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Viscous Flow Behavior of Low-Calorie Pistachio Butter: A Response Surface Methodology

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Abstract: Low- calorie pistachio butter is a novel food product which in its original form contains pistachio, sweetener and flavor improver. The viscous flow properties of low- calorie pistachio butter, as a novel food product, was studied by response surface methodology (RSM). The flow behavior of 42 formulas was assessed using Power law, Casson, Bingham and Herschel- Bulkley models. The Herschel-Bulkley model gave negative values for yield stress which has no physical meaning. The effects of three fat replacers (Balangu seed gum, Reihan seed gum, xanthan) and two sweeteners (isomalt and sucrose) on the rheological parameters of these models were investigated. All the samples showed a shear thinning behavior. The magnitudes of consistency coefficients and flow behavior indices in Power law model, the Casson yield stress and Casson viscosity and the Bingham yield stress and Bingham viscosity were 32.743- 388.645 Pa.s^n and 0.106- 0.515, 42.306- 282.319 Pa and 0.477- 1.440 Pa.s and 94.599- 357.058 Pa and 1.042- 3.736 Pa.s, respectively.

Key words: Low-calorie % Pistachio butter % Power law % Casson % Bingham

INTRODUCTION

Iran is the original home of pistachio and the annual amount of pistachio production in Iran constitutes 62% of the total world production. Pistachio butter is a pasty formed nutritive product which contains pistachio, sweetener and flavor improver (Taghizadeh and Razavi, 2009). Stressing the importance of diet in the prevention of certain diseases, nourishing scientists have emphasized on the reduction of calorie in consumers' diet. To respond part of this consumers' demand, the low-calorie version of full fat pistachio butter has recently been formulated (Emadzadeh *et al*., 2010a).

In general, fat replacers are implied to all the bulking agents or ingredients that somehow replaces fat in a system. The ideal fat replacer(s) reduces fat and calorie content of the product, while remains all the characteristics of the primary full fat product (Nabors, 2001). The largest numbers of fat replacers are carbohydrate-based. These ingredients are plant polysaccharides and include cellulose, gums, dextrins, fiber, maltodextrins, starches and polydextrose (Singh *et al*., 2000).

Xanthan is a versatile hydrocolloid that can be used in low-fat products due to its ordered molecular structure (Roller and Jones, 1996). Lallemantia royleana (with vernacular name Balangu) and Ocimum basilicum (with vernacular name Reihan) are mucilaginous endemic plants which grow in different parts of Iran. Recent rheological researches have approved that their mucilaginous extract can be used as a novel food hydrocolloid in food formulations (Razavi *et al*., 2009a; Hosseini-Parvar *et al*., 2010).

The time independent rheological properties of food stuffs have been previously studied by many researchers; Alpaslan and Hayta (2002) for the mixture of sesame paste and pekmez, Arslan *et al*. (2005) for tahin/ pekmez blends, Razavi *et al*. (2007) for low calorie sesame paste and Taghizadeh and Razavi (2009) and Razavi *et al*., (2010) for the industrial pistachio butter. Published work on the rheological behavior of low- calorie pistachio butter is apparently scarce. Exception is the time dependent rheological study performed by Emadzadeh *et al*. (2010b). Such studies, however, help in the understanding of storage events and unit operation and are thus of practical importance. Therefore, the objectives of

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this study were to fit different popular rheological models that are useful in the design of processing operations and related equipments and to determine the effects of fat replacers (xanthan gum, Reihan seed gum and Balangu seed gum) and sweeteners (sucrose and isomalt) at different levels on the rheological parameters of the fitted models.

MATERIALS AND METHODS

Preparation of Formulas: The O'hadi pistachio was obtained from Kashmar city, Khorasan province in Iran. Isomalt was procured from Sim-Sim industry, Mashhad, Iran. Sucrose and vanilla were obtained from local markets. Potassium sorbate and lecithin were purchased from Merck and Acrose companies, respectively. BSG and RGB were extracted using the optimized methods proposed by Mohammad Amini (2007) and Razavi (2009b), respectively. Diagram of the production process is presented in Fig. 1. The basic composition formula was suggested by the results of pre-experiments carried out in our laboratory.

Rheological Measurement: After the preparation process, the samples were kept at 4°C for 24 hours. Measurements were carried out using a rotational viscometer (Bohlin Model Visco 88, Bohlin Instruments, UK) equipped with a heating circulator (Julabo, Model F12-MCand, Julabo Labortechnik, Germany) and C14 spindle. All the experiments were performed at 25°C±0.2. A previous shearing of 15-30 s at 14.1 s^{-1} was applied to all samples to eliminate the flow time dependence. After eliminating the flow time dependence, sample flow was measured by registering the shear stress/ shear rate data at an increasing trend from 14.1 to 150 s^{-1}.

To describe the time independent flow behavior, the experimental data (shear stress-shear rate) were fitted by Power law (Eq. 1), Casson (Eq. 2), Herschel- Bulkley (Eq. 3) and Bingham (Eq. 4) models:

$$\tau = k\dot{\gamma}^{n} \quad (1)$$

Where, τ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), K is the consistency coefficient ($Pa.s^n$) and n is the flow behavior index (dimensionless).

$$\sqrt{\tau} = \sqrt{k_{0C}} + k_C\sqrt{\dot{\gamma}} \quad (2)$$

Where, k_{0C} ($Pa^{0.5}$) and k_C ($Pa^{0.5}.s^{0.5}$) are the intercept and slope of plot of $(\tau)^{0.5}$ versus $(\dot{\gamma})^{0.5}$, respectively.

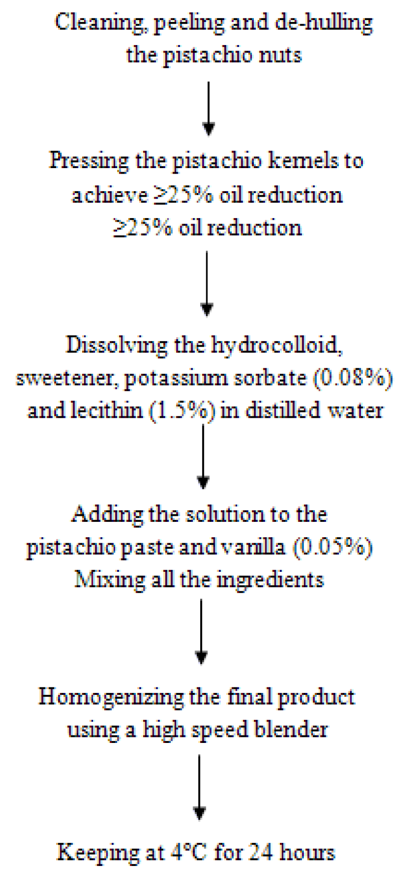

Fig. 1: Steps used in preparation of reduced- calorie pistachio butter product

Then, the magnitudes of k^2_{0C} and k^2_C have been used as the Casson yield stress (τ_{0c}, Pa) and Casson plastic viscosity (η_c, Pa.s), respectively.

$$\tau = \tau_0^H + K\dot{\gamma}^n \quad (3)$$

Where, τ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), τ_0^H is Herschel-Bulkley yield stress (Pa), K is the consistency coefficient ($Pa.s^n$) and n is the flow behavior index (dimensionless).

$$\tau = \tau_{0B} + \mu_B\dot{\gamma} \quad (4)$$

Where, τ is the shear stress (Pa), $\dot{\gamma}$ is the shear rate (s^{-1}), τ_{0B} is Bingham yield stress (Pa) and μ_B is Bingham viscosity ($Pa.s^n$).

Experimental Design: RSM with central composite design was used to determine the effect of different fat replacers and sweeteners at different levels on the rheological behavior of low- calorie pistachio butter.

Table 1: Faced central composite design for the independent variables (coded and uncoded levels)

	Independent variables											
	Coded levels			Uncoded levels for XG			Uncoded levels for BSG			Uncoded levels for RSG		
Run	Gum concentration (A)	Isomalt ratio (B)	Sucrose ratio (C)	Gum concentration	Isomalt ratio	Sucrose ratio	Gum concentration	Isomalt ratio	Sucrose ratio	Gum Concentration	Isomalt ratio	Sucrose ratio
1	1	1	3	0.06	0	1	0.01	0	1	0.01	0	1
2	1	1	1	0.06	0	0.25	0.01	0	0.25	0.01	0	0.25
3	1	2	2	0.06	0.5	0.63	0.01	0.5	0.63	0.01	0.5	0.63
4	1	3	1	0.06	1	0.25	0.01	1	0.25	0.01	1	0.25
5	1	3	3	0.06	1	1	0.01	1	1	0.01	1	1
6	2	1	2	0.08	0	0.63	0.025	0	0.63	0.017	0	0.63
7	2	2	2	0.08	0.5	0.63	0.025	0.5	0.63	0.017	0.5	0.63
8	2	2	2	0.08	0.5	0.63	0.025	0.5	0.63	0.017	0.5	0.63
9	2	2	2	0.08	0.5	0.63	0.025	0.5	0.63	0.017	0.5	0.63
10	2	2	2	0.08	0.5	0.63	0.025	0.5	0.63	0.017	0.5	0.63
11	2	2	2	0.08	0.5	0.63	0.025	0.5	0.63	0.017	0.5	0.63
12	2	2	2	0.08	0.5	0.63	0.025	0.5	0.63	0.017	0.5	0.63
13	2	2	3	0.08	0.5	1	0.025	0.5	1	0.017	0.5	1
14	2	2	1	0.08	0.5	0.25	0.025	0.5	0.25	0.017	0.5	0.25
15	2	3	2	0.08	1	0.63	0.025	1	0.63	0.017	1	0.63
16	3	1	1	0.1	0	0.25	0.04	0	0.25	0.023	0	0.25
17	3	1	3	0.1	0	1	0.04	0	1	0.023	0	1
18	3	2	2	0.1	0.5	0.63	0.04	0.5	0.63	0.023	0.5	0.63
19	3	3	1	0.1	1	0.25	0.04	1	0.25	0.023	1	0.25
20	3	3	3	0.1	1	1	0.04	1	1	0.023	1	1

As there may occur some systematic errors and therefore some unexplained variability in the observed responses, experiments were replicated in the center of design to make the estimation of pure error possible (Qiu *et al*., 2010). The experimental range was chosen on the basis of the results of preliminary experiments. The three dependent variables and experimental design in terms of coded and uncoded are presented in Table 1.

The following second-order polynomial equation of function X_i was fitted for each factor assessed:

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

The surface graphical presentations of the response surface models were performed using Minitab statistical software (MINITAB^{TM}, version 13.20). The response surfaces for these models were plotted as a function of two variables, while keeping other variable at the average value.

Rheological parameters of fitted models and coefficient of determinations were obtained by statistical model fitting software program namely Slide Write version 2.0.

To evaluate the goodness of fit, the R^2 and Root Mean Square Error (RMSE) statistics were used. In general, the determination coefficient will range from 0 to 1, with a R^2 value of 1 being the best. The RMSE values <10%, 10-20%, 20-30% and >30% represent the excellent, good, fair and poor fitting, respectively.

RESULTS AND DISCUSSION

Flow Behavior Properties: A typical rheogram for a sample containing RSG is shown in Fig. 2. Similar behaviors were observed for other fat replacers and at their all studied levels (Figures not shown). A non-Newtonian shear thinning behavior was observed for all cases. Alpaslan and Hayta (2002) and Arslan *et al*. (2005) reported the same flow behavior for the blends of sesame paste and pekmez.

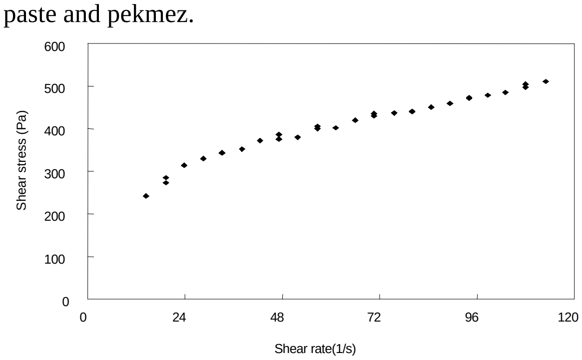

Fig. 2: A typical rheogram of low- calorie pistachio butter containing 0.01% RSG, no isomalt and the sucrose: pistachio paste ratio equal to 0.25

Table 2: The parameters of power law model and its coefficients of determination (R^2) for the studied formulas at their center point

Model	Rheological parameter	Samples containing BSG	Samples containing RSG	Samples containing XG
Power law	K	96.06±13.31	56.83±6.51	185.57±49.91
	n	0.32±0.09	0.39±0.03	0.26±0.03
	R^2	0.868-0.994	0.888-0.995	0.861-0.995
	RMSE	2.38-8.10	2.37-7.46	2.10-10.95
Bingham	J_0^B	218.21±57.36	165.71±30.97	194.45±17.48
	μ_B	1.57±0.4	1.73±0.47	1.81±0.28
	R^2	0.866-0.992	0.915-0.984	0.870-0.991
	RMSE	2.40-8.13	2.84-3.15	2.39-10.70
Casson	J_0^C	155.93±38.61	142.81±47.87	166.94±29.09
	0_C	0.70±0.15	0.75±0.18	0.92±0.14
	R^2	0.920-0.995	0.904-0.973	0.913-0.977
	RMSE	2.27-5.14	3.11-3.36	1.97-2.97

Table 3: Estimated coefficients and coefficients of determination (R^2) of the fitted quadratic equations for different responses in formulas containing RSG

	Predicted coefficients					
	Power law model		Bingham model		Casson model	
Coefficients	K	n	J_0^B	μ_B	J_0^C	0_C
Constant	300**	0	310	0	324[a]	2
A	-12681[a]	49*	-6117	116	1314**	191
B	-259**	0	-308	0	-540	-2
C	-116	0	-28	-1	80	-4
A^2	350728[a]	-1509*	186624	-3873[a]	22434	-5552
B^2	27	0[a]	-17	1[a]	143	1
C^2	93	0	30	1	43	3
AB	8849	-13**	12243	-24	18389	45
AC	-5246**	11[a]	-8334	30	-155656**	-32
BC	32*	0	49	0	2*	0
R^2	95.8	89.7	63.2	67.8	83.0	50.1
P- value						
Lack of fit	0.075	0.227	0.927	0.873	0.879	0.393

Fitting the Herschel- Bulckley model resulted in negative yield stress values which are not acceptable. The results relevant to this model were thus omitted. Taghizadeh and Razavi (2009) evaluated the flow behavior of pistachio butter and stated that negative yield stress values make the Herschel- Bulckley model an inappropriate model for data obtained at 45 and 65°C measurements.

For comparing the results of rheological model parameters at three formulas, the reference center point at which all treatments are at their average value was chosen (Table 2). According to the R^2 and RMSE values, it is obvious that the Power law, Bingham and Casson models can properly describe the flow behavior.

The flow behavior indices of Power law model confirm the pseudo-plastic behavior of three samples. Evaluating the yield stress models i.e. Bingham and Casson models revealed that the lowest yield stress values were obtained for sample containing RSG. This observation can make some anxious about the stability of product emulsions. There are also some positive points in processing (e.g. pumping or mixing) and sensory characteristics (e.g. spread ability). The magnitude of plastic viscosity for both Bingham and Casson models showed that the sample containing BSG and sample containing Xanthan gum have lowest and highest viscosities.

Diagnostic Checking of the Fitted Models: According to the conditions constructed using CCD, twenty experiments were carried out for each fat replacer (Table 1). Regression analysis of relationship between independent and dependent variables resulted in predicted equations for each parameter. The coefficients of determination and lack of fit of the models are reported in Tables 3-5. The linear, quadratic and interaction effects of each model and the P-value related to each coefficient are reported as well.

Table 4: Estimated coefficients and coefficients of determination (R^2) of the fitted quadratic equations for different responses in formulas containing BSG

	Predicted coefficients					
	Power law model		Bingham model		Casson model	
Coefficients	K	n	J_0^B	μ_B	J_0^C	0_C
Constant	101*	0	409*	0.3	510**	1.4[a]
A	-1092	29.4*	-8072	37.8[a]	-7416	43.1
B	-105	-0.3	23	-0.7	50	-2.2[a]
C	142	-0.2	-333	-0.1	-548	0.4
A^2	53380	-459.2*	126817	-614	56833	-811.1
B^2	1	0.3[a]	-10	0.5	-20	1.5
C^2	-82	0.4	5	0.5	147	-0.5
AB	1969	3.8	-3715	7.9	-3772	6.9
AC	-3870	-6.1	4435	-12.8	8239	-7.6
BC	13*	0	72	0.1	36	0.9
R^2	77.1	70.9	51.0	57.6	59.2	37.7
P- value						
Lack of fit	0.900	0.831	0.805	0.813	0.865	0.831

Table 5: Estimated coefficients and coefficients of determination (R^2) of the fitted quadratic equations for different responses in formulas containing XG

	Predicted coefficients					
	Power law model		Bingham model		Casson model	
Coefficients	K	n	J_0^B	μ_B	J_0^C	0_C
Constant	-567	0.80	796	0.02	541*	-2.3
A	19566	-14.47	-12182	22.22	-8748	70.7
B	21	0.19	-152	0.24	-127	-2.0
C	237	0.03	-125	-0.91	183	3.0
A^2	-100760	79.89	61355	85.11	65336	-116.8
B^2	8	-0.18	-119	-0.38	-93	3.8**
C^2	432	-0.15	-35	0.90[a]	47	-1.2*
AB	-1919	0.82	2611	-10.74	301	-36.7*
AC	-4303	2.23	740	0.15	-3760**	-20.6
BC	284*	-0.17[a]	-7	0.29	186**	1.4[a]
R^2	66.2	54.8	61.4	77.1	84.8	83.3
P- value						
Lack of fit	0.279	0.105	0.053	0.274	0.103	0.125

Regression coefficients of the models fitted on the data related to samples containing RSG are reported in Table 3. The effect of RSG on the consistency coefficient is significantly negative and positive for the linear and the quadratic terms, respectively (P#0.1). For formulas prepared using RSG, isomalt and sucrose individually have a negative significant and a non-significant effect on K, respectively. Interaction of two sweeteners, however, shows a positive significant effect on consistency coefficient (P#0.05). The statistical analysis shows that the interaction of RSG and isomalt has a negative effect on n-value (P#0.01), while this effect is positive for the interaction between RSG and sucrose (P#0.1). In spite of the great linear and quadratic effect of gum concentration, there no significant effect was observed on Casson viscosity. The individual effect of gum concentration and the interaction effect of gum concentration and sucrose content on Casson yield stress was positive and negative, respectively (P#0.01). According to the R2 values, the second order regression could not represent the Casson viscosity changes properly.

The coefficients of the predicted models related to the samples prepared using BSG and XG are presented in Tables 4 and 5, respectively. Sucrose and isomalt: pistachio paste ratio did not individually have significant linear effects on consistency coefficients of samples containing BSE. The interaction effects, however, showed a significant positive effect (P#0.1). The lowest R^2 values were obtained for the fitted second order regression on Casson viscosity data.

Table 6: Analysis of variance for the quadratic model of different responses

			XG			BSG			RSG		
Model	Response	Source	DF	MS	F	DF	MS	F	DF	MS	F
Power law	K	Regression									
		Residual	9	7468	2.17	9	1569.5	3.37	9	3357.46	22.85
		error	10	3434		10	465.6		10	146.92	
		Total	19			19			19		
		Regression	9	0.003	1.35	9	0.013	2.44	9	0.012	8.68
	n	Residual error	10	0.002		10	0.005		10	0.001	
		Total	19			19			19		
Bingham		Regression	9	4394.5	1.76	9	7414	1.04	9	5996.2	1.72
	J_0^B	Residual error	10	2490.4		10	7111		10	3492.9	
		Total	19			19			19		
		Regression	9	0.057	3.75	9	0.24	1.36	9	0.042	2.10
	μ_B	Residual error	10	0.015		10	0.017		10	0.020	
		Total	19			19			19		
Casson	J_0^C	Regression	9	4150.3	6.20	9	6705.1	1.45	9	10097	4.88
		Residual error	10	669.8		10	4628.5		10	2071	
		Total	19			19			19		
	μ_C	Regression	9	0.861	5.56	9	0.072	0.61	9	0.272	1.00
		Residual error	10	0.155		10	0.118		10	0.271	
		Total	19			19			19		

None of the sweeteners had significant effect on Casson yield stress values of samples containing XG, but their interaction effect is significantly positive (P#0.05). Similar result was observed for formulas containing RSG. The interaction effect of two sweeteners on the flow behavior index was significantly negative. While, for all three formulas this interaction effect on the consistency coefficient was in a positive significant form (P#0.05).

The analysis of variance was performed to assess how well the model represents the experimental data (Table 6). Results showed that in most cases, the quadratic regression was adequate for prediction within the range of experiments.

Analysis of Response Surface

Effect of Experimental Treatment on Power Law Parameters: The relationship between dependent and independent variables can be illustrated using three dimensional response surface graphs. The interaction effects of isomalt: pistachio paste ratio and BSG on consistency coefficient is shown in Fig. 3. Increasing the isomalt level led to an adverse decrease of K and higher levels of gum have made the consistency coefficient to increase slowly. The higher levels of gum concentration resulted in more water absorption and therefore, higher K values achieved. Razavi *et al*. (2007) studied the effects of fat replacers on the flow behavior of low- fat sesame butter. They used Power law models to describe the behavior and evaluated the effects of fat replacers on the Power law parameters. They reported that higher levels of gum produce higher magnitudes of consistency coefficient. Since the sweetener level is proportional to pistachio paste, increasing the isomalt ratio means the reduction in the pistachio paste proportion.

The response surface in Fig. 4. shows the correlative effect of isomalt and sucrose: pistachio paste ratios on the flow behavior index in formulas prepared using RSG. Increasing both sweeteners resulted in a decrease in pseudo-plasticity. It can be seen that isomalt decreased the n value more adversely. The solutions of sucrose and isomalt show a Newtonian behavior and therefore, increasing their substitution level increased the n value.

Fig. 5. shows the 3D response surface plot at varying BSG concentration and sucrose: pistachio paste ratio. Increasing the sweetener level decreased the pseudoplastic behavior. Increasing the BSG level to 0.03% resulted in an increase and then a decrease in n value. Similar trends were observed for the interaction effect of RSG and isomalt (Fig. 6), RSG and sucrose and also BSG and isomalt (Figs. not shown).

Razavi *et al*. (2007) reported that the n values of fitted Power law model in low- fat sesame butter were between 0.35 and 0.51. They also showed that increasing the fat replacers' level will led to a decrease in n values.

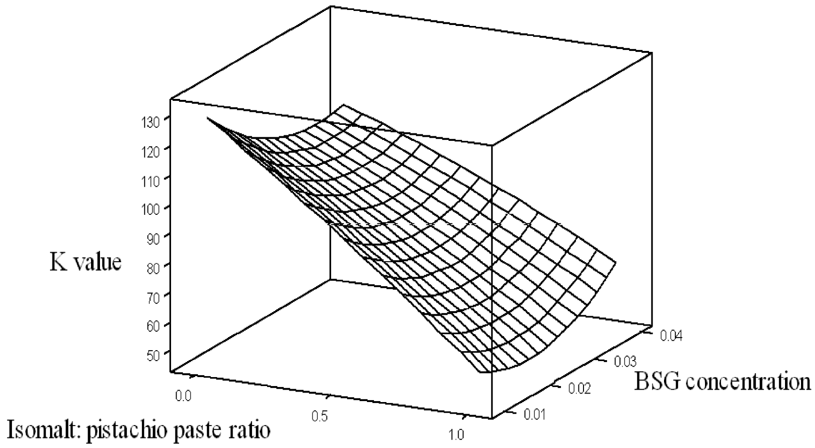

Fig. 3: Response surface for the effect of isomalt: pistachio paste ratio and BSG concentration on K value of Power law model in formulas prepared by BSG

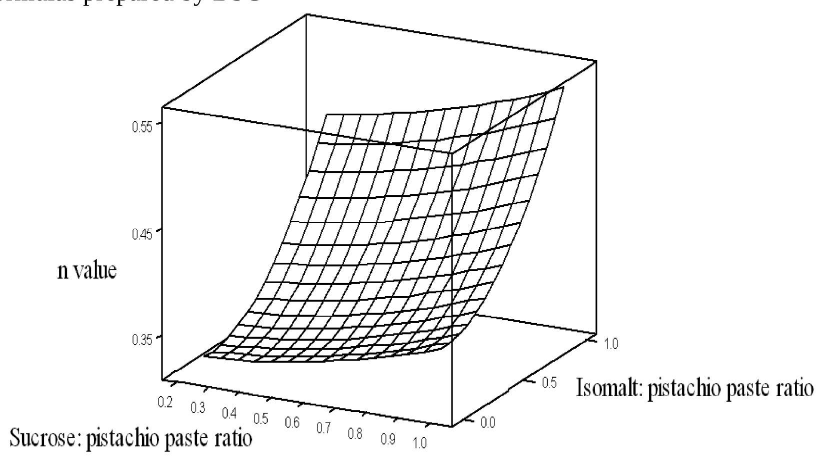

Fig. 4: Response surface for the effect of isomalt: pistachio paste ratio and sucrose: pistachio paste ratio on n value of Power law model in formulas prepared by RSG

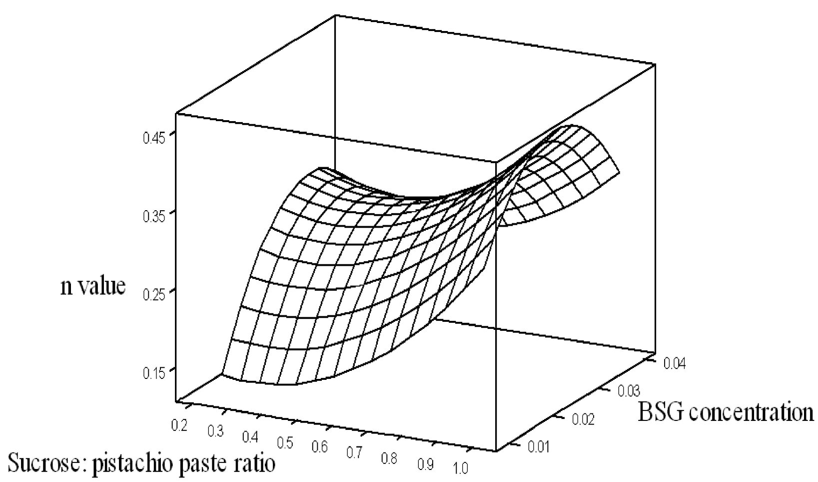

Fig. 5: Response surface for the effect of sucrose: pistachio paste ratio and BSG concentration on n value of Power law model in formulas prepared by BSG

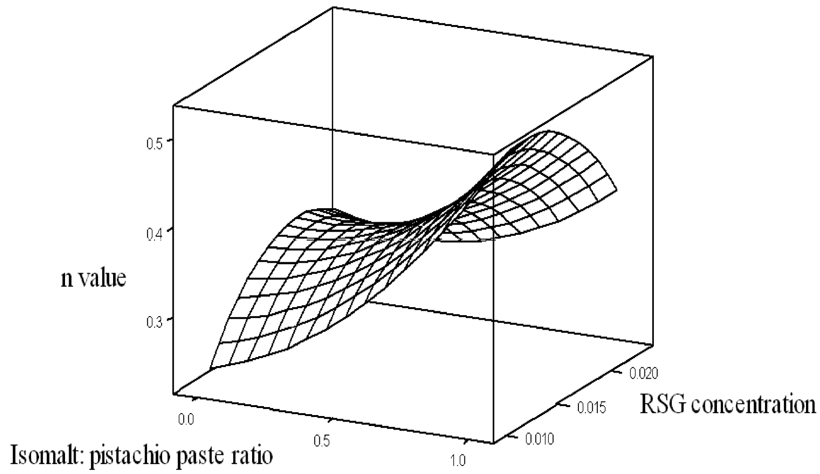

Fig. 6: Response surface for the effect of isomalt: pistachio paste ratio and RSG concentration on n value of Power law model in formulas prepared by RSG

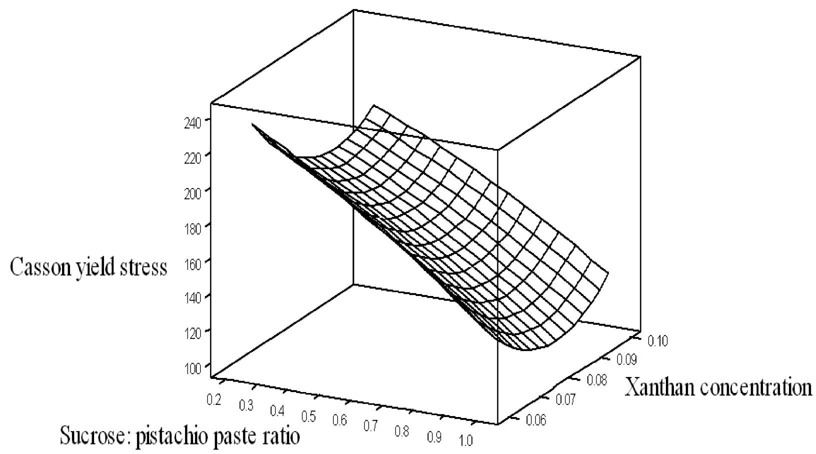

Fig. 7: Response surface for the effect of sucrose: pistachio paste ratio and XG concentration on Casson yield stress of formulas prepared by XG

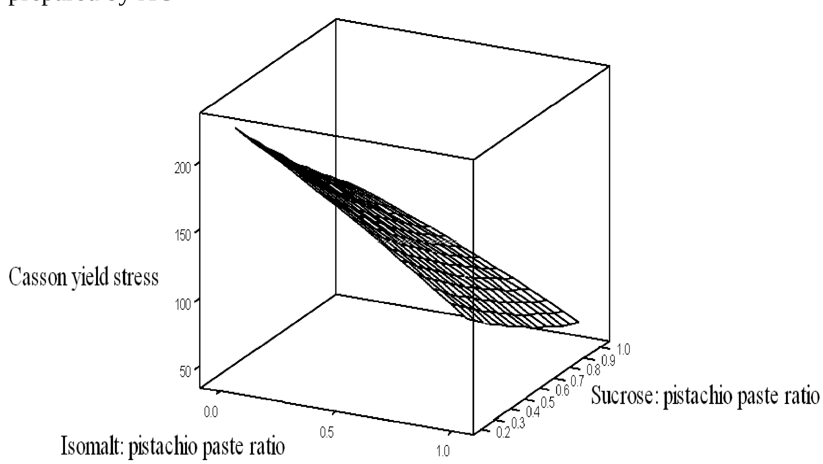

Fig. 8: Response surface for the effect of isomalt: pistachio paste ratio and sucrose: pistachio paste ratio on Casson yield stress of formulas prepared by RSG

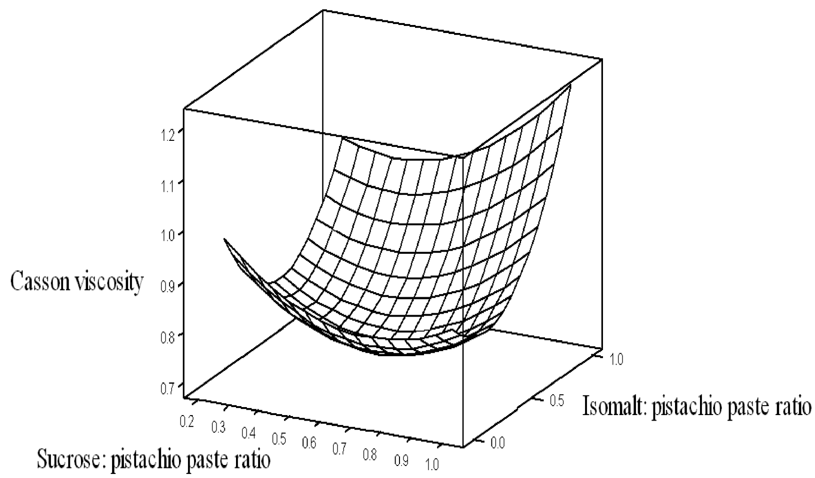

Fig. 9: Response surface for the effect of isomalt: pistachio paste ratio and sucrose: pistachio paste ratio on Casson viscosity of formulas prepared by RSG

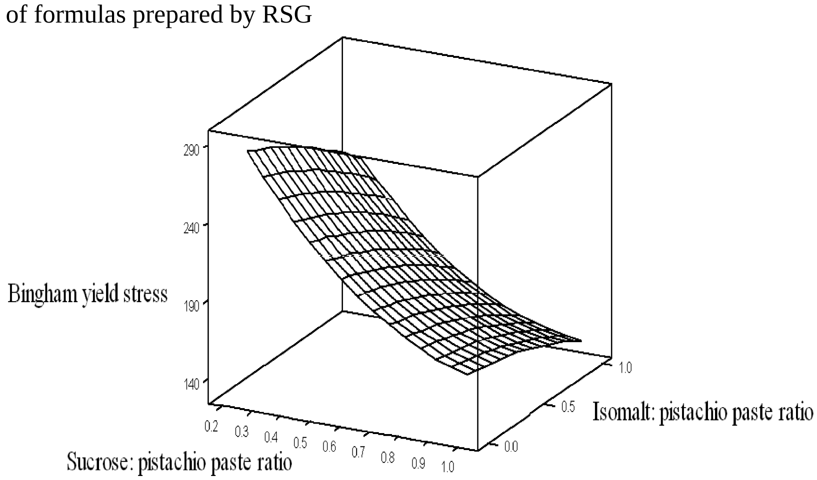

Fig. 10: Response surface for the effect of isomalt: pistachio paste ratio and sucrose: pistachio paste ratio on Bingham yield stress of formulas prepared by BSG

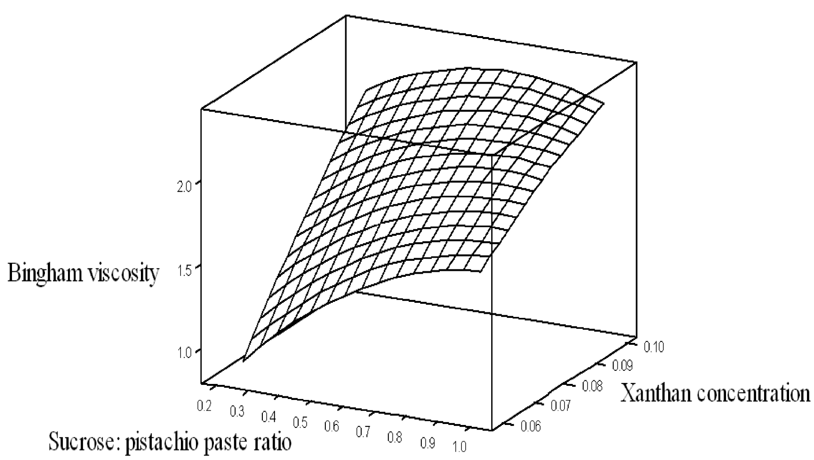

Fig. 11: Response surface for the effect of sucrose: pistachio paste ratio and XG concentration on Bingham viscosity of formulas prepared by XG

Effect of Experimental Treatment on Casson Parameters: The response surface in Figure 7 shows the combined effects of sucrose: pistachio paste ratio and xanthan concentration on the Casson yield stress value. As it was expected, increasing the gum concentration had an increasing effect on yield stress value, although it was not adverse. This behavior was probably caused by the increased intermolecular associations. Similar observation was previously reported by other researchers (Marcotte *et al*. 2001; Ahmed and Ramaswamy, 2004; Tarrega *et al*. 2006). Increasing the sucrose ratio means the reduction in the pistachio paste proportion, the amount of fiber and subsequently the strength of the product network.

The response surface in Fig. 8 shows the combined effects of sucrose and isomalt: pistachio paste ratios on Casson yield stress of formulas containing RSG. The higher sweetener content the lower yield stress values of the model.

The correlative effect of isomalt and sucrose: pistachio paste ratios on Casson viscosity is a synergistic effect for all formulas. The effect of sweeteners on Casson viscosity of formulas containing RSG is shown in Fig. 9.

Effect of Experimental Treatment on Bingham Parameters: The response surface in Fig. 10 shows the combined effects of sucrose and isomalt: pistachio paste ratios on Bingham yield stress of samples prepared using BSG. Changes in the yield stress are similar to the changes in Casson model. Formulas containing RSG showed similar trends (Fig. not shown).

The response surface for the Bingham viscosity with varying XG concentration and sucrose: pistachio paste ratio is shown in Fig. 11. The observed effect is similar to isomalt and XG interaction effect on Casson viscosity (Fig. not shown). Higher gum concentration resulted in higher magnitudes of Bingham viscosity. Increasing the isomalt content at the lower concentration of XG led to an increase in Bingham viscosity. But at higher gum concentration, the isomalt addition did not affect the attribute.

Citren *et al*. (2001) fitted the Bingham and Casson models on the rheological data to evaluate the yield stress values in stabilized and unstabilized peanut butters. They magnitudes of Bingham and Casson yield stress for the stabilized peanut butter were 374 and 363 Pa and for unstabilized ones were 27 and 22 Pa, respectively.

CONCLUSION

The response surface methodology was found suitable for determining the relationship between the level of fat replacers, sweeteners and rheological parameters of fitted models. A non- Newtonian shear-thinning behavior was found for all formulas. Increasing the gum level generally resulted in higher consistency coefficient and yield stress values and according to the formulation, higher levels of sweetener led to lower pistachio paste ratios and subsequently a decrease in consistency coefficient, viscosity and yield stress.

REFERENCES

Ahmed, J. and H.S. Ramaswamy, 2004. Effect of high hydrostatic pressure and concentration on rheological characteristics of xanthan gum, Food Hydrocolloids, 18: 367-373.

Alpaslan, M. and M. Hayta, 2002. Rheological and sensory properties of pekmez (grape molasses)/ tahin (sesame paste) blends. J. Food Engineering, 54: 189-193.

Arslan, E., M.E. Yener and A. Esin, 2005. Rheological characterization of tahin/ pekmez (sesame paste/ concentrated grape juice) blends. J. Food Engineering, 69: 167-172.

Citerne, G.P., P.J. Carreau and M. Moan, 2001. Rheological properties of peanut butter, Rheologica Acta, 40: 86-96.

Emadzadeh, B., S.M.A. Razavi, M. Nassiri Mahallati and R. Farhoosh, 2010a. Optimization of fat replacers and sweetener levels to formulate reduced- calorie pistachio butter: a response surface methodology, Submitted paper to J. Food Processing and Preservation.

Emadzadeh, B., S.M.A. Razavi and M. Nassiri Mahallati, 2010b. Effects of fat replacers and sweeteners on the time- dependent rheological characteristics and emulsion stability of low- calorie pistachio butter: A response surface methodology. Submitted paper to Food and Bioprocess Technology.

Hosseini Parvar, S.H., S.A. Mortazavi, S.M.A. Razavi, L.M. Merino and K.K.T. Goh, 2010. Steady shear flow behavior of gum extracted from *Ocimum basilicum* L. seed: Effect of concentration and temperature, J. Food Engineering (Revised manuscript).

Marcotte, M., A.R. Taherian Hoshahili and H.S. Ramaswamy, 2001. Rheological properties of selected hydrocolloids as a function of concentration and temperature, Food Research International. 34: 695-703.

Mohammad Amini, A., 2007. Modeling and optimization of mucilage extraction from Lallemantia royleana: a response surface – genetic algorithm approach. EFFOST/EHEDG Joint Conference. 14-16 November, Lisbon-Portugal.

Nabors L.B., 2001. Alternative sweeteners. Marcel Dekker, Inc, New York.

Qiu, L., G. Zhao, H. Wu, L. Jiang, X. Li and J. Liu, 2010. Investigation of combined effects of independent variables on extraction of pectin from banana peel using response surface methodology, Carbhydrate polymers, doi: 10.1016/j.carbpol.2010.01.018.

Razavi, S.M.A., M.B. Habibi Najafi and Z. Alaee, 2007. The time independent rheological properties of low fat sesame paste/ date syrup blends as a function of fat substitutes and temperature, Food Hydrocolloids, 21: 198-202.

Razavi, S.M.A., B. Emadzadeh and T. Mohammadi Moghaddam, 2009a. Synergistic interaction of Balangu seed gum with selected food hydrocolloids: The rheological investigation. Proceedings of the 5th International Symposium on Food Rheology and Structure, Jun. 14-18, Zurich, Switzerland.

Razavi, S.M.A., S.A. Mortazavi, L.M. Merino, S.H. Hosseini Parvar, A. Motamedzadegan and E. Khanipour, 2009b. Optimization study of gum extraction from Basil seeds (*Ocimum basilicum* L.), International Journal of Food Science and Technol., 44: 1755-1762.

Razavi, S.M.A., M. Taghizadeh and A. Shaker Ardekani, 2010. Modeling of time-dependent rheological properties of pistachio butter, International J. Nuts and Related ci., 1(1): 38-45.

Roller S. and S.A. Jones, 1996. Handbook of fat replacers. CRC Press.

Singh, S.K., M.E. Castell-Perez and R.G. Moreira, 2000. Viscosity and textural attributes of reduced- fat peanut pastes, J. Food Sci., 65(5): 849-853.

Taghizadeh M. and S.M.A. Razavi, 2009. Modeling time-independent rheological behavior of pistachio butter, International J. Food Properties, 12(2): 331-340.

Tarrega, A., E. Costell and M.A. Rao, 2006. Vane yield stress of native and cross-linked starch dispersions in skimmed milk: effect of starch concentration and 8-carrageenan addition, Food Sci. Tech. Int., 12(3): 253-260.