Vigna unguiculata*) using glyceryl monostearate and egg albumin as foaming agents. **European Food Research and Technology**, Berlin, v. 217, n. 6, p. 486-491, 2003.
- FRANCIS, F. J. **Encyclopedia of Food Science and Technology** 2 Ed. New York: John Wiley & Sons, 2000.
- GIOVANNUCCI, E.; RIMM, E. B.; LIU, Y.; STAMPFER, M. J.; WILLETT, W. C. A prospective study of tomato products, lycopene, and prostate cancer risk. **Journal of the National Cancer Institute**, Cary, v. 94, p. 391-398, 2002.
- KADAM, D. M.; WILSON, R. A.; KAUR, S.; MANISHA. Influence of foam mat drying on quality of tomato powder. **International Journal of Food Properties**, Muscat, v. 15, p. 211-220, 2012.
- KAMPF, N.; GONZALEZ, M. C.; CORRADINI, M. G.; PELEG, M. Effect of two gums on the development, rheological properties and stability of egg albumen foams. **Rheologica Acta**, v. 42, n. 3, p. 259-268, 2003.
- KARIM, A. A.; WAI, C. C. Characteristics of foam prepared from starfruit (*Averrhoa carambola* L.) puree by using methyl cellulose. **Food Hydrocolloids**, v. 13, p. 203-210, 1999a.
- KARIM, A. A.; WAI, C. C. Foam-mat drying of starfruit (*Averrhoa carambola* L.) puree. Stability and air drying characteristics. **Food Chemistry**, Barking, v. 64, p. 337-343, 1999b.
- KUDRA, T.; RATTI, C. Foam-mat drying: energy and cost analyses. **Canadian Biosystems Engineering**, Winnipeg, v. 48, p. 27-32, 2006.
- LENUCCI, M.S.; CADINU, D.; TAURINO, M.; PIRO, G.; DALESSANDRO, G. Antioxidant composition in cherry and high-pigment tomato cultivars. **Journal of Agricultural and Food Chemistry**, Washington, v. 54, p. 2606-2613, 2006.
- LEWICKI, P.P. Design of hot air drying for better foods. **Trends in Food Science and Technology**, v. 17, n. 4, p. 153-163, 2006.

MAYOR, L.; SERENO, A. M. Modelling shrinkage during convective drying of food materials: a review. **Journal of Food Engineering**, Amsterdam, v. 61, n. 3, p. 373–386, 2004.

MONTGOMERY, D. C. **Design and analysis of experiments** 5th ed. New York: John Wiley and Sons, 2001.

PINELA, J.; BARROS, L.; CARVALHO, A. M.; FERREIRA, I. C. F. R. Nutritional composition and antioxidant activity of four tomato (*Lycopersicon esculentum* L.) farmer varieties in Northeastern Portugal homegardens. **Food and Chemical Toxicology**, Oxford, v. 50, p. 829–834, 2012.

PRAKOTMAK, P.; SOPONRONNARIT, S.; PRACHAYAWARAKORN, S. Modelling of moisture diffusion in pores of banana foam mat using a 2-D stochastic pore network: Determination of moisture diffusion coefficient during adsorption process. *J. Food Eng.* 96,119–126. **Journal of Food Engineering**, Amsterdam, v. 96, p. 119–126, 2010.

RAHARITSIFA, N.; GENOVESE, D. B.; RATTI, C. Characterization of Apple Juice Foams for Foam-mat Drying Prepared with Egg White Protein and Methylcellulose. **Journal of Food Science**, Chicago, v. 71, n. 3, p. 141-151, 2006.

RATTI, C.; KUDRA, T. Drying of Foamed Biological Materials: Opportunities and Challenges. **Drying Technology**, v. 24, p. 1101–1108, 2006.

SANKAT, C. K.; CASTAIGNE, F. Foaming and drying behaviour of ripe bananas. **LWT - Food Science and Technology**, Zürich, v. 37, p. 517–525, 2004.

TAPIERO, H.; TOWNSEND, D. M.; TEW, K. D. The role of carotenoids in the prevention of human pathologies. **Biomedicine Pharmacotherapy**, Paris, v. 58, p. 100–110, 2004.

THUWAPANICHAYANAN, R.; PRACHAYAWARAKORN, S.; SOPONRONNARIT, S. Effects of foaming agents and foam density on drying characteristics and textural property of banana foams. **LWT - Food Science and Technology**, Zürich, v. 47, p. 348-357, 2012.

THUWAPANICHAYANAN, R.; PRACHAYAWARAKORN, S.; KUNWISAWA, J.; SOPONRONNARIT, S. Determination of effective moisture diffusivity and assessment of quality attributes of banana slices during drying. **LWT-Food Science and Technology**, Zürich, v. 44, p. 1502-1510, 2011.

THUWAPANICHAYANAN, R.; PRACHAYAWARAKORN, S.; SOPONRONNARIT, S. Drying characteristics and quality of banana foam mat. **Journal of Food Engineering**, Amsterdam, v. 86, p. 573-583, 2008.

THYBOA, A. K.; EDELENBOSA, M.; CHRISTENSENA, L. P.; SØRENSEN, J. N.; THORUP-KRISTENSEN, K. Effect of organic growing systems on sensory quality and chemical composition of tomatoes. **LWT - Food Science and Technology**, Zürich, v. 39, n. 8, p. 835–843, 2006.