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Optimization of Foaming Parameters and evaluation Foam-Mat Drying of white button mushroom (*Agaricusbisporus*)

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ABSTRACT

Recently, the quality of powder product was considered in food industry. Foam mat drying is an economical alternative to spray, drum and freeze-drying for the production of food powders. The high porosity and surface-to-volume ratio of foams during foam-mat drying improve final product quality. In this work, foaming properties of white button mushroom(*Agaricusbisporus*) were analyzedby response surface methodology. For optimization,xanthan gum (XG)solution range was considered between 0.05–0.3% w/w, mushroom concentration (water: mushroom puree) range was considered 1:0.5– 1:3.5 w/w and whipping time range was considered between 2–8 min. Based on face centered central composite design (CCF),twenty tests were done. Analysis of variance showed that the quadratic modelshaveconsiderable effects on both responses.In this research, the optimized pointwasobtainedat xanthan gum solution 0.2% w/w, mushroom concentration (water:mushroom puree) = 1:2.2 and whipping time= 6.19 minand the predicted values for foam density and drainage volumewere0.56 gcm^{-3} and 1.8 mL, respectively.At the second step, optimized foam dried at 50, 65 and 80°C and then drying behavior of optimized foam was investigated by different mathematical models. The results indicated that theMidilli model is high accurate model for evaluating the drying behavior of mushroom foam. At the third step, the influence of the drying temperatures on some qualitative characteristics of foam-matdried mushroom powder was investigated. It was found, as the temperature increased, water activity and water binding capacity decreased. Also, Lightness parameter for the temperature of 65°Cwas higher than other temperature.So, white button mushrooms can be processed into powder and used as a functional or nutritional addition in a variety of food products.

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1- Introduction

Button mushroom (*Agaricusbisporus*) isthemostimportantvariety of edible mushroomsand has highacceptanceydue to their nutrition facts and health benefits [1]. This mushroom is the most widely planted and consumed mushroom throughout the world and it contributes to about 40% of the world production of mushroom [2]. The high moisture content of these mushrooms has restricted their use by customers. Fresh mushrooms after picking are more perishable and have a short shelf life, so it should be suitable preservation method are considered [3]. Dehydration is one of the effective preservationmethodsthat has been applied worldwide for the preservation of the fresh mushrooms. It should be noted, mushroom structure is very susceptible to heating, soselectiontheefficientdehydration techniques more importantonquality of the dried mushroomlike color, rehydration ability and other properties.In recent years, foam mat drying (FMD)as anefficientmethod for drying liquid product had been implemented. In this process, food samplesare incorporated with foaming agents and subsequently whipped to make stable foam and then dried by dryer. In the next step,dried powder removed from the tray, milled and packaged and is ready to use. High surface area of foam product improves the mass transfer rates and allows operation done at lower temperatures and shorter drying times. It should be noted, thedried product by foam mat drying has a better-quality characteristics like color. it is porousstructureso it can be easily reconstituted [4, 5, 6, 7].Thismethod has been successfully introduced and applied to manycommercially successful powder such as tomato juice [8, 9] and tomato pulp [10], Alphonso mango pulp[11], Mango Pulp [12], beetroot [13],papaya pulp [14, 15].

To produce the best quality of powder inFMDmethod, the porous structure of the foam should be stable for at least one hour, so addition of the stabilizing and foaming agents is essential for the preparation of stable foam[5, 16].With regard to the previous studies of Aremu et al.[17]and preliminary experiments,proteins in the structure of the white button mushroom are able to make foam, thereforein this study,researchers conducted foam formation only with foam stabilizers.

Xanthan gum(XG) is anexo-polysaccharides widely used in food process manufacturing. In this study, XGwas employed as a foam stabilizer. Considerable increase in the viscosity of liquid samples and high-water solubility in different temperature rangesare some of the characteristics of the xanthan gum [18].Moreover, XG could prevent the trapping of air during whipping or mechanical mixing which results in a reduction of the foam expansion [19]. Furthermore, Muthukumaran [20]showed xanthan gum provides excellent stability compared to other investigated stabilizers for producing satisfactory egg white foam.

The aim of the presentworkwere: (1) Investigation the influences of whippingtime (WT), mushroom concentration (MC), and xanthan gumsolution (XG) on the foam density (FD) and foam stability (DV) of mushroomfoam and optimization the foaming parameters with response surface methodology (RSM), (2) Investigation the FMDcurves and choosing a high accuracy model forprediction of the drying process, (3)Evaluation the effect of the FMD temperatures on some qualitative characteristics of foammatdried mushroom powder including (water activity (aw), water binding capacity (WBC), and color).

2- Materials and methods

2-1- Material

In this study, the fresh mushroomwas prepared from the local markets of Mashhad, Iran.XG (Ceragem Chemical, USA) and sodium metabisulphite (Sigma Aldrich, USA)werebought.

2-2- Sample preparation

2-2-1- Preparation of button mushroom puree

To prepare mushroom puree, at the first step, sliced mushrooms were immersed into sodium metabisulphite 2% (w/w) solution for 10 min. Sodium metabisulphitepreventbrowning reactions and prevent undesirable discoloration during crushing. Afterward, for getting a homogeneous puree mushroom, sliced mushroomwerecrushed by a kitchen blender (Tefal, 210 w) at 15000 rpm for 1 min.

2-2-2- Preparation of gum`s solutions

For preparation of XG`s solutions, 1 g XG was mixed with 100 ml distilled water and was

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homogenized. Afterward,XG solutions was placed in the refrigerator (Hymallia, Iran)about one day to improved hydration.

2-3- Experimental Design and Statistical Analysis

In this research, CCF design with three input variables including, XG (0.05–0.3 w/w), WT (2–8 min) and MC (1:0.5 – 1:3.5 w/w) at three levels was implemented to optimize the foaming condition (FD and DV) of mushroom foam. 20 tests were done based on the CCF design and the center point in the design was repeated six times to evaluate the repeatability of the method. The input variables range, were selected based on the preliminary experiments. The plan of central composite design in coded levels of the three input variables is presented in Table 1. A second order polynomial equation (Eq. (1)) was fitted to each of the responses:

$$Y_k = \beta_{k0} + \sum_{i=1}^{3} \beta_{ki} x_i + \sum_{i=1}^{3} \beta_{kii} x_i^2 + \sum_{i=1}^{3} \beta_{kij} x_i x_j + e_k \quad (1)$$

Where Y_k= response variable (Y_1= FD; Y_2= DV) and xi, and x_j represent the coded input variables (i=1, 2, 3=X, M, W), respectively. Where, X = XG solution, M = MC (water:mushroom puree), W = WT. The coefficients of the polynomial are represented by Bk_0. Bk_0 is the value of the fitted response at the center point of the design, i.e., point (0, 0, 0) and Bki, Bkii and Bkij which are the linear, quadratic and interaction regression coefficients, respectively.

Table 1 Responses acquired for different process parameter combinations

Experiment No.	Process Variables(coded value)			Response	
	XG (X)	WT (W)	MC (M)	DV (ml)	FD (gcm^{-3})
1	0.17(0)	8(+1)	1:2(0)	5	0.58
2	0.17(0)	5(0)	1:2(0)	3	0.58
3	0.17(0)	5(0)	1:2(0)	2	0.57
4	0.17(0)	5(0)	1:0.5(-1)	0	0.65
5	0.3(+1)	2(-1)	1:3.5(+1)	1.80	0.8
6	0.05(-1)	8(+1)	1:0.5(-1)	10.50	0.84
7	0.05(-1)	2(-1)	1:0.5(-1)	12	0.91
8	0.3(+1)	5(0)	1:2(0)	0	0.60
9	0.17(0)	5(0)	1:2(0)	4	0.62
10	0.3(+1)	8(+1)	1:3.5(+1)	2	0.64
11	0.3(+1)	8(+1)	1:0.5(-1)	0	0.58
12	0.17(0)	5(0)	1:2(0)	3	0.59
13	0.17(0)	5(0)	1:2(0)	4	0.62
14	0.17(0)	2(-1)	1:2(0)	4.75	0.66
15	0.05(-1)	8(+1)	1:3.5(+1)	25	0.55
16	0.17(0)	5(0)	1:2(0)	1	0.59
17	0.05(-1)	5(0)	1:2(0)	23	0.55
18	0.05(-1)	2(-1)	1:3.5(+1)	33	0.58
19	0.17(0)	5(0)	1:3.5(+1)	4	0.55
20	0.3(+1)	2(-1)	1:0.5(-1)	0	0.77

Regression analysis and analysis of variance (ANOVA) were employed to fit the models to the experimental value and evaluate the statistical significance of the model terms represented by Eq. (1).

Evaluation of the models was done by model analysis, lack-of-fit test, R^2, adjusted R^2 and predicted R^2 coefficients [21].

2-4- Foam preparation

In this research, thespecific amount of stabilizer, mushroom puree and distilled water recommended by CCF design, were mixed and whippedusing stirrer (model No. SM88, Sonny, China) with a speed of 1500 rpm (maximum speed) at defined times. A flow chart of the mushroom foam preparation is presented in Fig. 1

2-5- Evaluatingthefoam Density

For evaluating the FD parameter, the mass of the constant volume of the foam (50ml) was measured at ambient temperature and then foam density was calculated from Eq. 2[3].

$$Foam\ density = \frac{Weight\ of\ foam\ (g)}{Volume\ of\ Foam\ (cm^3)} \quad (2)$$

2-6- Evaluating the drainage volume

Drainage volume was evaluated with the method provided by Bag et al.[22] and Sauter and Montoure, [23]withlittlechanges. Thus, the mushroomfoam was poured into the Buchner filter (80 mm diameter)that covered with mesh cloth. After one hours, the amount of liquid drainage from the foam sample was considered as a foam stability parameter.

2-7- Drying procedure

The optimized mushroom foams were putuniformly in aluminum plates (9.5 cm diameter) with a foam thickness about3.0 mm, and then were driedat50, 65, and 80 °C. Drying experiment was donein laboratory hot air drier (Soroush Medical Company, Khorasan Razavi province) with centrifugal fanandair velocity of 1.5 m/s.Weight loss recorded by digital balance (model AND.EK-300i, Japan) at regular intervals until the mushroom foam samples to get a stableweight.Two replications were carried out for each temperature.

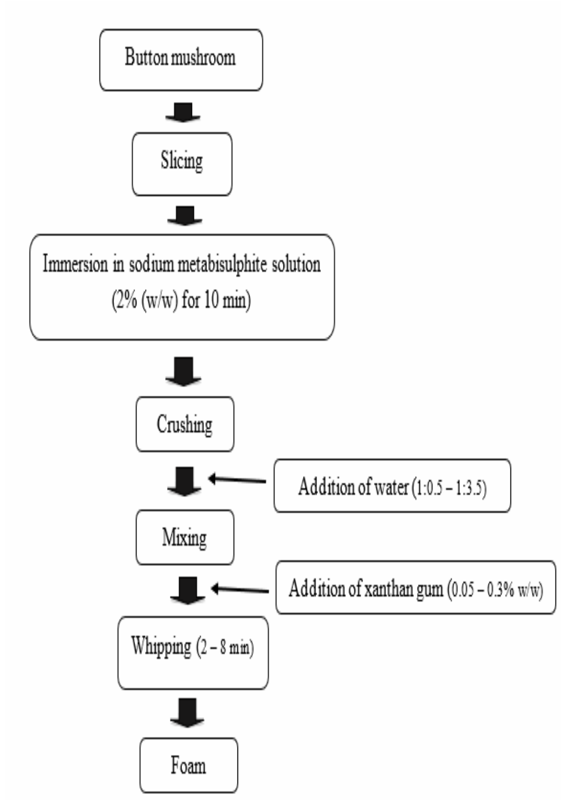

Fig 1 Flowchart for preparation of mushroom foam.

2-8- Data analysis

The statistical analysis of the data, three dimensional (3D) plotting and optimization of foaming parameters of mushroom foams was done by Design Expert 6.0.2 software (Stat Ease Inc., Minneapolis, MN). Numerical and graphical optimization methods in Design Expert software was applied for optimizing the independent variables including MC, XG and WT. All the process parameter selected in their specific range except xanthan gum solution which maximized level was chosen at 0.2%. The desired goals for both responses were at minimized range.

2-9- Mathematical modeling of drying process

Mathematical modeling of drying process of mushroom foamswas done by twelve moisture ratio models (Table2) and high accuracy model for simulation drying process was selected.

The moisture ratio (MR) was simplified to M/Mo instead of the (M _ Me)/(Mo _ Me) which M, Mo, Me are the moisture content of the foam at each moment, initial moisture content and equilibrium moisture contents, respectively[25, 26].

Evaluation the mathematical models for simulation the thin layer drying process was done by R^2, χ^2, RMSE and SSE values which defined as follows (Eq. 3-6)[24]:

$$R^2 = \frac{\sum_j^n (MR_{exp,i} - MR_{pre})^2 - \sum_j^n (MR_{exp,i} - MR_{pre,i})^2}{\sum_j^n (MR_{exp,j} - MR_{pre})^2} \quad (3)$$

$$\chi^2 = \frac{\sum_{i=1}^{N} (MR_{exp,i} - MR_{pre,i})^2}{N - n} \quad (4)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N} (MR_{pre,i} - MR_{exp,i})^2\right]^{1/2} \quad (5)$$

$$SSE = \frac{\sum_j^n (MR_{Pre,i} - MR_{Exp,i})^2}{n} \quad (6)$$

Where $MR_{pre,i}$, $MR_{exp,i}$, N and n are the ith predicted MR, the ith experimental MR, the number of observations and the number of constants in drying model, respectively. MATLAB version 7.0 software was applied to examine the constants and coefficients of the mathematical models.

Table 2 Mathematical models references.

Model name	Model	References
Newton	$MR = \exp(-kt)$	O'Callaghan et al. (1971) .[27]
Page	$MR = \exp(-kt^n)$	Page (1949) .[28]
Modified page	$MR = \exp[((-kt))^n)$	Kingsly and Singh (2007) .[29]
Henderson &Pabis	$MR = a\exp(-kt)$	Kingsly and Singh (2007).[30]
Modified Henderson &Pabis	$MR = a\exp(-kt) + b\exp(-gt) + c\exp(-ht)$	Karathanos (1999) .[31]
Logarithmic	$MR = a\exp(-kt) + c$	Togrul and Pehlivan (2002) .[32]
Appromiximation of diffusion	$MR = a\exp(-kt) + (1-a)\exp(-kbt)$	Yaldiz et al. (2001) .[33]
Simplified Fick's diffusion equation	$MR = a\exp\left(-c\left({}^{t}/_{L^2}\right)\right)$	Diamante and Munro (1991) .[34]
Midilli	$MR = a\exp(-kt^n) + bt$	Midilli et al. (2002) .[35]
Jena & Das	$MR = a\exp(-kt + b\sqrt{t}) + c$	Jena and Das (2007) .[36]
Logestic	$MR = {}^{a}/_{1+b}\exp(kt)$	Chandra and Singh (1995) .[37]
Weibull distribution	$MR = a - b\exp(-kt^n)$	Machado et al. (1998) .[38]

2-10- Analysis of the powder

2-10-1- Water activity (aw)

Determination of aw of mushroom powders was evaluated with water activity meter (HygroLab 2, Rotronic Instrument Corp, USA) at constant temperature 24.5 ± 0.5 °C. In each experiment, 2 g of the mushroom powder was transferred in the instrument cup and aw was determined.

2-10-2- Water binding capacity (WBC)

WBC was determined from the techniqueimplemented by McConnell et al. [39] with a little change. In this method, 1 g of mushroom powder samples was suspended in 30mL of distilled water and kept for 18 hours in ambient temperature. Then mixture was centrifuged (Sigma, 2-16KC, Germany) at 3400 g-force for 40 min. The volume of liquid separated after centrifugation (supernatant) was evaluated and WBC was determined by using the below equation (Eq.7):

$$\text{water binding capacity}\left(\frac{ml}{gr}\right) = \frac{\text{volume of water added} - \text{volume of supernatant}}{\text{weight of Sample}} \quad (7)$$

2-10-3- Color evaluation

The color of the mushroom foams was evaluated with Chroma-meter (Chroma Meter model CR-410, Minolta Co. Ltd.,Osaka, Japan) and L^* (lightness) and a^* (redness),parameters were examined.Calibration was done by using a standard white plate.To evaluate the color parameter, foam samples poured in a plate and then color surface was measured by Chroma-meter.

3- Results and discussion

3-1- Evaluating the Foaming properties

The influences of process parameters on foaming characteristicsofmushroomfoams are presented in Table 1.

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From the ANOVA, it was found the quadratic models were highly significant ($p<0.001$) for two responses(Table 3). The high value of R^2, adjusted R^2 and predicted $R^2$for response variables and non-significant lack of fitindicated that modelshavehighaccuracyfor predicting response at any combination of variables in experimental range.

The optimum values with desirability of 0.950 was found at XG solution (0.2% w/w), MC (1:2.2) and WT (6.19 min). The predicted values for FD and DV parameters at optimum point were 0.56 gcm^{-3} and 1.8 mL, respectively.

Table 3 Analysis of variance (ANOVA) for response surface models (Eqs. 8 and 9)

Source	Drainage volume			Foam density		
	Sum of squares	**F-Value**	**Prob > F**	**Sum of squares**	**F-Value**	**Prob > F**
(a) Model analysis						
Mean	952.89			8.31		
Linear	1189.69	13.21	0.0001	0.066	2.58	0.0896
2Fi	142.33	1.82	0.1925	0.072	4.84	0.0179
Quadratic	301.56	27.48	<0.0001	0.056	21.22	0.0001
Cubic	27.69	4.67	0.0470	0.00229	0.53	0.7203
Residual	8.89			0.00651		
Total	2623.05			8.51		
(b) Lack of fit						
Linear	473.64	31.51	0.0007	0.14	34.80	0.0005
2fI	331.33	30.30	0.0008	0.063	22.28	0.0017
Quadratic	29.74	4.35	0.0662	7.046×10^{-3}	3.98	0.0780
Cubic	2.06	1.50	0.2746	7.748×10^{-3}	13.40	0.0146
Pure error	6.83			1.772×10^{-3}		
(c) R-square analysis	Adjusted R-Squared	Predicted R-Squared	PRESS	Adjusted R-Squared	Predicted R-Squared	PRESS
Linear	0.6584	0.4675	889.33	0.1998	-0.4350	0.29
2fI	0.7041	-0.0830	1808.87	0.5345	-1.4962	0.51
Quadratic	0.9584	0.8084	319.93	0.9178	0.8027	0.040
Cubic	0.9831	-0.5181	2535.47	0.8987	-27.6221	5.84

3-2- Foam density (FD)

FD determination is one of the most common methods for evaluation the foam expansion. As shown in Table 1, FDwas in range from0.55 to 0.91 gcm^{-3}. Also, R^2 and predicted R^2valueswere 0.947 and 0.826 that were in good agree with adjusted R^2 of 0.917(Table 4).In the current study, there were generally significantlinear correlation between MC and WT at 0.1%. Also, the relationship between XG solution – MC and XG solution – WT were significant at 0.1% and 5%,respectively.Quadratic effect of MC and WT were significant at 5% and 0.1% levels, respectively.whereas XG solution was not significant at 5% (Table 4).

The effect of input variables on FD parameter was explained by the below equation (Eq. 8):

$$FD = +0.59 - 0.00502X - 0.062M - 0.053W + 0.047M^2 + 0.07W^2 + 0.089XM - 0.031XW \quad (8)$$

Where, X is XGsolutiong/100 g; Mis the MC(w/w) and Wis WT (min).The response surface plots for FD scores in relation to MC–XGsolution and XGsolution – WTwerepresentedin Figs. 2 and 3, respectively.As the MCdecreased, the FD increased significantly ($p<0.001$).Similar results were reported for bael fruit[22] and star fruit [4].

High viscosity from increasing MC factor, prevented the incorporating air into foam during whipping and FD decreasedsignificantly [7, 23].Also, it is observed, in low level of MCparameter, with increasing theXG solution, FD parameter decreased significantly (Fig. 2). This behavior can be explained based on protein–polysaccharide interaction and improving the foaming power. According to Laneuville et al. [41] polysaccharideslike XG, through increasing the viscosity of the suspension, reducing protein – protein interactions, shielding active charged groups and decreasing the collision rate between molecules, prevent the protein aggregation and improving the foaming properties in foam system.

As shown in Fig. 3, FD decreased steadily with increasing WT.It is from, aerating the foam samples during whipping and decreasing the FD. It should be noted that, after the initial decreasing foam density, a little increase in foam density was observed about 6 min of WT. This maybe occurred due to extended of the WT which make the thinning of the liquid film between the bubbles thatcause the bubbles structure tocollapsedue to the mechanical force from stirrer[40, 42]. Also, increasing the whipping time or “overbeating” make to accelerateaggregation and precipitation in proteins structure of foam samples and decreasing the foaming capacity of mushroom foam, consequently[43].

Table 4 Regression summary and ANOVA table for Foam density

Source	Sum of squares	DF	Mean squares	F-Value	Prob > F
Model	0.19	7	0.028	31.08	< 0.0001 significant
X	2.520×10^{-4}	1	2.52×10^{-4}	0.28	0.6040
M	0.038	1	0.038	43	< 0.0001
W	0.028	1	0.028	31.58	0.0001
M^2	6.968×10^{-3}	1	6.968×10^{-3}	7.84	0.0160
W^2	0.016	1	0.016	17.79	0.0012
XM	0.064	1	0.064	72.11	< 0.0001
XW	7.454×10^{-3}		7.454×10^{-3}	8.39	0.0134
Residual	0.011	12	8.882×10^{-4}	-----	-----
Lack-of-fit	8.887×10^{-3}	7	1.270×10^{-3}	3.58	0.0895 not significant
Pure error	1.772×10^{-3}	5	3.543×10^{-4}	-----	
Total	0.2	19			
R-Squared	0.9477				
Adj R-Squared	0.9172				
Pred R-Squared	0.8265				

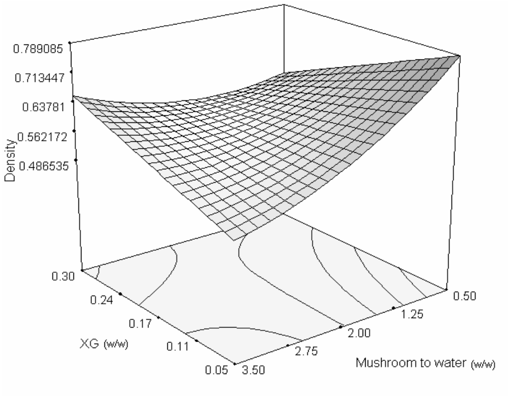

Fig 2 Effect of input variables (MC and XG solutions) on FD parameters of mushroom foams.

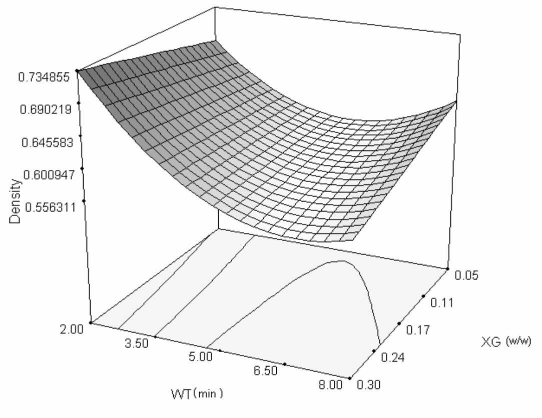

Fig 3 Effect of input variables (XG solution and WT) on FD parameters of mushroom foams.

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3-3- Drainage volume

Foam structure naturally are unstable and delicate. High surface energy in the air – water interface and the different density between two phases makes foams thermodynamically unstable in nature[20].

Foam stability commonly evaluated by DV parameter, which is related the flow of the liquid phase through foam capillary or external forces[44].

In the current study, there were significant linear correlation between XG solution and MC at the 0.1 % level of significance. Also, the quadratic effect of XG solution was found to be significant at the same level. There was a significant interaction between XG solution and MC at 0.1% level (Table 5).

The effect of input variables on DV parameter was explained by the below equation (Eq. 9):

$$DV = +3.08 - 9.97X + 4.33M + 7.66X^2 - 3.96XM \quad (9)$$

Table 5 Regression summary and ANOVA table for Drainage volume

Source	Sum of squares	DF	Mean squares	F-Value	Prob > F
Model	1600.1	4	400.03	85.65	< 0.0001 significant
X	994.01	1	994.01	212.83	< 0.0001
M	187.49	1	187.49	40.14	< 0.0001
X^2	293	1	293	62.73	< 0.0001
XM	125.61	1	125.61	26.89	0.0001
Residual	70.06	15	4.67	-----	-----
Lack-of-fit	63.22	10	6.32	4.63	0.0524 not significant
Pure error	6.83	5	1.37	-----	
Total	1670.16	9			
R-Squared	0.9581				
Adj R-Squared	0.9469				
Pred R-Squared	0.9045				

Where, X is the XGsolutiong/100 g of the mixture; M is the MC(w/w) and W is the WT (min).The variations inDVparameterof the mushroom foams with XGsolution and MCin 3 D surface plot are presented in Fig. 4. It is clear that XGsolution had more effect on DV. As the XGsolution increased, continuous decrease in DV parameter was occurred. XG by increasing the viscosity of liquid foam, improved the interfacial viscoelasticity of foam lamellaeand helps to stabilize the foam system [45, 46].Our results are in agreement with those of Azizpour et al. [6],Abbasi et al. [7] and Salahi et al. [19].

As the plot shows, with decreasing the MC factor (water: mushroom puree) or in other word with decreasing the dilution rate, DV parameter decreased significantly. Enhancement of foam stability could be from increasing the total solid content inmushroomsuspensionspecially protein compounds which improve the water holding in foam structure and improve foam stability.

According to German & Phillips [47] and Wilde & Clark [48], proteinsstructureshave a major role in increasing the foam stability by reducing the interfacial tension to low level and making more mechanical strength in the bubble walls by interacting with lamella and form the electrostatic, hydrophobic, and covalent and hydrogen bonding.

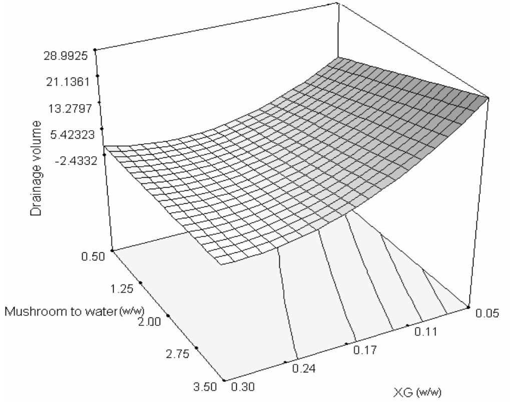

Fig 4 Effect of input variables (MC and XG solution) on DV parameters of mushroom foams.

3-4- Evaluation of dryingprocess

Evaluation of FMD curves of optimized foams at FMDtemperatures50, 65 and 80 °C was shown in Fig. 5. It is found that by increasing

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the FMD temperature, the FMD time decreased consequently, and FMD temperature has a significant influence on the FMD time.For example, when the FMD temperature was increased from 50 to 80 °C, the FMD time decreased approximately 50% which related to the increasing of the heat and mass transfer rate during the foam samples.FMD time required to reachthe equilibrium moisture content were about 87, 57 and 39 min at 50, 65 and 80 °C,respectively.Similar results for FMD of banana and shrimp foam samples have been reported [49, 50].

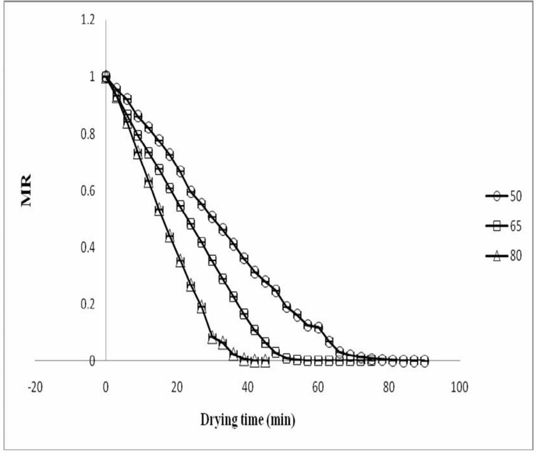

Fig 5 drying curves for dryingtemperatures.

3-5- Fitting of the FMD curves

The MR of optimized foam at three FMD temperatures (50, 65 and 80°C) was fitted in twelvedrying models and thestatistical analysis results are presented in Table 6. In all drying models, R^2values was bigger than 0.93, which indicates that all mathematical modelshave high correlationwith experimental values.As shown in Table 6, Midilli model has the maximum value of R^2 and minimum values of χ^2, SSE and RMSE. In Fig 6, the MR values from Midilli model was compared by experimental values, which confirm Midilli model is high accurate model for evaluating FMD behavior of mushroom foams. Constants and coefficients oftheMidilli model at FMD temperature are presented in Table 7.

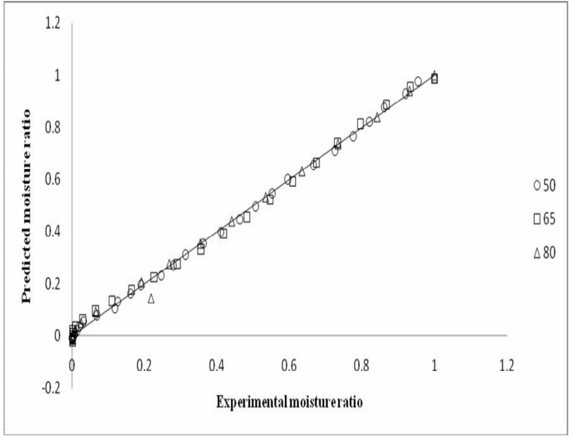

Fig 6 Experimental and predicted MR values for different drying conditions.

Table 6 Statistical results of 12 models at three drying temperatures

Drying air temperature												NO
80				65				50				
SSE	RMSE	X^2	R^2	SSE	RMSE	X^2	R^2	SSE	RMSE	X^2	R^2	
0.1173	0.0884	0.00733	0.936	0.1918	0.08759	0.00737	0.935	0.0222	0.0868	0.00742	0.935	1
0.0154	0.0332	0.00096	0.991	0.0279	0.03414	0.00107	0.990	0.0194	0.0258	0.00062	0.994	2
0.0154	0.0345	0.00012	0.991	0.0417	0.04261	0.00189	0.989	0.0201	0.0268	0.00074	0.994	3
0.0876	0.0791	0.00626	0.952	0.148	0.07854	0.00643	0.950	0.1572	0.0736	0.00561	0.954	4
0.0788	0.0887	0.00754	0.957	0.1825	0.09554	0.00668	0.983	0.0283	0.0336	0.00118	0.991	5
0.0183	0.0375	0.00141	0.990	0.0580	0.05025	0.00264	0.980	0.0354	0.0351	0.00127	0.990	6
0.0239	0.0428	0.00184	0.987	0.0491	0.04621	0.00225	0.983	0.0391	0.0373	0.00145	0.988	7
0.0876	0.0821	0.00674	0.952	0.148	0.08023	0.00672	0.950	0.1572	0.0749	0.00582	0.954	8
0.0074	**0.0249**	**0.00062**	**0.995**	**0.0098**	**0.02118**	**0.00047**	**0.996**	**0.0038**	**0.0119**	**0.00019**	**0.998**	9
0.0110	0.0303	0.00091	0.994	0.0391	0.0422	0.00187	0.986	0.0191	0.0266	0.00073	0.994	10
0.0876	0.0821	0.00675	0.952	0.148	0.08023	0.00673	0.950	0.1572	0.0749	0.00582	0.954	11
0.0068	0.0268	0.00071	0.995	0.0156	0.02665	0.00074	0.994	0.0069	0.0160	0.00028	0.998	12

Table 7 Statistical results of Midilli model and its constants and regression coefficients at three drying temperatures

Drying air temperature (^{o}C)	**a**	**B**	**k**	**n**	**SSE**	RSME	X^2	R^2
50	0.9869	-0.04655	-0.05565	0.7237	0.0038	0.0119	0.00019	0.998
65	0.9862	-0.06049	-0.06322	0.7382	0.0098	0.02118	0.00047	0.996
80	0.9984	-0.08422	-0.07814	0.7448	0.0074	0.0249	0.00062	0.995

3-6- Evaluating the mushroom powder

3-6-1- Water activity

The aw values of mushroom powder are presented in Table 8. It was found as the FMD temperature increased, the aw of mushroom powders decreased significantly ($P<0.05$). it should be noted, in all mushroom powder samples, aw was below the 0.6, that indicate the available water for chemical reactions and microbiological growth is insufficient and mushroom powder from FMD will have a good shelf life [52]. A considerable reduction in aw parameter could be from the porous structure of mushroom foams which accelerating the moisture loss during drying process. Also unfolding and denaturation of proteins structure make the holding water in protein structure reduced and consequently aw reduced [42].Some research in their studies on FMD of foods reported the same conclusion [52, 53].

3-6-2- Color

The most important factor that is expected to affect marketability of the food dried product is color. Millard reaction and browning enzymatic are the most important reasons for color changing in mushroom during drying process.according to the previous studies, the color parameters L^* and a^*, are well correlated to color changes and darkening due to browning reactions in food product [54]. By increasing the browning reactionL^*parameterwill decrease and a^* parameter will increase. Therefore, in present study L^* and a^* parameters were considered as color evaluation index (Table 8)

As shown in Table8, L^* for mushroom powders dried the 50 and 80°Cwerehigher than the mushroom powder which dried in 65°C.Also, a^* in mushroom powder dried at 65°C was more than the mushroom powder dried in 50 and 80°C. In other word, mushroom powder from FMD at 65°C has less lightness (more browning) compared to the dried powder produced in 50 and 80°C. Whereas, there was not significant difference between L^* parameters for mushroom powders dried at 50 and 80°C.It should be note that, temperature and time of drying process are the important parameter on color change and browning reaction during drying process [55].This result can be from the less browning reaction (especially enzymatic browning) at 50°Ccompared with the drying temperature of 65°C.Also,longer drying time at 65°C caused the final powders has lower lightnessthan the mushroom powder dried at 80°C.in other word low drying time in drying process at 80 makes the final powder has a better color.

3-6-3- Water binding capacity

Another important parameter for evaluation the quality of the food dried products is water binding capacity (WBC). WBC represents the amount of water that dried product can be absorb, which depends on the structure of proteins and the capability to hydration [56].

As shown in Table 8 by increasing the drying temperature, WBC decreased, which is related to the denaturation of proteins that causes the aggregation and coagulation of the protein molecules [52].

It should be noted, reduction in WBC with increasing drying temperature was insignificant, that it could be from the presence of xanthan gum that has heat resistance property and improve WBC parameter.

Table 8 Effect of drying temperature on some properties of mushroom powder.

Water binding capacity	**Color**		**Water activity**	**Drying temperature (°C)**
	a^*	L^*		
4/23 ^{a}	1/20± 0/^{a}728	68/44 ± 0/^{a}077	0/142± 0/^{a}008	50
4/085 ^{a}	4/17± 0/^{b}721	59/89 ± ٠/^{b}756	0/079 ± 0/^{b}026	65
3/39 ^{a}	2/18± 0/^{ab}474	68/19± ٠/^{a}848	0/050± 0/013 ^{b}	80

Different letters (a–c) within a same column differ significantly ($P < 0.05$)

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4- Conclusion

In this paper, RSM was implementedfordetermination of the optimized point of foaming condition of mushroom foamwithXGsolutionin the range of 0.05–0.3% (w/w), MCof 1/0.5– 1/3.5 (w/w) and WT of 2–8 min as input variables. The results showed,the developed model were more efficient tools and techniques for predicting foaming properties of mushroomfoamsto the experimental data.The optimized foaming conditions point wasobtainedatXG= 0.2% w/w, MC= 1:2.2(w/w) and WT 6.19 min.Drying curve studies showedthatFMDtemperature has a considerable influenceon the diffusion of water through the foam, and by increasing the FMD temperatures, moisture lost was increased. Evaluating the mathematical modeling the FMD curves was shown that Midilli model is appropriate and high accurate model for investigating theFMD behavior of mushroom foams. Evaluation the physico chemical properties of mushroom powder show, with increasing the FMD temperature, water activity and water binding capacity decreased consequently. also, Lightness parameter for the temperature of 50, 65 and 80°Cwas bigger than the 65°C.

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بهینه سازی شرایط تولید کف و ارزیابی فرآیند خشک کردن کف پوشی قارچ دکمه ای سفید(*Agaricusbisporus*)

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چکیده

اخیرا کیفیت فرآورده های پودری در صنایع غذایی مورد توجه قرار گرفته است. خشک کردن به روش کف‌پوشی یک روش اقتصادی جایگزین برای خشک کردن به روش پاششی، غلطکی و انجمادی برای تولید پودرهای غذایی است. تخلخل و نسبت سطح به حجم بالا در نمونه های کف در حین خشک شدن کفپوشی، کیفیت محصول نهایی را بهبود می بخشد. در این پژوهش، خصوصیات کف زایی قارچ دکمه ای سفید (**Agaricusbisporus**)با روش سطح پاسخ مورد تجزیه و تحلیل قرار گرفت.جهت بهینه سازی، محلول صمغ زانتان (**XG**) بین ۰/۰۵– ۰/۳ درصد وزنی، غلظت سوسپانسیون (آب: پوره قارچ) بین ۰/۵: ۱– ۳/۵: ۱ وزنی/وزنی و محدوده زمان هم زدن بین ۲ تا ۸ دقیقه در نظر گرفته شده است.بر اساس طرح مرکب مرکزی متمرکز شده(**CCD**)، بیست آزمایش انجام شد. تجزیه و تحلیل واریانس نشان داد که مدل های درجه دوم اثرات قابل توجهی بر هر دو پاسخ دارند. در این پژوهش، نقطه بهینه در محلول صمغ زانتان ۰/۲٪ وزنی/وزنی، غلظت سوسپانسیون (آب: پوره قارچ) ۲/۲: ۱ و زمان هم زدن ۶/۱۹ دقیقه و مقادیر پیش‌بینی شده برای دانسیته کف و میزان مایع جدا شده از کف به ترتیب ۰/۵۶ گرم در سانتی‌متر و ۱/۸ میلیلیتربه دست آمد. در مرحله دوم، کف بهینه شده در دماهای ۵۰، ۶۵ و ۸۰ درجه سانتیگراد خشک شد و سپس رفتارخشک شدن کف بهینه شده توسط مدل های مختلف ریاضی بررسی شد. نتایج نشان داد که مدل میدیلی مدلی با دقت بالا برای ارزیابی رفتار خشک کردن کف قارچ است. در مرحله سوم، تأثیر دمای خشک کردن بر برخی ویژگی‌های کیفی پودر قارچ خشک شده مورد بررسی قرار گرفت. نتایج نشان داد که با افزایش دما، فعالیت آبی و قابلیت جذب آب کاهش یافت. همچنین پارامتر روشنایی در دمای ۶۵ درجه سانتیگرادبالاتر از سایر دماهای خشک کردن بود. بنابراین قارچ دکمه ای سفید را می توان به پودر تبدیل کرد و به عنوان یک افزودنی کاربردی یا تغذیه ای در انواع محصولات غذایی استفاده کرد.

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