Journal of Food Processing and Preservation ISSN 1745-4549

FOAM-MAT DRYING OF CANTALOUPE (*CUCUMIS MELO*): OPTIMIZATION OF FOAMING PARAMETERS AND INVESTIGATING DRYING CHARACTERISTICS

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Received for Publication April 14, 2014
Accepted for Publication October 27, 2014

doi:10.1111/jfpp.12414

ABSTRACT

In the present study, foam-mat drying technique is used to dry cantaloupe pulp into powder. Foaming conditions, namely amount of egg white powder, xanthan gum and whipping time, optimized using response surface methodology for minimizing foam density and drainage volume. To evaluate drying behavior of the optimized foam, drying was carried out in a batch-type thin-layer dryer at three drying temperatures (40, 55 and 70C) on 3- and 5-mm thicknesses. Ten thin-layer drying models were evaluated in the kinetics research. Based on the statistic tests performed, Weibull distribution model can describe drying behavior of foams for all drying processes. Moreover, Fick's second law was employed to calculate the effective moisture diffusivity that varied from 3.283×10^{-9} to 9.483×10^{-9} m^2/s and from 4.053×10^{-9} to 1.216×10^{-8} m^2/s with activation energy values of 31.714 and 33.043 kJ/mol for foam thicknesses of 3 and 5 mm, respectively.

PRACTICAL APPLICATIONS

Cantaloupe (*Cucumis melo*) is a popular fruit and widely consumed in the world. Cantaloupe has many potential health benefits, but it is seasonal fruit and its shelf life is limited. Moreover, cantaloupe is sensitive to high-temperature processes. Foam-mat drying is an alternative for preservation of cantaloupe in the form of dried powder using medium temperatures. Cantaloupe pulp powder have a longer shelf life and may be a suitable source of β-carotene and vitamin C. This powder, because of its ability to contribute special characteristics such as flavor, color and water-binding properties to the final product, can be used as instant beverages, ingredients for bakery or extruded cereal products, ice cream, yogurt as well as pharmaceutical tablets.

INTRODUCTION

Cantaloupe has many potential health benefits as it contains vitamins, minerals and pigments, which provide high antioxidant and anti-inflammatory properties (Vouldoukis *et al.* 2004). Cantaloupe is an excellent source of vitamin C and a good source of vitamin A, vitamin B_6 as well as potassium. One hundred grams of cantaloupe provides 61.17 and 67.64% of the daily value for vitamin C and vitamin A, respectively (Solval *et al.* 2012). However, Cantaloupe is a highly perishable fruit with short storage life which is limited to approximately 2 weeks (Ayhan *et al.* 1998). Because of the pleasant aroma and high sugar content, cantaloupe is a suitable raw material for the juice industry (Vaillant *et al.* 2005). Cantaloupe and its products are sensitive to high-temperature treatments, because thermal processing of cantaloupe pulp results in off-flavor formation, color, vitamins and aromatic compound degradation (Hayashi 1996). The use of suitable technologies in the food industry might reduce the processing time and improve the industrial operating conditions, resulting in high-quality products that preserve the natural characteristics of foods (Butz and Tauscher 2002; Cárcel *et al.* 2011). Using drying medium may transfer and convert thermal energy into materials to improve the drying process with the suitable qualities of the final product, such as high nutritional value and rich flavor (Zheng *et al.* 2011). Foam-mat drying can be used to heat-sensitive, sticky, viscous and high-sugar content food products, which are difficult to dry (Labelle 1984). This method includes drying a thin layer of foamed materials, followed by disintegration of the dried mat to yield a powder. It has been successfully applied to many fruits and other food materials such as soy milk (Akintoye and Oguntunde 1991), star fruit (Karim and Wai 1999), cowpea (Falade *et al.* 2003), apple juice (Raharitsifa *et al.* 2006), mango (Rajkumar *et al.* 2007), banana (Thuwapanichayanan *et al.* 2008), mandarin (Kadam *et al.* 2011), tomato juice (Kadam and Balasubramanuan 2011), sea buckthorn (Kaushal *et al.* 2011) and shrimp (Azizpour *et al.* 2013). Because of the porous structure of the foamed materials, mass transfer is enhanced leading to shorter drying times and consequently acquiring higher quality in the dried product (Brygidyr *et al.* 1977). The foam properties such as structure, density and stability have important influence on moisture migration during drying and accordingly, the quality of final product. Foams that do not collapse for at least 1 h are mechanically or thermally stable for the entire drying process (Ratti and Kudra 2006). Egg white (EW) with its excellent foaming properties is a suitable candidate for foam-mat drying. It has been used for foaming of various tropical fruits such as mango, mandarin and banana. Often stability of foams made only by EW is not adequate for foam-mat drying. Thus, the addition of food stabilizers would enhance the stability and also plays an important role in improving the drying process. Xanthan gum (XG) is one of the widely used polysaccharides in food process manufacturing. XG forms cohesive flexible films, thus contributing stability to foams and emulsions. Therefore, it has been used as stabilizer, thickener and foam enhancer in different food products (Symers 1980). The effect of heat on the performance of XG is usually negligible.

Response surface methodology (RSM) is a combination of mathematical and statistic techniques and is used to investigate the interaction effects of independent variables on responses (Saxena *et al.* 2010; Shanker *et al.* 2010). Bag *et al.* (2011) used RSM to optimize the process parameters for foaming of bael (*Aegle marmelos* L.) fruit pulp to achieve maximum foam expansion and stability. The process parameters for microwave-assisted foam-mat drying of blackcurrant were also optimized using RSM (Zheng *et al.* 2011). There is considerable information on foam-mat dried fruit juice powders, but there is not any scientific literature that related to study on foam-mat drying of cantaloupe. The main objectives of this study were: (1) to optimize the effective parameters (EW and XG concentration, and whipping time [WT]) in foaming cantaloupe pulp; (2) to study the effects of drying temperature and foam thickness on the drying characteristics and select a suitable model for thin-layer drying of foam; and (3) to compute effective moisture diffusivity and activation energy of foam during drying.

MATERIALS AND METHODS

Materials

Fresh cantaloupe (*Cucumis melo*) was obtained from the local market (Mashhad, Iran). XG and EW powders were purchased from Sigma Chemical Company (St. Louis, MO) and Gol Powder Company, Golestan Province, Iran, respectively.

Sample Preparation

Fresh cantaloupes were cut, peeled and diced into smaller pieces. Cantaloupe pulp was extracted using a blender (Robert Bosch Standmixer MMB 2000 /05 FD 8611 Type CNSM03EV, 600W, Slovenia). Based on preliminary tests, XG solutions were prepared by dissolving a suitable amount of the selected gum powder in distilled water and stirring with a magnetic stirrer to obtain a uniform solution. The resulted solutions were refrigerated at 4C for 18–24 h to complete hydration. XG solutions were prepared to give a final concentration of 0.05, 0.13 and 0.2 % w/w.

Foam Preparation

A glass beaker was used as a container to form the foam. According to the experimental design, to prepare 100 g of samples, appropriate amount of cantaloupe pulp, EW and XG solution were poured to a 250-mL beaker. The mixture then was whipped with a mixer (Gosonic, model No. GHM-818, 250W, China) with maximum speed of 5,400 rpm at ambient temperature during given time, which was recommended by Design-Expert software version 6.02 (Stat-Ease, Inc., Minneapolis, MN).

Experimental Design

RSM was used to estimate the main effects of the process variables on foam density (FD) and drainage volume (DV) in cantaloupe pulp foam. The experiment was established based on a face-centered central composite design (CCD). In this experimental design, three coded levels for each variable were selected: −1, 0 and +1 corresponded to the low-level, mid-level and high-level of each independent variable, respectively. The independent variables and representative coded and uncoded levels are given in Table 1. The experimental range was chosen on the basis of the results of preliminary tests. The independent variables were consisted of EW (1–3% w/w), XG (0.05–0.2% w/w) and WT (2–10 min). CCD generated 20 runs to investigate the effect of

TABLE 1. INDEPENDENT VARIABLES AND THEIR LEVELS IN THE CENTRAL COMPOSITE DESIGN

Independent variables	Coded values		
	−1	0	+1
X_1: egg white (g/100 g)	1	2	3
X_2: xanthan gum (g/100 g)	0.05	0.13	0.2
X_3: whipping time (min)	2	6	10

independent variables on FD and DV (Table 2). Because some systematic errors and therefore some unexplained variability may occur in the observed responses, experiments were replicated (six replications) in the center of design to make the approximation of pure error possible (Qiu *et al.* 2010). To investigate the behavior of the response surfaces, a second-order polynomial equation was fitted to the experimental data of each independent variable as given later:

$$Y = \beta_0 + \sum_{i=1}^{3}\beta_i X_i + \sum_{i=1}^{3}\beta_{ii} X_{ii}^2 + \sum_{i=1}^{2}\sum_{j=i+1}^{3}\beta_{ij} X_i X_j \qquad (1)$$

where, Y is the estimated response (i.e., FD and DV); β_0, β_i, β_{ii}, and β_{ij} are constant coefficients and X_i and X_j represent the coded independent variables. The adequacy of regression model and the goodness of fit were determined by model analysis, lack-of-fit, and coefficient of determination

TABLE 2. CENTRAL COMPOSITE DESIGN AND EXPERIMENTAL DATA OBTAINED FOR THE RESPONSE VARIABLES

	Independent variables			Response	
Run no	EW (X_1)	XG (X_2)	WT (X_3)	FD (g/cm^3)	DV (mL)
1	2 (0)	0.2 (+1)	6 (0)	0.586 ± 0.008	2 ± 1.0
2	2 (0)	0.13 (0)	10 (+1)	0.525 ± 0.010	4 ± 0.0
3	1 (−1)	0.2 (+1)	2 (−1)	0.847 ± 0.011	3.5 ± 0.5
4	2 (0)	0.05 (−1)	6 (0)	0.518 ± 0.010	13.5 ± 0.5
5	2 (0)	0.13 (0)	6 (0)	0.556 ± 0.009	5 ± 1.0
6	3 (+1)	0.2 (+1)	2 (−1)	0.687 ± 0.013	0 ± 0.0
7	1 (−1)	0.13 (0)	6 (0)	0.664 ± 0.008	5 ± 0.0
8	2 (0)	0.13 (0)	6 (0)	0.560 ± 0.010	5 ± 1.0
9	1 (−1)	0.2 (+1)	10 (+1)	0.690 ± 0.012	2 ± 0.5
10	2 (0)	0.13 (0)	6 (0)	0.550 ± 0.009	4 ± 0.5
11	3 (+1)	0.2 (+1)	10 (+1)	0.532 ± 0.010	0 ± 0.0
12	3 (+1)	0.05 (−1)	2 (−1)	0.582 ± 0.011	15 ± 1.0
13	2 (0)	0.13 (0)	2 (−1)	0.681 ± 0.012	5 ± 1.0
14	2 (0)	0.13 (0)	6 (0)	0.572 ± 0.010	5 ± 0.0
15	3 (+1)	0.13 (0)	6 (0)	0.480 ± 0.012	3.5 ± 0.5
16	3 (+1)	0.05 (−1)	10 (+1)	0.454 ± 0.009	13 ± 0.0
17	1 (−1)	0.05 (−1)	2 (−1)	0.732 ± 0.011	17 ± 1.5
18	2 (0)	0.13 (0)	6 (0)	0.555 ± 0.010	4 ± 0.0
19	1 (−1)	0.05 (−1)	10 (+1)	0.617 ± 0.008	16 ± 1.0
20	2 (0)	0.13 (0)	6 (0)	0.565 ± 0.011	4 ± 0.5

DV, drainage volume; EW, egg white; FD, foam density; XG, xantham gum; WT, whipping time.

parameters (Lee *et al.* 2000; Kaur *et al.* 2009). The response surfaces for these models were plotted as a function of two variables, while keeping other variable at the average value. The surface graphic presentation of the response surface models, analysis of variance (ANOVA) and evaluation of the regression models were performed using Design-Expert software.

Determination of Foam Properties

FD. The density of foamed cantaloupe pulp was determined in terms of mass over volume and expressed in g/cm^3. Fifty milliliters of foam was poured into a 50-mL graduated cylinder and weighed at ambient temperature (22–25C) (Bag *et al.* 2011). The foam transferring was carried out very carefully to prevent destruction of its structure and trapping the air voids were avoided while filling the cylinder (Karim and Wai 1999).

DV. Many factors such as drainage, film rupture and disproportionation of bubbles can be used to determine stability of foams. Generally, measuring the drainage of foam is one of the best methods to determine foam stability. In order to the assessment of foam stability, the drainage test was performed based on the method described by Narender and Pal (2009) and Bag *et al.* (2011) with slight modification. In the modified method, the foam (50 g) was filled into a Buchner filter with a diameter of 80 mm, which was covered with mesh cloth and was placed on a 25-mL graduated cylinder. The amount of liquid (mL), which separated from the foam by natural gravity collected in the measuring cylinder was recorded as a result of drainage after 1 h at ambient temperature (22–25C). Measurements of FD and DV were carried out in duplicate and averages were reported.

Drying of Cantaloupe Pulp Foam

Cantaloupe pulp foam was dried using a batch-type cabinet drier (Soroush Medical Company, Khorasan Razavi Province, Iran) equipped with a centrifugal fan. For the foam-mat drying of cantaloupe pulp, the optimized foam was spread uniformly on aluminum plates with a diameter of 10 cm and thicknesses of 3 and 5 mm (load of 12 ± 0.01 g and 20 ± 0.01 g of foam, respectively), and then put into the drying chamber. The foam thickness was obtained by multiplying the known density of foam by drying area. Drying was carried out under different air temperatures (40, 55 and 70C) and a superficial air velocity of 1.5 m/s. Moisture loss from the foams was determined at regular intervals by weighing the plate outside the drying chamber using an electronic balance (model AND.EK-300i, A&D Company, Japan) with accuracy of ± 0.01 g. Drying was continued to gain constant moisture content. Experiments were performed in triplicate.

Drying rate (DR) is one of the important parameters that helps toward the understanding of the drying characteristics of a material. The DR of cantaloupe pulp foam was calculated using Eq. 2:

$$\mathrm{DR} = \frac{M_{\mathrm{t}} - M_{\mathrm{t+\Delta t}}}{\Delta t} \tag{2}$$

where $M_{\mathrm{t+\Delta t}}$ is moisture content at $\mathrm{t} + \Delta\mathrm{t}$ (kg water/kg dry solid), t is the time (min) and $\Delta\mathrm{t}$ is time difference (min).

Mathematical Modeling of Drying Curves

Moisture content of cantaloupe pulp foam during thin-layer drying was expressed in term of moisture ratio (MR) using the following equation (Erenturk *et al.* 2004; Kadam *et al.* 2009):

$$\mathrm{MR} = \frac{M_{\mathrm{t}} - M_{\mathrm{e}}}{M_{\mathrm{i}} - M_{\mathrm{e}}} \tag{3}$$

where M_{t}, M_{i} and M_{e} are moisture content at any time of drying, initial moisture content and equilibrium moisture content (kg water/kg dry solid), respectively. To select a suitable model for describing drying process of cantaloupe pulp foam, drying curves were fitted with 10 thin-layer drying MR models (Table 3). The constants and coefficients of the selected models were computed using MathWorks Matlab version 7.8.0 (R2009a) software. The fitting quality of the proposed models was evaluated based on the primary statistic criterions such as determination of coefficient (R^2), reduced chi-square (χ^2) and root mean square error (RMSE) (Ertekin and Yaldiz 2004; Akpinar 2006). The model with the highest values of R^2 and lowest values of χ^2 and RMSE was selected as best model describing thin-layer drying characteristics of cantaloupe pulp foam.

Determination of Effective Moisture Diffusivity and Computation of Activation Energy

The knowledge of effective moisture diffusivity and activation energy is essential for designing and modeling mass transfer in food-processing operations such as drying. The effective moisture diffusivity was calculated using method of slopes (Maskan *et al.* 2002; Goyal *et al.* 2007). A Fick's diffusion model with slab geometry was used to describe the transport of moisture during drying inside a single cantaloupe pulp foam mat. The following equation is expressed as Crank (1975):

$$\mathrm{MR} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} exp\left(-\frac{(2n-1)^2 \pi^2 D_{\mathrm{eff}} t}{4L^2}\right) \tag{4}$$

where, MR is moisture ratio, $n = 1, 2, 3 \ldots$ is number of terms taken into consideration, t is drying time (s), D_{eff} is effective moisture diffusivity ($\mathrm{m^2/s}$) and L is foam thickness (m). By taking the first term of Eq. (4) for long drying times, it can be simplified as Eq. (5) and expressed in a logarithmic form (Falade and Solademi 2010):

$$\ln(\mathrm{MR}) = \ln\left(\frac{8}{\pi^2}\right) - \left(\frac{\pi^2 D_{\mathrm{eff}} t}{4L^2}\right) \tag{5}$$

From Eq. (5), a plot of ln(MR) versus drying time gives a straight line with a slope (K) that can be used to determine the D_{eff}:

$$K = \frac{\pi^2 D_{\mathrm{eff}}}{4L^2} \tag{6}$$

The effective moisture diffusivity can be related to temperature by a simple Arrhenius-type relationship as given in Eq. (7) (Lopez *et al.* 2000; Akpinar *et al.* 2003):

$$D_{\mathrm{eff}} = D_0 \exp\left(-\frac{E_{\mathrm{a}}}{RT}\right) \tag{7}$$

where, D_0 is the pre-exponential factor of Arrhenius equation ($\mathrm{m^2/s}$), E_{a} is the activation energy (kJ/mol), R is the universal gas constant (kJ/mol.K) and T is the absolute temperature (K). Activation energy was calculated by plotting the $\ln(D_{\mathrm{eff}})$ against the reciprocal of absolute temperature ($1/T$).

TABLE 3. THIN-LAYER DRYING MATHEMATICAL MODELS FITTED TO THE MOISTURE RATIO (MR) VALUES

Model name	Model equation	Reference
Newton	$\mathrm{MR} = \exp(-kt)$	Lemus-Mondaca *et al.* 2009
Page	$\mathrm{MR} = \exp(-kt^n)$	Sun *et al.* 2007
Henderson and Pabis	$\mathrm{MR} = a\exp(-kt)$	Akgun and Doymaz 2005
Two-term	$\mathrm{MR} = a\exp(-bt) + c\exp(-dt)$	Zielinska and Markowski 2010
Modified Henderson and Pabis	$\mathrm{MR} = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	Sacilik *et al.* 2006
Logarithmic	$\mathrm{MR} = a\exp(-kt) + c$	Liu *et al.* 2009
Wang and Sing	$\mathrm{MR} = 1 + at + bt^2$	Uribe *et al.* 2011
Approximation of diffusion	$\mathrm{MR} = a\exp(-kt) + (1-a)\exp(-kbt)$	Menges and Ertekin 2005
Midilli–Kucuk	$\mathrm{MR} = a\exp(-kt^n) + bt$	Vega-Gálvez *et al.* 2011
Weibull distribution	$\mathrm{MR} = a - b\exp(-kt^n)$	Babalis *et al.* 2006

RESULTS AND DISCUSSION

The results of FD and DV with different combinations of independent variables are presented in Table 2. The quadratic model was selected as a suitable statistic model for both FD and DV. ANOVA showed this model is highly significant ($P < 0.01$) for both responses (FD and DV). Moreover, lack-of-fit was not significant for response surface models at 99% confidence level, indicating this model is adequately accurate for predicting responses (Table 4).

Effect Process Variables on Foam Properties

FD. The foamability can simply be evaluated through the measurement of the FD (Wilde and Clark 1996). The higher amount of incorporated air during whipping, the higher the foam expansion; the higher amount of air presented in the foam, the higher the whipability (Falade *et al.* 2003).

ANOVA (Table 4) indicated that FD was highly significant at 1% level on linear terms of EW, XG and WT. There was no significant interaction term, but quadratic terms of EW and WT had significant effect at 5 and 1% level, respectively. After neglecting the no significant terms in Eq. (1) by backward elimination procedure, the final empirical model in terms of coded factors that have significant effect on FD was presented as following equation:

$$FD = 0.973 - 0.169X_1 + 0.586X_2 - 0.062X_3 + 0.022X_1^2 + 3.674 \times 10^{-3} X_3^2 \quad (8)$$

where, X_1 is EW concentration (g/100 g), X_2 is XG concentration (g/100 g) and X_3 is WT (min). From the Eq. (8), it can be understood that an increase in the negative coefficients of the first-order terms (EW and WT), FD will be decreased while increase in the positive coefficient (XG) would lead to increase of FD. Additionally, any increase in the quadratic terms, will cause increase in FD. The variation of FD with EW, XG and WT are graphically shown in the 3-D surface plots (Fig. 1a,b). It can be seen that increasing the EW from 1 to 3%, will make the FD to be decreased significantly ($P < 0.01$). From the figure, it is observed that increasing XG concentration had the adverse effect on the foam expansion and leaded to increase in FD. When XG is added to any liquid it increases the viscosity of the liquid. Viscous liquid would prevent the trapping of air during whipping or mechanical mixing which results in reduction of the foam expansion (Bikerman 1973). These consequences are in agreement with results reported for the foam-mat drying of other fruits such as star fruit (Karim and Wai 1999) and bael fruit (Bag *et al.* 2011). Increasing WT resulted to decrease FD. During the whipping process, air was brought into the liquid puree and entrapped in the liquid as bubbles that led to a decrease in FD. Density of the cantaloupe pulp foam differed from 0.454 to 0.847 g/cm^3 (Table 2).

TABLE 4. ANALYSIS OF VARIANCE EVALUATION OF LINEAR, QUADRATIC, AND INTERACTION TERMS FOR EACH RESPONSE VARIABLE AND COEFFICIENT OF PREDICTION MODELS

		Foam density				Drainage volume		
Source	df	Coefficient	Sum of squares	*P* value	df	Coefficient	Sum of squares	*P* value
Model	9	0.947	0.16	< 0.0001**	9	29.916	537.30	< 0.0001**
X_1	1	−0.157	0.066	< 0.0001**	1	−1.371	14.40	0.0004**
X_2	1	0.511	0.019	< 0.0001**	1	−248.992	448.90	< 0.0001**
X_3	1	−0.056	0.050	< 0.0001**	1	−0.468	3.02	0.0386*
X_1X_2	1	-8.866×10^{-3}	3.380×10^{-6}	0.9122	1	−0.833	0.033	0.8137
X_1X_3	1	-3.625×10^{-4}	1.682×10^{-5}	0.8060	1	0.0156	0.031	0.8127
X_2X_3	1	−0.029	5.951×10^{-4}	0.1645	1	0.625	0.28	0.4394
X_1^2	1	0.020	1.549×10^{-3}	0.0360*	1	0.045	5.682×10^{-3}	0.9199
X_2^2	1	1.058	3.943×10^{-5}	0.7075	1	630.303	34.57	< 0.0001**
X_3^2	1	3.534×10^{-3}	8.134×10^{-3}	0.0002**	1	0.018	0.24	0.5177
Residual	10		2.645×10^{-3}		10		5.34	
Lack-of-fit	5		1.557×10^{-3}	0.3520^{ns}	5		3.84	0.1628^{ns}
Pure error	5		1.088×10^{-3}		5		1.50	
Total	19		0.17		19		542.64	
R^2		0.9841				0.9901		
Adj- R^2		0.9698				0.9813		
Pre- R^2		0.9358				0.9210		
Adeq Precision		34.171				32.712		

* Significant at 5% level.

** Significant at 1% level.

df, degrees of freedom; ns, lack-of–fit, is not significant at $P > 0.05$.

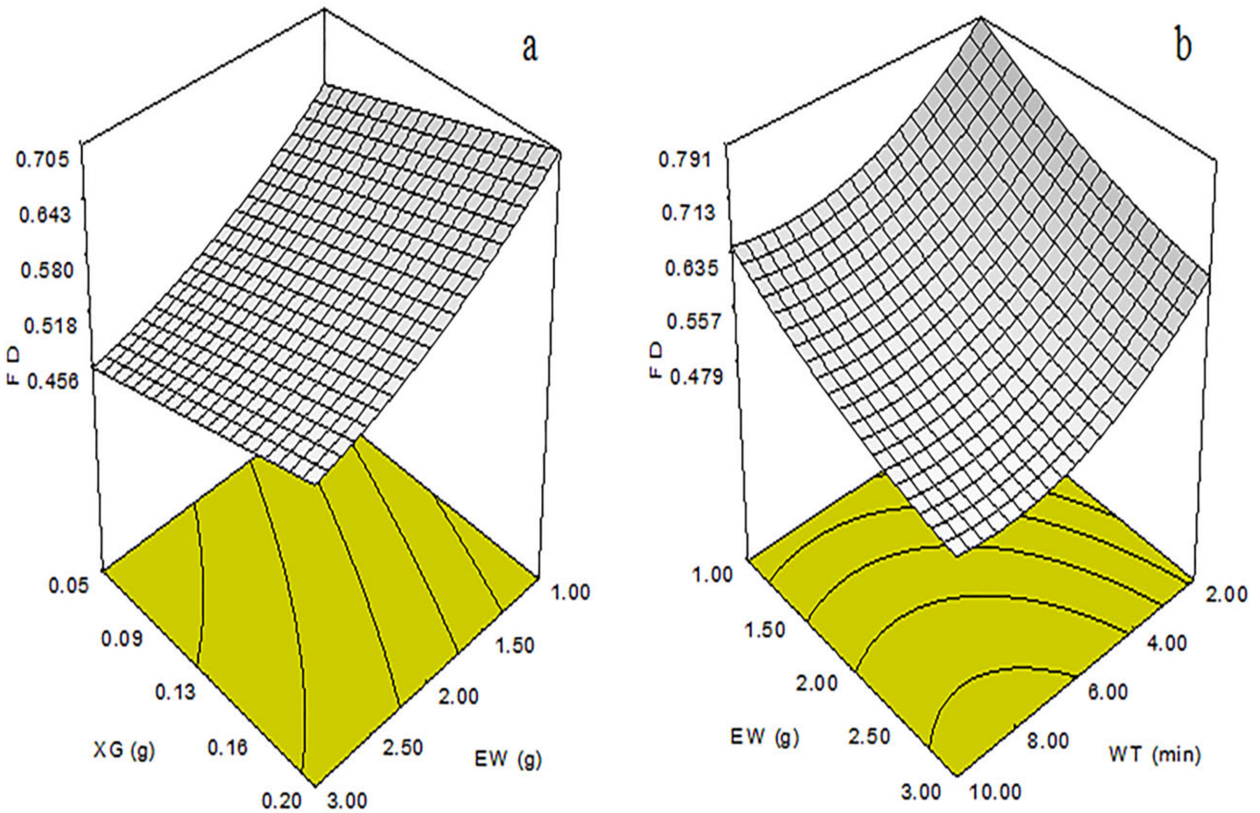

FIG. 1. RESPONSE SURFACE AND CONTOUR PLOTS FOR FD. (A) EFFECTS OF EW AND XG ON FD; (B) EFFECTS OF EW AND WT ON FD
EW, egg white; FD, foam density; XG, xanthan gum; WT, whipping time.

DV

Determination of foam stability is important and is the key step in studying foam properties. Drainage is the liquid flow through foam driven by capillary forces or external forces such as gravity. Foam stability is influenced by the physical and rheological properties of the interface and the continuous phase. Thickness of the interface, foam size distribution, interface permeability and surface tension are effective on DV (DeVries 1958). ANOVA (Table 4) shows that the linear terms of EW, XG and WT as well as quadratic term of XG have a significant effect on DV. After neglecting the insignificant terms of Eq. (1) by backward elimination procedure, the final empirical model in terms of coded factors that have significant effect on DV was presented as follows:

$$DV = 29.258 - 1.20X_1 - 256X_2 - 0.137X_3 + 666.667X_2^2 \quad (9)$$

where X_1, X_2 and X_3 are EW (g/100 g), XG (g/100 g) and WT (min), respectively. The variations of DV of the cantaloupe pulp foam with different combinations of the process parameters are graphically shown in the 3-D surface plot (Fig. 2a,b). From the figure, it can be observed that the addition of foam stabilizer plays a significant role in the stability of foam ($P < 0.01$). Foam is more stable at high viscosity because increasing the viscosity of the aqueous phase, leads to the creation of a network structure in the bulk phase that would keep the interfacial wall from easily breaking, which causes to improve foam stability (Prins 1988). As expected, increasing amount of EW from 1 to 3% led to decrease in drainage ($P < 0.01$). The increase in foaming agent led to increase in viscosity and yield stress of the continuous phase, and/or to increase in the thickness and strength of the adsorbed films at the air–water interface (Carp *et al.* 1997; Karim and Wai 1999; Eduardo *et al.* 2001). Moreover, as the WT increased, the DV was decreased ($P < 0.05$). Increasing WTs causes to more denaturation of EW proteins that leads to form a stable foam. Similar results were reported by Raharitsifa *et al.* (2006). DV of the foam differed from 0 to 17 mL (Table 2). The lowest liquid drainage indicates that there is a good interaction between cantaloupe pulp, EW and XG in term of stability.

The optimum values of variables for best product quality in terms of minimum FD and DV corresponded to EW 3% (w/w), XG 0.17% (w/w) and WT 8.80 min. The amount of FD and DV for foam at these optimum conditions were $0.501 \pm 0.011 g/cm^3$ and 0.25 ± 0.15 ml, respectively.

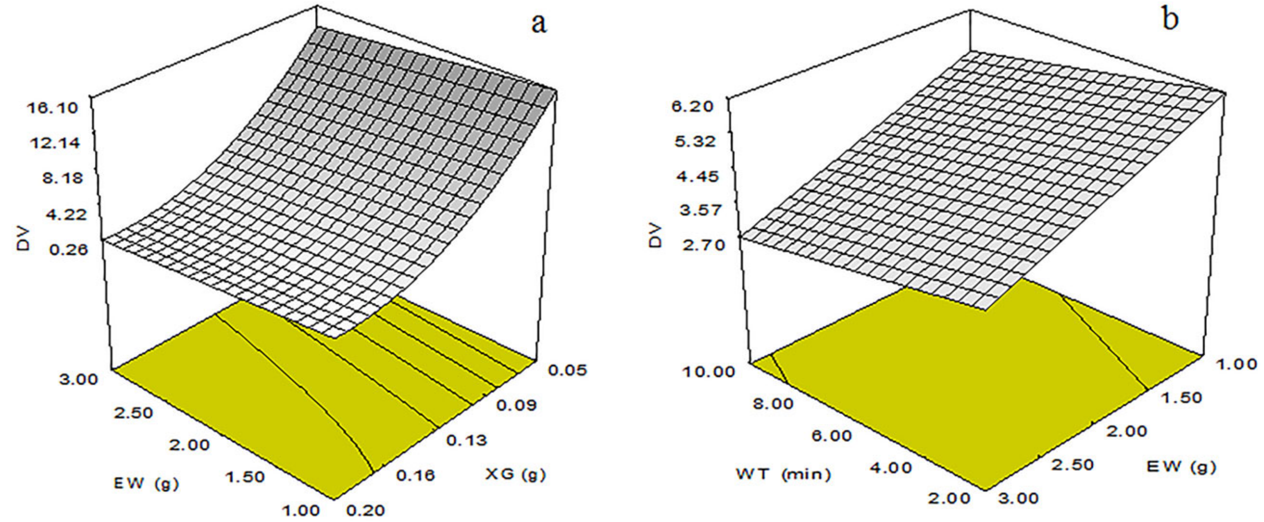

FIG. 2. RESPONSE SURFACE AND CONTOUR PLOTS FOR DV. (A) EFFECTS OF XG AND EW ON DV; (B) EFFECTS OF EW AND WT ON DV
DV, drainage volume; EW, egg white; XG, xanthan gum; WT, whipping time.

Drying Characteristics of Cantaloupe Pulp Foam

Drying curves of cantaloupe pulp foams produced with two foam thickness of 3 and 5 mm in different drying air temperatures of 40, 55 and 70C are shown in Fig. 3. As shown in this figure, the increase in drying temperature and decrease in foam load led to acceleration of the dehydration of cantaloupe pulp foam. The drying study showed that times required to drying foamed cantaloupe pulp in thicknesses of 3 and 5 mm with drying air temperatures of 40, 55 and 70C were 140, 90, 65 and 270, 150 and 110 min, respectively.

In Fig. 4, DR versus moisture content of cantaloupe pulp foam-mats is presented. This figure indicates that DR of foamed cantaloupe pulp was higher during the initial stage as compared with the final stage and foam-mat drying of cantaloupe pulp was occurred principally in the falling rate period .Two falling rate periods can be observed for drying of foams. Because of the presence of foamed surface with higher moisture content, the highest DRs were registered at the initial stage of drying. At the end of the primary drying stage, all the free available water is evaporated and it is marked by a sharp drop in DR. The second falling rate period indicates that internal mass transfer resistance is controlling moisture removal and also moisture diffusion

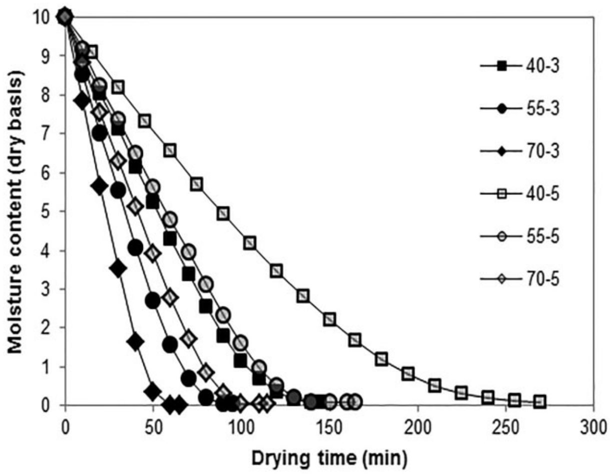

FIG. 3. DRYING CURVES OF CANTALOUPE PULP FOAMS FOR DIFFERENT DRYING AIR TEMPERATURES IN THICKNESSES OF 3 AND 5 MM

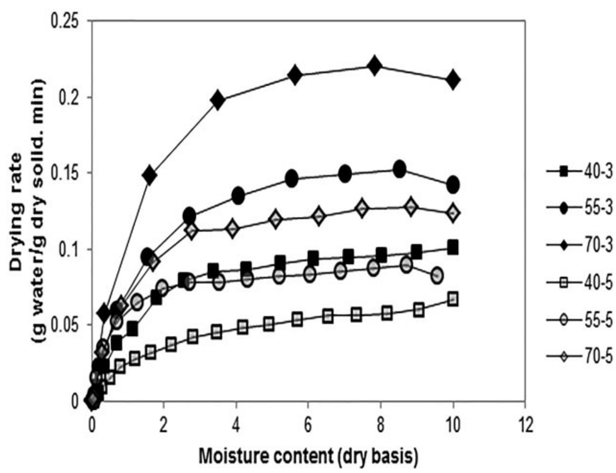

FIG. 4. DRYING RATE VERSUS MOISTURE CONTENT OF CANTALOUPE PULP FOAM MATS AT THE SELECTED DRYING TEMPERATURES IN THICKNESSES OF 3 AND 5 MM

TABLE 5. CONSTANTS AND STATISTIC PARAMETERS OBTAINED FROM WEIBULL DISTRIBUTION MODEL FOR ALL DRYING PROCESSES

Foam thickness (mm)	Temperature (C)	*a*	*b*	*k*	*n*	R^2	χ^2	RMSE
3	40	–0.063	–1.023	0.001	1.533	0.9979	0.0002	0.0161
	55	–0.086	–1.062	0.003	1.476	0.9982	0.0002	0.0157
	70	–0.080	–1.058	0.005	1.507	0.9975	0.0004	0.0041
5	40	–0.075	–1.041	0.001	1.391	0.9986	0.0001	0.0121
	55	–0.071	–1.033	0.001	1.567	0.9970	0.0004	0.0192
	70	–0.083	–1.054	0.002	1.533	0.9973	0.0004	0.0192

a, b, k, n, constants of Weibull distribution.
RMSE, root mean square error

depends on pore structure and interactions of moisture with the foam structure (Okos *et al.* 1992). In this stage, diffusion of bound water is the main mechanism controlling the water transport. As can be seen in this figure, DRs of cantaloupe pulp foam mats were higher when drying was performed at higher drying temperatures and lower thickness. The moisture content corresponding to the bound water ranges from 0.11 kg/kg db to 0.21 kg/kg db, depending on the type of fruit (Lim *et al.* 1995).

Fitting of Drying Curves

In order to select the appropriate drying model, moisture content for all drying processes were converted to MR and the curve fitting computations with drying time were done using thin-layer drying models. The higher values of R^2 and lower values of χ^2 and RMSE were selected as the basis for goodness of fit. Results showed that in all cases, the highest values of R^2 and lowest values of χ^2 and RMSE were obtained with the Weibull distribution model. Thus, the Weibull distribution model may be assumed to be an efficient model to represent the thin-layer drying behavior of foam-mat drying of cantaloupe pulp. Constants and statistic parameters of the Weibull distribution model are presented in Table 5. Accuracy of the Weibull distribution model was verified by comparing the predicted MR to the experimental values for all drying processes (Fig. 5a,b). It can be observed that there is an appropriate correlation between the experimental and predicted values of MR.

Effective Moisture Diffusivity and Activation Energy

Figure 6 shows the plot of logarithmic MR (ln MR) versus drying time of cantaloupe pulp foam mats. It is apparent that their relationship is nonlinear that indicated the variation in D_{eff} with moisture content. At each foam cantaloupe sample, two trend lines were drawn by considering two steps (step1 and step 2) of falling rate periods during drying. It was noted that the effective moisture diffusivity was higher when the drying temperature increased. Result showed that at the higher thickness, the internal moisture migration occurs along a longer distance rather than lower thickness. Therefore, an increase in moisture diffusivity occurs both with increase in drying temperature and sample thickness (Fig. 7). Similar results were reported for foam-mat drying of mango pulp (Rajkumar *et al.* 2007). The average moisture diffusivity values for 3-mm foam thickness ranged from 3.283×10^{-9} to 9.484×10^{-9} m^2/s and

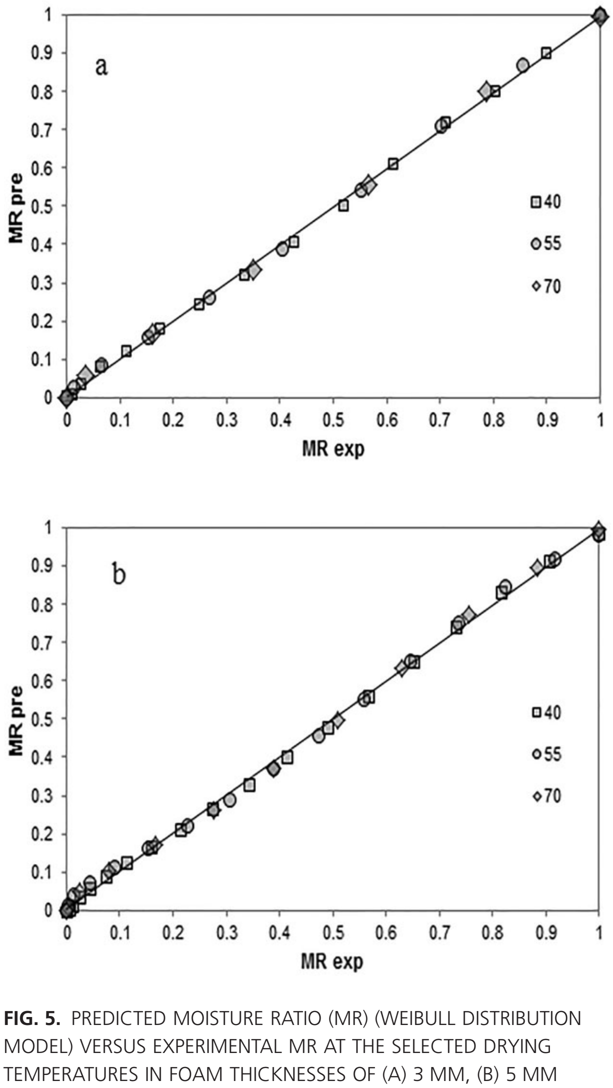

FIG. 5. PREDICTED MOISTURE RATIO (MR) (WEIBULL DISTRIBUTION MODEL) VERSUS EXPERIMENTAL MR AT THE SELECTED DRYING TEMPERATURES IN FOAM THICKNESSES OF (A) 3 MM, (B) 5 MM

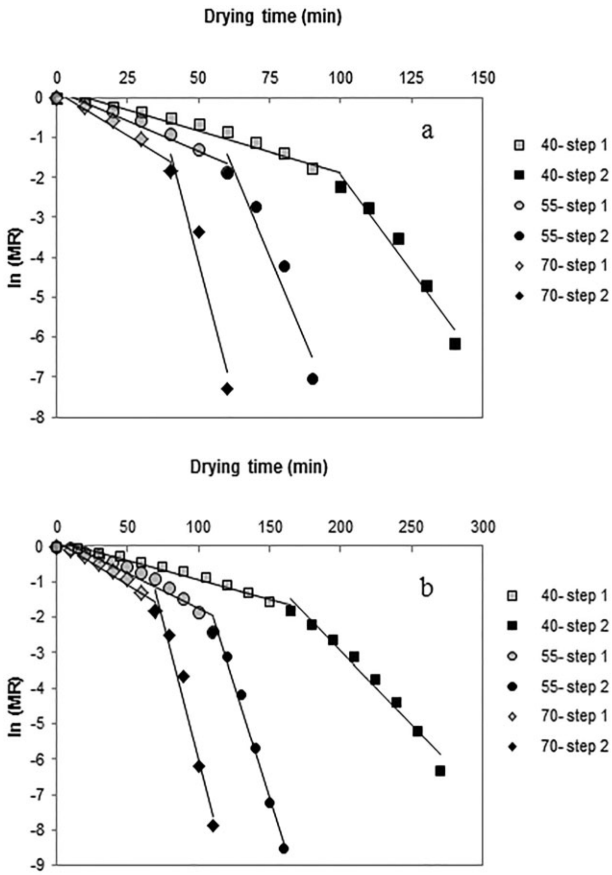

FIG. 6. RELATIONSHIP BETWEEN LOGARITHMIC MOISTURE RATIO, ln(MR) AND DRYING TIME OF FOAMED CANTALOUPE PULP AT THE SELECTED DRYING TEMPERATURES IN FOAM THICKNESSES OF (A) 3 MM, (B) 5 MM

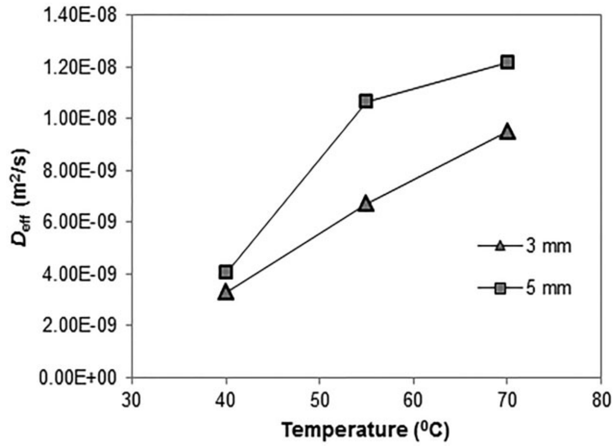

FIG. 7. D_{eff} VERSUS DRYING TEMPERATURE IN TWO THICKNESS FOR THIN-LAYER DRYING OF CANTALOUPE PULP FOAM

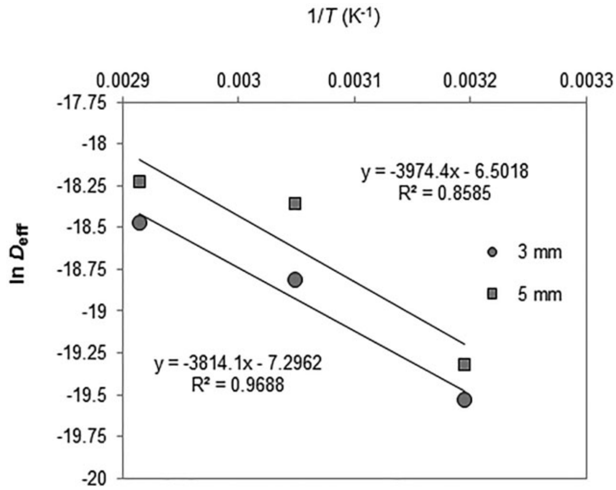

FIG. 8. ARRHENIUS-TYPE RELATIONSHIP BETWEEN EFFECTIVE MOISTURE DIFFUSIVITY AND RECIPROCAL ABSOLUTE TEMPERATURE

while for 5-mm thickness, they ranged from 4.053×10^{-9} to 1.216×10^{-8} m²/s at temperatures from 40 to 70C (Table 6).

The activation energy (E_a) was calculated by plotting ln (D_{eff}) versus $1/T$ (Fig. 8). The activation energies of moisture diffusivity for hot-air drying of cantaloupe pulp

TABLE 6. EFFECTIVE MOISTURE DIFFUSIVITY AND ACTIVATION ENERGY (E_a) OBTAINED FOR CANTAIUPE PULP FOAM

Foam thickness (mm)	Temperature (C)	Step	R^2 value	Effective moisture diffusivity (m²/s)	Average effective moisture diffusivity (m²/s)	D_0 (m²/s)	E_a (kJ/mol)
3	40	1	0.960	1.095×10^{-9}	3.283×10^{-9}	6.789×10^{-4}	31.714
		2	0.948	5.470×10^{-9}			
	55	1	0.944	1.824×10^{-9}	6.748×10^{-9}		
		2	0.954	1.167×10^{-8}			
	70	1	0.951	2.553×10^{-9}	9.483×10^{-9}		
		2	0.939	1.641×10^{-8}			
5	40	1	0.982	2.026×10^{-9}	4.053×10^{-9}	1.501×10^{-3}	33.043
		2	0.962	6.079×10^{-9}			
	55	1	0.962	3.040×10^{-9}	1.064×10^{-8}		
		2	0.966	1.824×10^{-8}			
	70	1	0.956	4.053×10^{-9}	1.216×10^{-8}		
		2	0.969	2.026×10^{-8}			

foam in thicknesses of 3 and 5 mm were 31.714 and 33.043 kJ/mol, respectively. Azizpour *et al.* (2013) reported similar values for foam-mat drying of shrimp (E_a 32.16 kJ/mol).

CONCLUSION

In this research, EW powder and XG were used to produce cantaloupe pulp foam. Foaming parameters were optimized by RSM. The results of investigation on drying behavior of cantaloupe pulp foam demonstrated that the drying process occurred in the falling rate period. The curve fitting computations with drying time were showed that, Weibull distribution model can describe drying behavior of cantaloupe pulp foams. In addition, the obtained results showed that the effective moisture diffusivity increased with the increase in air temperature and foam thickness.

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