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Optimization of the new formulation of ice cream with native Iranian seed gums (*Lepidium perfoliatum* and *Lepidium sativum*) using response surface methodology (RSM)

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Abstract In this study, effect of Qodume shahri (*Lepidium perfoliatum*) and cress (*Lepidium sativum*) on rheological properties of ice cream were investigated. The gums were added to the ice cream formulation and different quality attributes including pH, acidity, melting characteristics, viscosity, overrun, texture analysis and sensory evaluation were determined. Results showed that ice cream formulations containing both the gums had improved overrun, melting rate, first dripping time, viscosity, hardness and adhesiveness. The gum concentrations beyond 0.2% level led to a negative effect on gumminess and chewiness of ice cream. Both the gums addition to improved quality attributes and textural properties of ice cream.

Keywords Ice cream · *Lepidium perfoliatum* seed gum · *Lepidium sativum* seed gum · Rheological properties · Response surface methodology (RSM)

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Introduction

Ice cream is a highly complex food matrix that generally comprises of a mixture of ingredients: air, water, milk fat, milk solids-not-fat (MSNF), sweetener, stabilizer, emulsifier and flavoring agents (Goff and Hartel 2013). In order to improve the quality of ice cream, it is needed to obtain the optimal formulation and processing parameters. The two important factors affecting the ice cream texture and acceptability are stabilizers and emulsifiers. Stabilizers are ingredients which are used in small amounts in ice cream formulations and impart specific and important functions to the finished product (Bahramparvar and Mazaheri-Tehrani 2011). The basic purposes for using stabilizers in ice cream formulation are to increase mixture viscosity, prevent shrinkage and slow down moisture migration from ice cream during storage period, to reduce the rate of meltdown, to stabilize the mixture to prevent wheying off, to produce smoothness in body and texture, to help in suspension of flavoring particles, to allow easier pumping and more accurate filling during processing and finally to retard or reduce ice and lactose crystal growth during storage (Goff and Hartel 2013; Clarke 2004). So far many stabilizers have been used in the formulation of ice cream, but attempts to find new sources of hydrocolloids in order to create better quality ice cream have continued (Bahramparvar and Mazaheri-Tehrani 2011; Bahramparvar et al. 2013; Marshall et al. 2003).

On the one hand, there are wide variety of stabilizers and gums that are usually used singly or in combination to achieve optimum results by the most ice cream manufacturing plants (Bahramparvar et al. 2013; Marshall et al. 2003; Martinou-Voulasiki and Zerfiridis 1990; Moeenfard and Mazaheri-Tehrani 2008; Mahdian and Karazhian 2013). Different stabilizers such as gums due to their useful synergistic effects are used for cost reduction in ice cream

industry as a fat replacer agent (Bahramparvar and Mazaheri-Tehrani 2011; Bahramparvar et al. 2013).

Response surface methodology (RSM) is one of the most important multivariate techniques extensively used in recent years to model and optimize formulations and processing conditions in food technology. In fact, RSM is a collection of mathematical, statistical and frequently used techniques that are useful through fitting the experimental data with polynomial equation and models to describe the factors tested on responses, and it can assess the impact of the input variables and their interactions (Munoz-Insa et al. 2013; Kahyaoglu 2008; Kittisuban et al. 2014; Iborra-Bernad et al. 2013; Pourfarzad et al. 2013; Gan et al. 2007; Lu et al. 2014; Feng et al. 2014).

In today's societies, the high demand for plant based gums has extremely increased in the food industry, medicines and drug delivery systems (Mirhosseini and Tabatabaee-Amid 2012). *Lepidium perfoliatum* and *Lepidium sativum* are two major and new sources of plant-based gums, which both belong to the Cruciferae family. The *L. perfoliatum* is native to Egypt, Arabia, Iraq, Iran and Pakistan (Amin 2005) and *L. sativum* grows widely in the Middle East, Europe and USA (Karazhiyan et al. 2009) and is locally called Qodume shahri and cress, respectively. The *L. perfoliatum* and *L. sativum* seeds contain a large amount of gum with high-molecular weight and mucilaginous substances, which diffuses out when soaked in water. They are widely employed for the treatment of many diseases and also can be used as a potential thickening and stabilizing agent in the food industry (Koocheki et al. 2009; Amin 2005; Koocheki et al. 2013; Behrouzian et al. 2014a, b; Karazhiyan et al. 2009; Sahraiyan et al. 2013; Karazhiyan et al. 2011; Naji et al. 2012). Finally, studies on compounds of plant hydrocolloids have brought numerous applications in food and pharmaceutical industries and it will be followed by economic benefits. According to the above literature, the main objectives of this research include:

1. Study of the possibility of using *L. perfoliatum* and *L. sativum* seeds gums as a novel stabilizer in ice cream formulation.
2. Study of the synergistic effects of blend of these gums in the formulation of ice cream.
3. Study of the rheological, textural and sensory properties of the produced final products.
4. Optimizing of the ice cream formulation containing *L. perfoliatum* and *L. sativum* seeds gums.

Materials and methods

Extraction procedure

The seeds were purchased from the local medical plant shop and cleaned manually. Extraction procedure for Qodume shahri seed gum (QSSG) and cress seed gum (CSG) were performed under the following conditions water to seed ratio 1:30, pH 8 and 10, solution temperature 48 and 35 °C respectively. It should be noted that the pH was adjusted constantly by the addition of 0.1 mol/L NaOH or HCl. The seed-water slurry was removed using a juicer machine and were dried in an oven for 24 h in 50–55 °C. Ultimately, the collected gums were milled and sieved using a sifter, then packed. It was maintained in a cool and dry place until required for trials (Razavi et al. 2011; Koocheki et al. 2009; Karazhiyan et al. 2011).

Ice cream preparation

In this work, ice cream samples were standardized by adding of cream (to obtain milk fat of 4%), sugar (16%), stabilizer-emulsifier mixture (0.2%) and skim milk powder (to adjust total solid to 30%). Then, depending on the applied treatments different amounts of both gums were mixed and it was heated to approximately 40 °C and then homogenized (10,000 rpm at 5 min) in order to reach uniform ingredients mixture. After blending of ice cream ingredients the prepared mixture was pasteurized at 85 °C for 30 min and then cooled to refrigerator temperature (4 °C). To ensure complete hydration, the ice cream mixture, was stored at 5 ± 1 °C overnight. The aged ice cream mixture was frozen using homemade ice cream maker and was filled into 50 ml plastic cups. At the end, the ice cream was hardened at -18 °C for subsequent experiments. The applied stabilizer (TB 100) was purchased from Nano Gum Mehr company (Tehran, Iran).

Viscosity and flow behavior of ice cream mixture

The apparent viscosity of the ice cream mixture was taken after 24 h aging at 5 ± 1 °C and it was measured by using a Brookfield Viscometer (model RV-DV II Brookfield, Middleboro, MA, USA), with spindle No. 5 at speed 100 rpm. The rheological behavior of aged ice cream mixture was obtained through calculation of shear rate and shear stress values according to Mitschka's equations (Mitschka 1982) at speeds 10–200 rpm. The flow curves (shear stress versus shear rate and apparent viscosity versus shear rate) were plotted. Eventually, the rheological properties were fitted to three rheological models including Power Law, Herschel-Bulkley and Casson. All the experiments were performed in three replications.

The equations of three fitted rheological models were:

Power law model: $\tau = k (\gamma)^n$ (1)

Herschel$-$Bulkley model: $\tau = \tau_0 + k (\gamma)^n$ (2)

Casson model: $\tau^{0.5} = \tau_0^{0.5} + k (\gamma)^{0.5}$ (3)

where τ is the shear stress (Pa), k is the consistency index (Pa.s^n), γ is the shear rate (s^{-1}), τ_0 is the yield stress and n is the flow behavior index (dimensionless).

pH and acidity measurement

The pH of the ice cream mixture samples was measured by a Methrom-827 digital pH meter (model pH; Methrom, Herisau, Switzerland). The titratable acidity of aged ice cream mixture was determined through titration with 0.1 N standardized NaOH in the presence of phenolphthalein and was calculated based on the percentage of lactic acid as described by Eq. 4. Before measurements, ice cream samples were stirred with a little distilled water (Eq. 4) (Moeenfard and Mazaheri-Tehrani 2008).

$$\text{Acidity} = [N \times 0.009/V] \times 100 \qquad (4)$$

Overrun

The overrun was determined by comparing the weight of ice cream mixture and ice cream in a container with known volume. The overrun of the samples was determined by the following equation (Eq. 5) (Akin et al. 2007):

$$\text{Overrun} (\%)$$
$$= \frac{\text{Weight of unit mix} - \text{weight of equal volume of ice cream}}{\text{Weight of equal volume of ice cream}} \times 100 \qquad (5)$$

Melting characteristics

A piece of ice cream with weight of 30 ± 1 g was placed on a sieve with pore diameter of 2 mm and incubated at 25 ± 1 °C in oven. After 60 min the molten liquid weight, based on the percentage of the initial weight was measured as the melting rate. The first dripping time also was recorded during melting (Rezaei et al. 2011).

Textural analysis

Instrumental texture profile analysis (TPA) was performed on the ice cream samples using a Texture Analyser TA-XT-plus (Stable Micro Systems, Surrey, UK), equipped with a 2 mm diameter stainless steel cylindrical probe and set up to record the desired forces for penetrating distance = 15 mm, force = 5 g, probe speed during penetration = 3.3 mm/s, probe speed pre-and postpenetration = 3 mm/s. Factors evaluated in this test were hardness (maximum force during penetration), adhesiveness (negative area of peak force during withdrawal), gumminess (hardness × cohesiveness) and

chewiness (springiness × gumminess). Before testing, samples were stored at −10 °C for 24 h (Akalin et al. 2008).

Sensory evaluation of ice cream

Sensory evaluation of the ice cream samples was carried out by a sensory panel test with seven trained panelists in three replications. Before testing of ice cream samples, they were placed for 5 min at room temperature (22 ± 1 °C). The sensory characteristics of samples, including texture, color, flavor, and total acceptability were assessed using a 5-point hedonic scale method (1 = very bad, 2 = bad, 3 = not bad- not good, 4 = good and 5 = very good).

Experimental design

Response surface methodology (RSM) and central composite rotatable design (CCRD) was used to investigate the simultaneous effects of QSSG and CSG concentration on the physiochemical and textural characteristics of the ice cream samples. The two variables QSSG and CSG concentration (for each one 0, 0.1 and 0.2%) were selected after the preliminary testing. The CCRD in experimental design consisted of four factorial design, four axial points and five replications at the central point. It is notable that in this study, a CCRD was used with a α equal to 1. All treatments were performed twice. Experimental design or coding level version of an independent variable associated with each treatment is given in Table 1. Regression analyses were carried out for the experimental data and were fitted to a second-order polynomial equation (Eq. 6) for each response.

$$Y = b_0 + b_1 x_1 + b_2 x_2 + b_{11} x_1^2 + b_{22} x_2^2 + b_{12} x_1 x_2 + \varepsilon \qquad (6)$$

Table 1 Experimental runs to study the effect of QSSG and CSG on the properties of ice cream samples

Run	Block	QSSG (b_1)	CSG (b_2)
1	Block 1	0.10	0.10
2	Block 1	0.00	0.20
3	Block 1	0.10	0.10
4	Block 1	0.10	0.00
5	Block 1	0.10	0.10
6	Block 1	0.20	0.20
7	Block 1	0.20	0.10
8	Block 1	0.10	0.20
9	Block 1	0.10	0.10
10	Block 1	0.20	0.00
11	Block 1	0.00	0.10
12	Block 1	0.00	0.00
13	Block 1	0.10	0.10

where Y is the predicted response; x_1 and x_2 are the independent variables related to QSSG and CSG, respectively; b_0 is a model constant; b_1 and b_2 are the linear effects; b_{11} and b_{22} are the Quadratic effects; and b_{12} are the interaction effect.

Results and discussion

Model fitting from RSM

Regression analysis and Analysis of Variance (ANOVA) of experimental data linked to the all models were done in order to determine the adaptation of mathematical models and significant regression coefficients (the intercept, linear, quadratic and interaction terms of the models) and their results are shown in Tables 2 and 4. The correlation coefficient (R^2) shows that regression model is able to explain model well. In fact, R^2 is the suitable standard for measuring the efficiency of the model to describe the rate of parameters change (Liu et al. 2014; Kahyaoglu 2008; Kittisuban et al. 2014; Erdem et al. 2014).

The "fitness" of the mathematical models was examined by three factors, including: the correlation coefficient (R^2), probability values (p-values) and lack of fit values (Tables 2, 4). The suitability of the model was evaluated using the lack of fit and were calculated using the least square technique. Regression equations were obtained from the predicted responses for each factor to the actual levels of variables. Finally, the second-order polynomial response surface model was fitted for each dependent variable (Eq. 6). Actual R^2 and predicted R^2 values were good for models with respect to adhesiveness (0.908 and 0.328) and melting rate (0.985 and 0.911) respectively. The p-values obtained from lack-of-fit ranged from 0.0541 (chewiness) to 0.8344 (overrun) and best results were related to the rheological and textural properties ($p > 0.05$).

pH and acidity

The pH and acidity (% lactic acid) of the aged ice cream mixtures ranged from 6.56 to 6.66 and 18–19 (% lactic acid), respectively. There was a trend to lower pH and higher acidity in mixtures with increasing QSSG and CSG but no significant effect was observed in pH and acidity of samples containing the two gums ($p > 0.05$). This finding is in agreement with the results of Bahramparvar et al. (2009). They found that addition of *Lallemantia royleana* (Balangu) seed, palmate-tuber salep and carboxymethyl-cellulose gums in ice cream lead to non significant changes in the ice cream pH and acidity. In another study, Rezaei et al. (2011) showed that by addition of arabic and guar gums in frozen yoghurt, no significant effect was observed in pH and acidity of produced frozen yoghurt.

Table 2 Regression coefficients of predicted quadratic polynomial models for physicochemical properties of ice cream containing QSSG and CSG

Source	DF	Overrun Coefficient	Melting rate Coefficient	First dripping Coefficient	Apparent viscosity (cp) Coefficient
Model	5	+52.18**	+90.18**	+1162.24**	+384.32**
Linear					
b_1	1	−151.166**	+6.39**	+299.86**	+5636.35**
b_2	1	−64.51**	+1.89**	−826.81*	+3636.35**
Quadratic					
b_{11}	1	+282.50**	−289.66**	+7846.55*	−8977.59*
b_{22}	1	+35 ns	−175.156*	+6546.55 ns	−6177.59 ns
Interaction					
b_{12}	1	+168.50*	−149.75 ns	+2125 ns	−4325 ns
Residual	7				
Lack of fit	3	ns	ns	ns	ns
Pure error	4				
Total	12				
R^2		0.976	0.985	0.950	0.973
Adj-R^2		0.959	0.974	0.914	0.953
Pred-R^2		0.943	0.911	0.734	0.812
CV		3.56	1.23	3.77	6.02

ns non significant

* Significant at 5%

** Significant at 1%

Rheological properties

Viscosity

As shown in Fig. 1a, ice cream mixtures without gum (control sample (0, 0%)) had a low viscosity while mixtures with high level of QSSG and CSG (0.2%, 0.2%) were very viscous. The QSSG concentration had a positive effect on the apparent viscosity in linear and quadratic terms with significant levels of 1 and 5%, respectively (Table 2). In comparison, a positive linear effect ($p \leq 0.0001$) of the amount of CSG of apparent viscosity was found. It can be seen that the highest viscosity values were obtained at the experimental zone where gums concentrations were higher ($0.12 < QSSG < 0.2\%$ and $0.05 < CSG < 0.2\%$).

Many studies have investigated the viscosity and rheological characteristics of ice cream and ice cream mixtures (Soukoulis et al. 2008; Wittinger and Smith 1986; Bahramparvar et al. 2013; Mahdian and Karazhian 2013; Rezaei et al. 2011; Varela et al. 2014; Martinou-Voulasiki and Zerfiridis 1990; Kaya and Tekin 2001; Bahramparvar et al. 2009). They reported that stabilizers are macromolecules (mostly polysaccharides), that are able to interact with water and also interact with proteins and lipids in the mixture and so increase the mixture viscosity (Bahramparvar and Mazaheri-Tehrani 2011). Razavi et al. (2011) also studied the apparent viscosity of hydrocolloid obtained from these two types of seeds. They observed that apparent viscosity in QSSG was higher than CSG and also found that the effect of seed type on the apparent viscosity was significant. These results most likely related to the chemical structure and molecular weight of them. Basically, hydrocolloid with higher size and molecular weight due to higher friction between the molecules lead to increased viscosity (Behrouzian et al. 2014a; Koocheki et al. 2013). Finally, considering that the water-holding capacity of QSSG is higher than CSG it is expected such influence on viscosity of ice cream mixtures.

Flow behavior

Figure 2 showed the effect of the addition of the different concentrations of QSSG and CSG individually and blend on the flow behavior characteristics of ice cream formulations by plotting apparent viscosity–shear rate and shear stress–shear rate. Also, the parameters obtained experimentally from the mentioned three models (the Power-law, Herschel-Bulkley and Casson models) are summarized in Table 3. Based on the results of this study, addition of gums caused enhancement of consistency coefficient (k) which leads to a decrease in the flow behavior index (n). The increase in shear stress with an increase in shear rate indicate that the sample shows clearly non-Newtonian

pseudoplastic rheological behavior (shear thinning flow). In fact, the deviation from the Newtonian behavior increased with the increase of the gum concentration in all ice cream mixtures. Ice cream mixtures mostly exhibit shear thinning behavior (Bahramparvar and Mazaheri-Tehrani 2011) which is linked to a complex involvement of partially broken-down micellar casein at the droplet surface of the homogenized ice-cream mixture (Kaya and Tekin 2001; Soukoulis et al. 2008) and increased alignment of constituent molecules of the gel network in mixtures (Farhoosh and Riazi 2007).

The parameters obtained from the data fitting of shear stress versus shear strain for three models in ice cream mixtures with a correlation coefficient (R^2) of the fitting of the data is given in Table 3. Although all models showed a high correlation coefficient, from the standpoint of being in better agreement with the experimental data and compatibility with theories, Herschel-Bulkley model does the best. Based on our findings, the values of the flow behavior index (n) and consistency index (k) were between 0.38–0.68 and 0.24–11.52 in ice cream mixtures, respectively. As can be seen, samples containing high levels of QSSG and CSG have the highest consistency coefficient and the lowest flow behavior index than other mixture samples, while the control sample showed the lowest and highest values respectively. In this case Bahramparvar and Mazaheri-Tehrani (2011) reported that the flow behavior index values ranged from 0.37 to 0.98 that is in agreement with our results. The relationship between shear rate to shear stress and also viscosity to shear rate in mixtures containing QSSG was similar to that of mixtures containing CSG but the slope of the curve in samples containing QSSG is greater than CSG (with equal amounts). The main reason for such an effect on rheological properties can be attributed to the higher viscosity of samples containing QSSG than CSG.

Overrun

The results shown in Table 2 exhibited the effects of the independent variables on the overrun of ice cream. The overrun value of ice cream ranged from 28.75 to 52.53%. This result shows the significant linear, Quadratic and interaction effects of both gum ($p \leq 0.0001$), ($p < 0.01$) and ($p < 0.05$), respectively except for the quadratic effect of CSG ($p > 0.05$). The interaction between QSSG and CSG for overrun was also significant ($p < 0.05$). The Fig. 1b showed the counter plot curve of QSSG and CSG effect on the ice cream overrun. As can be seen the minimum overrun was observed in the formulation containing 0.09–0.2% QSSG and 0.025–0.2% CSG. Results showed that higher level of overrun value was found in lower levels of QSSG and CSG. According to the results of other
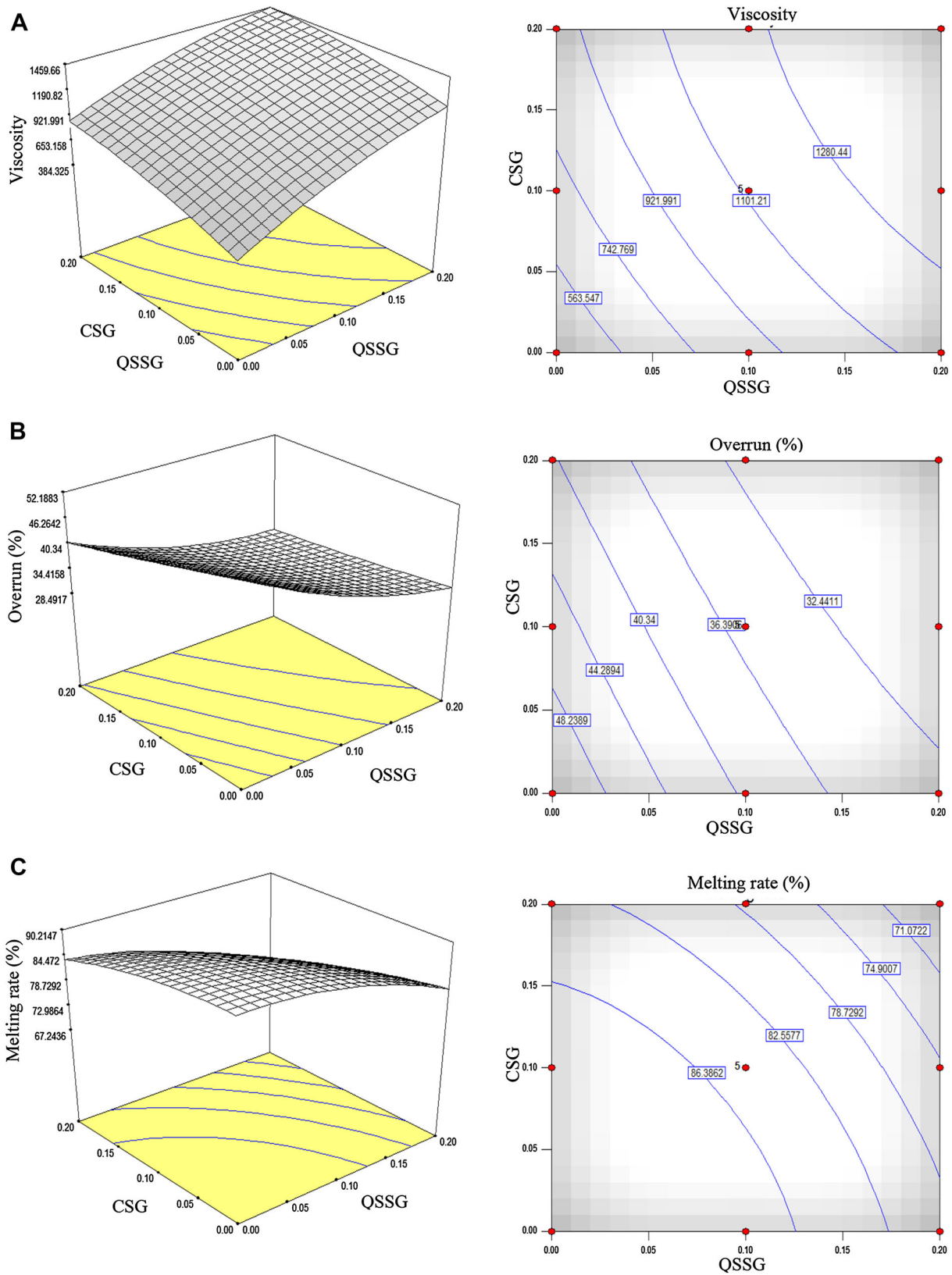
Fig. 1 Response surface showing (3D surface and contour) of the effect of CSG and QSSG concentrations on the overrun (**a**), melting rate (**b**), first dripping time (**c**) and apparent viscosity (**d**)
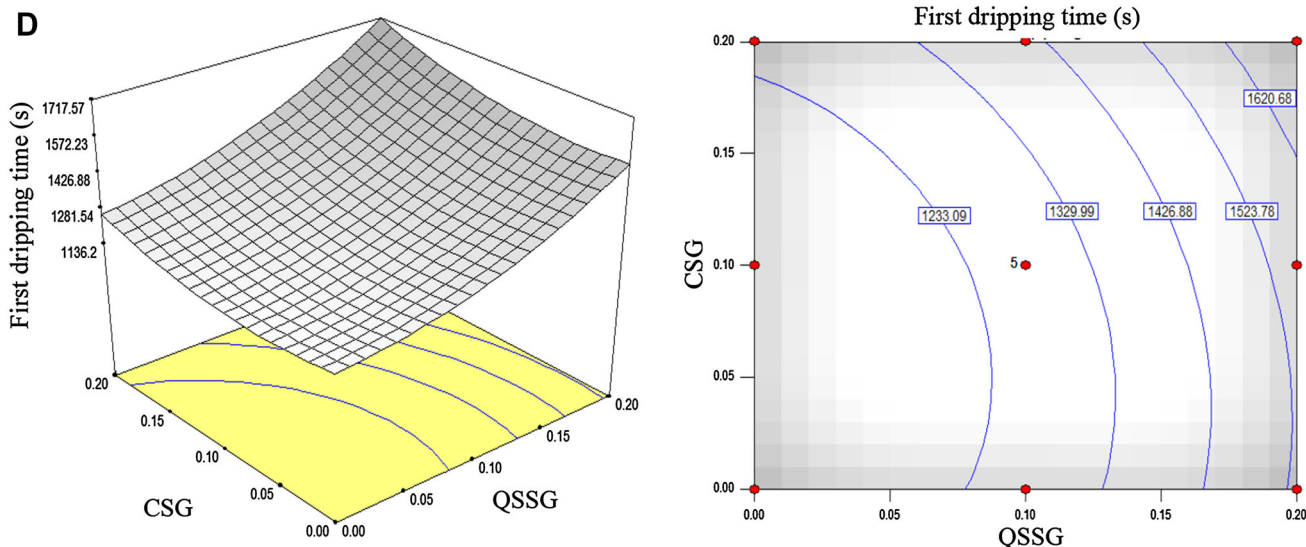
D

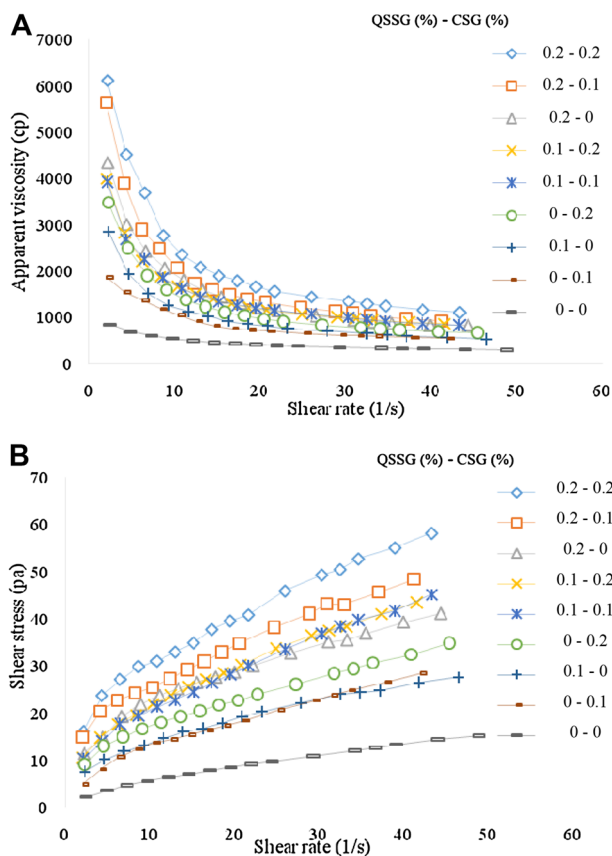
First dripping time (s)

Fig. 1 continued

Fig. 2 **a** Apparent viscosity and **b** shear stress as a function of shear rate for samples with different concentrations of QSSG and CSG

researchers the overrun of ice cream increases with increase of stabilizers (Cakmakci and Dagdemir 2013; Bahramparvar and Mazaheri-Tehrani 2011; Goff and

Hartel 2013; Clarke 2004) but this trend was not observed in this study. In fact, increasing the gums concentration lead to decrease in the ice cream samples overrun and this decrease was more enhanced in the QSSG than CSG. This finding is in agreement with the results of Bahramparvar et al. (2009) that showed an overrun reduction by adding stabilizers to the ice cream. Bahramparvar et al. (2009) and Issariyachaikul (2008) also stated that the overrun reduction in ice cream could be associated with the inefficiency of the laboratory batch home ice cream maker in the integration of air cells in the ice cream mixture and also the need for long freezing time of final mixture.

Melting properties

The values of melting rate are presented in Table 2. Data analysis showed that all effects (linear ($p < 0.0001$), Quadratic ($p < 0.05$), and interaction ($p < 0.05$), respectively) were significant in different levels of QSSG and CSG. Figure 1c represents the contour plot obtained from interaction of QSSG and CSG on melting rate. As can be seen samples with higher consistency coefficients had the highest resistance to flow and therefore melted more slowly (Muse and Hartel 2004). According to the results the lowest and highest amount of melting rate was observed in the ice cream samples containing 2% QSSG, 2% CSG gums and control samples, respectively. The overrun and crystal structure of ice are two effective factors on the melting rate of ice cream (Goff and Hartel 2013). Sofjan and Hartel (2004) also stated that increasing the stabilizers concentration, increased the viscosity of serum phase and so more time is needed for distributing water into the concentrated serum phase.

Table 3 The values of Power law, Herschel–Bulkley and Casson model parameter for ice cream containing QSSG and CSG

Run	QSSG (%)	CSG (%)	Power Law model			Herschel–Bulkley model				Casson model		
			k	τ_0	R^2	k	τ_0	n	R^2	k	τ_0	R^2
1	0	0	1.29	0.63	0.999	1.25	0.09	0.64	0.999	0.36	0.38	0.999
2	0	0.1	3.61	0.55	0.997	2.99	1.09	0.58	0.997	0.45	1.87	0.996
3	0	0.2	6.06	0.45	0.996	2.72	5.54	0.62	0.998	0.32	3.70	0.998
4	0.1	0	4.92	0.45	0.999	3.63	2.02	0.51	0.999	0.24	2.74	0.999
5	0.1	0.1	6.16	0.52	0.997	3.01	5.85	0.68	0.998	0.57	4.17	0.999
6	0.1	0.2	7.08	0.48	0.999	4.95	3.44	0.56	0.999	0.51	4.8	0.999
7	0.2	0	8.56	0.41	0.998	9.82	1.72	0.38	0.999	0.27	5.85	0.995
8	0.2	0.1	10.08	0.42	0.993	3.45	10.47	0.65	0.997	0.40	7.25	0.997
9	0.2	0.2	11.52	0.42	0.995	5.63	9.14	0.57	0.996	0.48	8.96	0.997

On the other hand, the analysis of variance (ANOVA) results of first dripping time is shown in Table 2. The Quadratic of CSG and interaction effects was not significant ($p > 0.05$) while the effects of linear ($p < 0.005$), and Quadratic ($p < 0.05$), note worthily increased first dripping time during melting of ice cream (Fig. 1d). However, it appears that the effect of stabilizers on the thermal properties of ice cream such as thermal conductivity, start to melt and the melting temperature can affect the melting rate (Marshall et al. 2003).

Textural analysis

Hardness

Hardness is defined as the necessary force to attain a given deformation when applied as an external force and it is an important textural property of ice cream (Bahramparvar et al. 2013). Using force and deformation information related to ice cream and comparing the curves obtained with this method can be applied to obtain the optimal formulation. The ice cream hardness can be affected by several factors, including: the initial freezing point, the total solids, the amount and type of stabilizer and overrun (Hartel et al. 2003; Goff and Hartel 2013). The results of Table 4 showed that the linear effect of QSSG and CSG were highly significant ($p \leq 0.0001$) while the quadratic effect of QSSG only ($p < 0.05$) was noticeable.

There was a general trend showing an increase in hardness of ice cream as both gum increased (Fig. 3a). The importance of the independent variables on the hardness of ice cream could be ranked in the following order: QSSG > CSG. The increase in hardness with increase gum concentration might be due to low air content in the ice cream matrix. Many authors have found that increased overrun tends to decreases the hardness of ice cream and reported that the presence of dispersed air in the ice cream matrix causes easier penetration of the probe into the texture (Wilbey et al. 1998; Muse and Hartel 2004; Goff and

Hartel 2013). Another effective factor in ice cream hardness is the nature of the serum phase. Actually, stabilizers by increasing viscosity lead to harder texture of the ice cream (Soukoulis et al. 2008; Muse and Hartel 2004).

Adhesiveness

Adhesiveness or stickiness is defined as the amount of required work in order to overcome the attractive forces among the surface of the food product and the surface of the material with which it comes in contact (Bahramparvar et al. 2013). Adhesiveness values varied from −12.8 (control sample) to −33.86 g s (0.2% QSSG and 0.2% CSG). Similar in hardness, QSSG and CSG results in increase in this factor in ice cream samples and the linear effect ($p < 0.001$) of both gum and the quadratic effect of QSSG ($p \leq 0.01$) are noticeable in samples without any impact on their interaction effect of ice cream (Table 4; Fig. 3b). These results may be due to the fact that stabilizers can form a sticky network between fractions in ice cream (El-Nagar et al. 2002).

Gumminess

Gumminess is the energy required to disintegrate a semi-solid food product to a state ready for swallowing and linked to foods with low hardness levels. Based on ANOVA results (Table 4), both gums individually influence on gumminess. As a result, the linear ($p < 0.05$), and Quadratic ($p \leq 0.01$) effects of gums were significant, but just like most factors, the interaction effect was not significant. Accordingly, addition of gums caused enhancement in gumminess. According to Fig. 3c, lower QSSG (0–0.12%) and CSG (0–0.14%) concentration gives low gumminess, while maximum gumminess was achieved with higher QSSG (0–0.2%) and CSG (0.19–0.2%) concentration. Gumminess has non suitable effect on appearance and texture hence these two gums had negative effects on appearance and

Table 4 Regression coefficients of predicted quadratic polynomial models for textural properties of ice cream containing QSSG and CSG

Source	DF	Hardness (g) Coefficient	Adhesiveness (g s) Coefficient	Gumminess (−) Coefficient	Chewiness (g) Coefficient
Model	5	+18.37**	−14.95**	+627.41**	+398.25**
Linear					
b_1	1	−44.368**	+33.01**	−2381.31**	−1761.50**
b_2	1	−15.70**	−4.91**	−833.01*	+87.90**
Quadratic					
b_{11}	1	+572.24**	−430.10*	+32,542.36**	+30,905.55**
b_{22}	1	+182.24 ns	−137.60 ns	+16,696.36*	+13,808.55 ns
Interaction					
b_{12}	1	+187.50 ns	−12.50 ns	−10,042.75 ns	−8503.75 ns
Residual	7				
Lack of fit	3	ns	ns	ns	ns
Pure error	4				
Total	12				
R^2		0.934	0.908	0.932	0.945
Adj-R^2		0.888	0.843	0.884	0.906
Pred-R^2		0.662	0.328	0.511	0.588
CV		10.67	−10.53	12.71	13.97

ns non significant

* Significant at 5%

** Significant at 1%

texture of final product. This finding is in agreement with the results of Wittinger and Smith (1986) and Soukoulis et al. (2008) who showed that stabilizers are able to increase ice cream gumminess.

Chewiness

Chewiness is defined as the required energy for chewing a solid food to the point required for swallowing it. Since chewiness is directly related to the gumminess it also increased obviously with increasing of gumminess. Table 4 shows the chewiness statistic for each attribute. Samples without gum and containing 0.2% QSSG and 0.2% CSG had the lowest value (305.53 g) and the highest value (1533.97 g), respectively (Fig. 3d). Chewiness increased with increase in QSSG and CSG concentration. Similar patterns also were reported by Wittinger and Smith (1986) that showed the addition of gums (locust bean and guar) on ice cream increased chewiness.

Sensory evaluation

The results of sensory evaluation of prepared ice cream samples in this study are shown in Table 1 of supplementary material. All samples showed significant differences. Scoring on colour so showed that there was no significant difference between samples of content QSSG (0%), CSG (0%) and QSSG (0%), CSG (0.1%) and QSSG (0.1%), CSG (0%). By adding these gums are visible values statistically differences between samples of ice cream, too. In terms of texture, the highest and the lowest score were given to QSSG (0.1%), CSG (0.2%) and QSSG (0%), CSG (0%), respectively. In general, the general acceptance accrued for control sample fewer score while the best example belong to sample of QSSG (0.2%), CSG (0%). This suggests that these gums alone were able to make the favorite features in ice cream.

Optimization

For optimizing ice cream formulation, desirability functions of RSM were applied to measure the optimum levels of independent variables. In this product, overrun, melting rate, first dripping time, viscosity, hardness, adhesiveness, gumminess and chewiness values were selected as control parameters. According to RSM analysis, the changes of these properties in ice cream could be successfully described by quadratic model.

As well as using the contour plots for each of the responses, matched the conditions that set for the independent variables (for optimizing the rheological and textural characteristics) and the best region was selected as the optimum conditions. Through analyzing the curves obtained in this study and evaluation of the relationships among response and variables, an optimum formulation of ice cream was provided (Fig. 4). It has moderate levels of
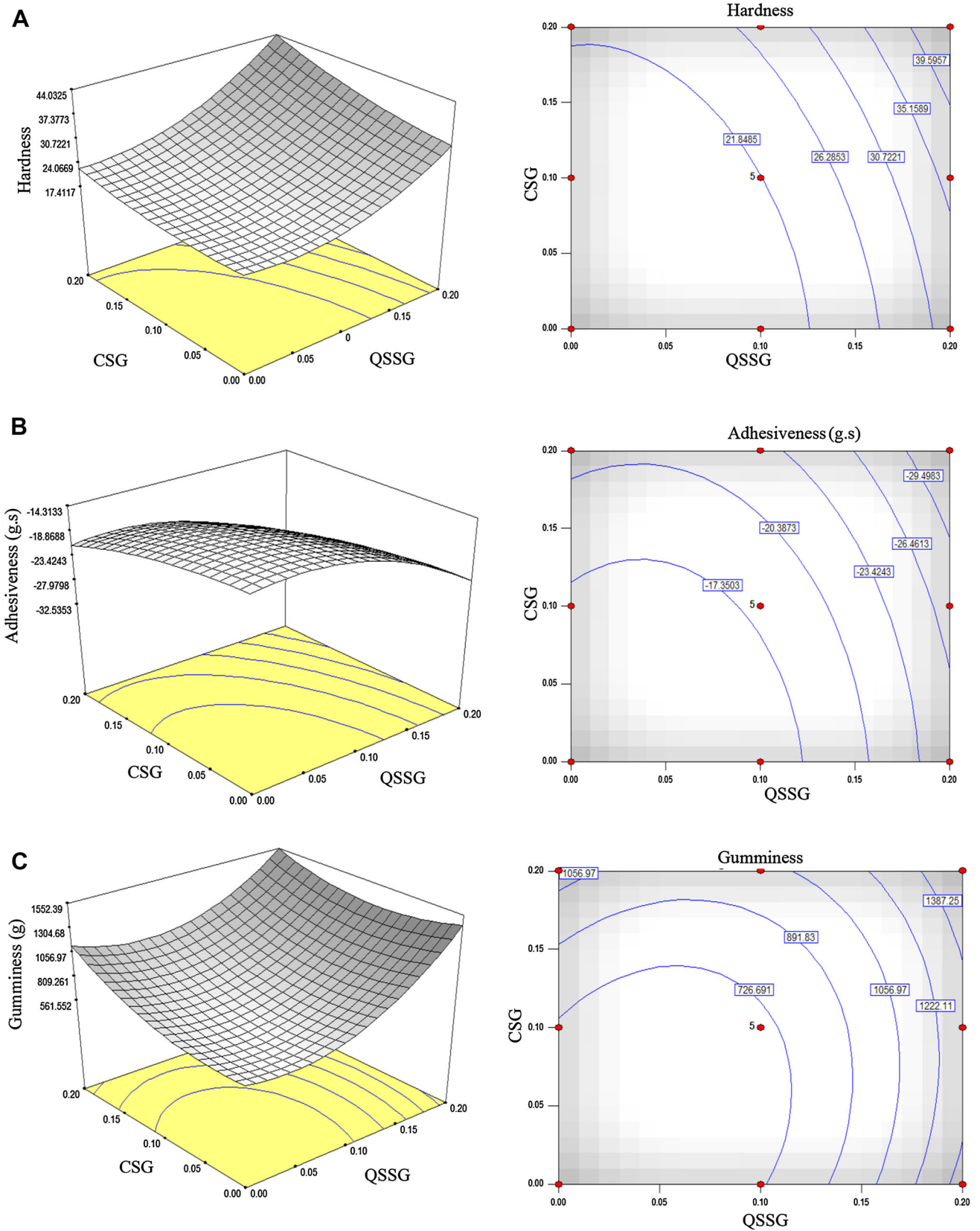
Fig. 3 Response surface showing (3D surface and contour) of the effect of CSG and QSSG concentrations on hardness (**a**), adhesiveness (**b**), gumminess (**c**) and chewiness (**d**)
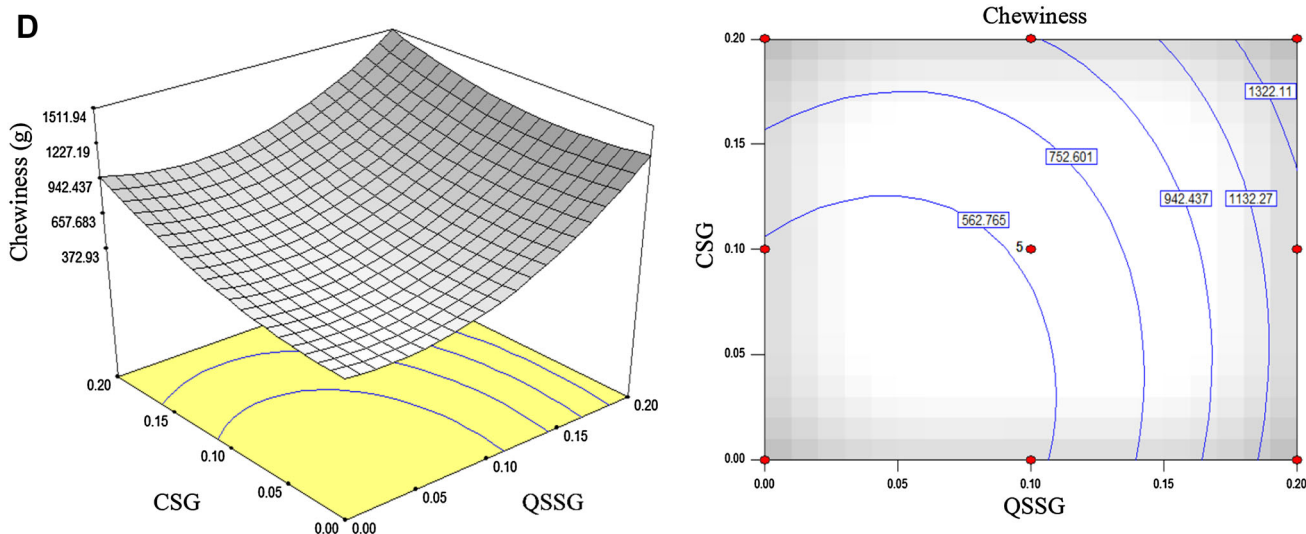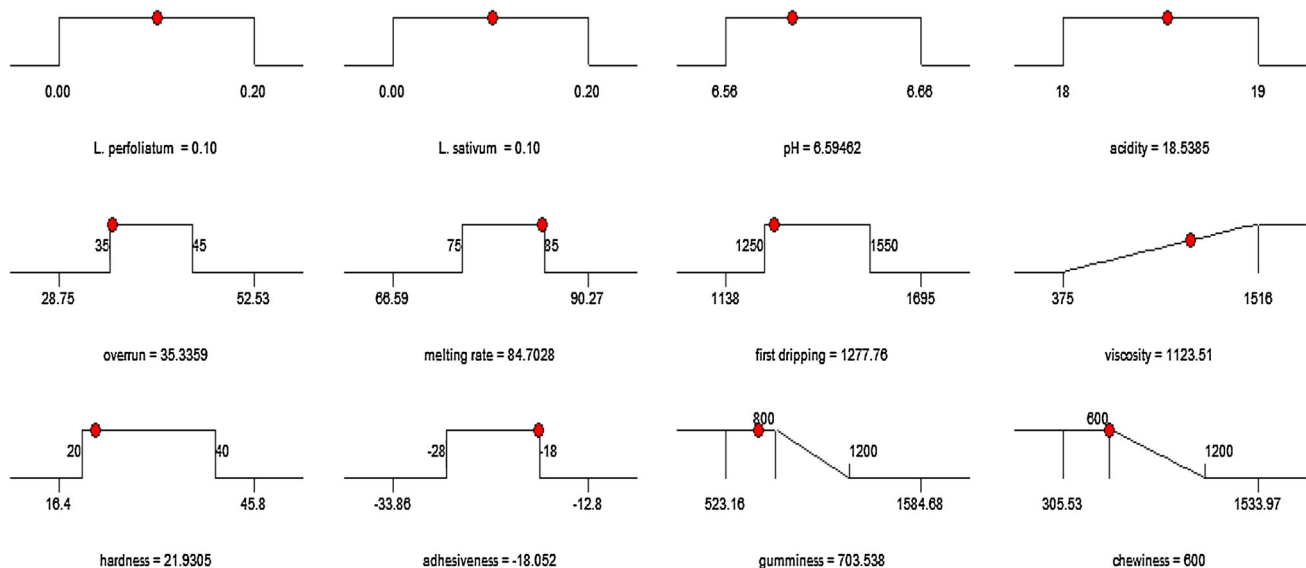
Fig. 3 continued

Fig. 4 Simultaneous optimization of ice cream with CSG and QSSG

pH (6.56–6.66), acidity (18–19), overrun (35–45), melting rate (75–85), first dripping time (1250–1550), hardness (20–40), adhesiveness (−28 to −18); maximum amounts for viscosity (375–1516) and minimum amounts for gumminess (800–1200), chewiness (600–1200).

In the optimization process the same weight and importance were given to all parameters. According to the conditions one solution predicted based on desirability. The optimal condition was found to be QSSG (0.1%) and CSG (0.1%) concentration. The overall desirability value was equal to 0.869. At this point, pH, acidity, overrun, melting rate, first dripping time, hardness, adhesiveness, viscosity, gumminess and chewiness were 6.59, 18.54, 35.34 (%),

84.70 (%), 1277.76 (s), 1123.51 (cp), 21.93 (g), −18.05 (g s), 703.54, 600 (g), respectively (Fig. 4).

Conclusion

The RSM was used to determine the optimum *L. perfoliatum* and *L. sativum* seed gum concentration to be used in ice cream production. The analysis showed that they improve ice cream properties, notably overrun, melting rate, first dripping time, viscosity and hardness, adhesiveness but the results indicated that increase in concentrations of both gums had a negative effect on gumminess and

chewiness of ice cream. Also, for optimizing of ice cream formulation, desirability functions in RSM analysis were applied successfully in this work. Therefore, the models proposed in this study can be used to optimize ice cream formulation containing native Iranian seed gums.

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