

Effects of Carboxymethyl Cellulose, Cress Seed Gum, Whey Protein Concentrate and Whipping Time on the Physical, Textural and Rheological Properties of Camel Milk Whipped Cream

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Abstract

In this study, the effects of different amounts of carboxymethyl cellulose (CMC) (0 to 0.2%), cress seed gum (CSG) (0 to 0.2%), whey protein concentrate (WPC) (2 to 8%), and whipping time (WT) (2 to 8 min) on the physical and rheological properties of camel milk whipped cream were investigated. The results showed that with increasing the WT and WPC levels, overrun increased and samples with higher CMC had higher overrun than samples with higher CSG. The results also showed that the effect of different levels of WPC on the overrun of the samples was highly dependent on the whipping time and different concentrations of gums. With increasing the WPC and WT (in high WPC values), the foam stability of the samples increased and changing the ratio of CSG and CMC gums had no significant effect on the foam stability. The results of the back extrusion test showed that with increasing the WT and CSG, the hardness and adhesiveness of the samples increased. The results showed that with increasing the WPC and WT, the infinite and zero shear rate viscosities increased, while with increasing the WPC, the relaxation time of the samples decreased. The highest area of hysteresis was related to the samples containing the same amounts of CMC and CSG, but increasing the WPC reduced the area of hysteresis. To optimize the whipped cream formulation, the overrun, foam stability, hardness, consistency, and infinite shear rate viscosity were considered to be maximum, and adhesiveness and flow behavior index were adjusted to be minimum. According to the optimization results, the sample containing 0.15% CMC, 0.05% CSG, 2% WPC and produced with 7.2 min WT was the optimized formulation.

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Introduction

Camels are one of the castles considered as an important source of milk production in countries with hot and dry climate, and most camel milk, usually after fat separation, is

dried because of the problems exist in its processing. Examination of the general pattern of camel milk fatty acids in comparison with other species such as cow, goat, and sheep has shown that short-chain

fatty acids (C₄-C₁₂) are much less found in camel milk. However, the concentration of C_{14:0}, C_{16:0}, and C_{18:0} fatty acids are relatively high and the amount of C_{16:1} is higher than other species. The proportion of unsaturated fatty acids in camel milk is higher than in other milk sources (Hagrass *et al.*, 1987). In terms of body metabolism, the presence of more unsaturated fatty acids in camel's milk (43.1%) compared to cow's milk (38.8%) is interesting. Also, camel milk contains significant amounts of essential fatty acids (C_{18:2n-6}) (Al haj & Al Kanhal, 2010). Therefore, the use of camel milk fat as a valuable by-product has a special status in food industry. Production of fatty camel milk products, including whipped cream, which is one of the most widely consumed dairy products in the food industry, will provide a good market for producers, provided it maintains consumer-friendly characteristics and can be used in cream pastries, desserts, and cakes (Camacho *et al.*, 1998). The right quality whipped cream should be easily applied and create a good foam with a high volume of whipping (Smith *et al.*, 2000). Duration, whipping, foam stability, and consistency of the resulting foam are the most important features of this product (Kadam *et al.*, 2010). Also, even though whipped cream is popular with consumers because of its good taste, due to its high-fat content and consequently its high-calorie content, it can cause cardiovascular diseases as well as increase blood lipid levels. By producing a cream with a lower fat content, these problems and worries can be reduced (Worrasinchai *et al.*, 2006).

On the other hand, reducing fat weakens the rheological and sensory properties of foods such as taste, mouthfeel, and texture (Rudan *et al.*, 1998). Therefore, it is a challenge to produce a low-fat product with the same characteristics as a high-fat product. In whipped cream, fat reduction also leads to a reduction in quality, especially stability, so these properties should be improved by adding fat substitutes such as whey proteins and

appropriate hydrocolloids (Smith *et al.*, 2000). The factors that have a greater effect on the rheological properties and the main property of the foam (foam ability and foam stability) include the foam solids (protein and fat), type and concentration of foam stabilizers, and whipping time and temperature (Dickinson & Stainsby, 1988). In the present study, it has been also attempted to select the appropriate type and level of fat substitutes that have the greatest effect on improving the properties of whipped cream, so whey protein concentrate (WPC) and a mixture of carboxymethyl cellulose (CMC) and cress seeds gum (CSG) were used in the formulation of camel whipped cream. WPC is of great commercial importance and has many food applications due to its interesting properties such as gel-forming ability, water holding capacity, foaming and emulsifying properties (Richert *et al.*, 1974). CSG is an emerging hydrocolloid with a high molecular weight that has excellent functional properties such as stabilizing, thickening, and gel-forming (Naji *et al.*, 2012). Also, CSG has high foam ability and higher emulsion stability compared to Qodomeh Shahri seed gum, Qodomeh Shirazi seed gum, sage seed gum, guar gum, xanthan gum, and locust bean gum (Alghooneh *et al.*, 2019). Another biomarker of interest is carboxymethyl cellulose (CMC), which is an anionic derivative of cellulose. This gum is used as thickener and stabilizer agents in food products, especially cream (Saha & Bhattacharya, 2010). Therefore, it seems that the use of a good ratio of CSG and CMC in the presence of WPC can help to improve the properties of camel whipped cream. Besides, in the production of whipped cream, by increasing whipping time (up to a certain time), the volume and stiffness of the product increases, while these properties are reduced with a further increase of whipping time. The suitable whipping time depends on the product formulation, including the type and the amount of stabilizers (Raharitsifa *et al.*,

2006). Therefore, it will be interesting to find the appropriate amounts of WPC, CSG and CMC and whipping time in accordance with the required technological aspects and the expectations of camel whipped cream consumers. Although various studies have been conducted on the effects of fat substitutes and whipping time on the properties of whipped cream made from cow's milk (Nguyen *et al.*, 2015; Noda & Shiinoki, 1986; Smith *et al.*, 2000; Zhao *et al.*, 2009), there is no information about camel milk whipped cream characterization.

Therefore, the purpose of this study was to investigate and optimize the effect of WPC, CMC, CSG, and WT and their interaction on the physical and rheological properties of camel milk whipped cream so that in addition to improving its properties economically, whipped cream camel milk production is also cost-effective by determining the optimal conditions.

Materials and methods

Preparation of whipped camel cream

Camel milk was purchased from a local market in Mashhad, Iran, and then its fat was separated by a separator in the Food Research and Training complex of the Ferdowsi University of Mashhad after preheating at 37 °C. Then, using Pearson square, with a mixture of skim milk and separated fat, camel cream samples with 37% fat were prepared. According to Table (1), the samples containing CSG (0-0.2%), CMC (0-0.2%), and WPC (2-8%) were formulated. After pasteurization at 80 °C for 5 min in a water bath and homogenization at 50 °C and 3000 rpm for 1 min by an Ultra Turrax homogenizer (IKA, Germany), the samples were placed in a refrigerator for complete hydration overnight at 4-6 °C. The next day, the samples were whipped at 25 °C with a stirrer at a maximum of 1500 rpm for 2-8 min, depending on the sample code shown in Table (1).

Table 1. The actual range of process and mixture variable in mixture-process variable experiments

Independent variables name	Symbol	Variable type	Variable range		
			-1	0	+1
CMC (%)	X ₁	Mixture	0	0.1	0.2
CSG (%)	X ₂	Mixture	0	0.1	0.2
WPC (%)	X ₃	Process	2	5	8
WT (min)	X ₄	Process	2	5	8

CMC, Carboxymethyl cellulose; CSG, cress seed gum; WPC, Whey protein concentrate; WT, whipping time

Overrun determination

To determine the overrun, the weight of a certain volume of cream is measured before and after whipping. Then the overrun was calculated using the following relationships (Eq. 1), (Emam-Djome *et al.*, 2008):

$$\text{Overrun}(\%) = \frac{\text{weight of the unwhipped cream} - \text{weight of the whipped cream}}{\text{weight of the whipped cream}} \times 100 \quad (1)$$

Foam stability measurement

Foam stability was determined based on the method of Padiernos *et al.* (2009) with a slight change. So that immediately after the production, 20 g of the foam was carefully poured into the Buchner funnel with a diameter of 80 mm, in which a plastic mesh with 40 mesh was placed (to prevent the foam from coming out) and placed on a 20 mL graduated cylinder. Over time, the liquid was separated from the foam due to gravity and collected in a cylinder. The weight of unsealed liquid to the weight of the original foam was recorded as a percentage of foam stability after 1 h.

Back extrusion test

A texture analyzer (TexturePro CT V1.5 Build 20, Brookfield Engineering Laboratories, INC., USA) was used to perform the back extrusion test (Bourne, 1978). To do this test, a cylindrical container with a diameter of 50 mm and a height of 100 mm and a probe with a diameter of 45 mm and a height of 100 mm, and a deformation speed of 1 mm/s was applied. The temperature of the samples was set at 10 °C and the deformation level was 60%. The measured textural parameters were hardness

(peak force during the first cycle, N), and adhesiveness (the negative area under the curve, mJ).

Steady shear rheological measurements

The steady shear flow behavior of the samples was evaluated over a wide range of shear rates from 14 to 600 s⁻¹ at 10 °C using a rotary viscometer (Visco88, Bohlin Ltd., UK) equipped with a suitable spindle (bob and cup) (C25). Then, the Power-law model (Eq. 2) and Cross model (Eq. 3) were used to fit the flow behavior of the samples as follows (Rao, 2010).

$$\tau = k(\dot{\gamma})^n \tag{2}$$

Where *k* is consistency coefficient (Pa.s^{*n*}) and *n* is the flow behavior index (dimensionless)

$$\eta = \eta_{\infty} + \frac{\eta_0 - \eta_{\infty}}{1 + (\tau\dot{\gamma})^m} \tag{3}$$

Where, η_0 is zero shear rate viscosity (Pa.s); η_{∞} is infinite shear rate viscosity (Pa.s); τ is relaxation time (s); and *m* is cross model flow behavior index (dimensionless).

Hysteresis area estimation

The hysteresis loop was obtained by registering shear stress at shear rates from 14 to 400 s⁻¹ in 300 s and down in 300 s. Areas under the upstream data points (*A_{up}*) and the downstream data points (*A_{down}*), as well as the hysteresis area (*A_{up}*-*A_{down}*), were calculated using the Origin Pro software (version 2019b), (Tárrega *et al.*, 2004).

Experimental design and statistical analysis

In this study, the components of the mixture design including CMC were defined as zero to 0.2% and CSG as zero to 0.2% in a way that constituted 0.2% of the total formulation and process factors including WPC between 2 to 8% and WT between 2 to 8 min (Table 1). In such a way that the total number of final treatments were 22. The results of the research were analyzed using the Design-Expert software (version 11, Stat-Ease Inc., USA) using mixture-process variable experiments and each response was modeled

with the combinatorial Steff regression in mixture-process experimental design by the following Eq. (4), (Bello & Vieira, 2011).

$$\tag{4}$$

$$Y = \sum_{k=1}^q y_k^0 x_k \sum_{k=1}^{q-1} \sum_{l=i+1}^q y_{kl}^0 x_k x_l \sum_{i=1}^m \left[\sum_{k=1}^q y_k^i x_k \sum_{k=1}^{q-1} \sum_{l=k+1}^q y_{kl}^i x_k x_l \right] Z_i + \sum_{k=1}^{m-1} \sum_{l=i+1}^m \left[\sum_{k=1}^q y_k^{ij} x_k + \sum_{k=1}^{q-1} \sum_{l=k+1}^q y_{kl}^{ij} x_k x_l \right] Z_i Z_j + \epsilon_0$$

In the above model:

$$\sum_{k=1}^q y_k^0 x_k + \sum_{k=1}^{q-1} \sum_{l=i+1}^q y_{kl}^0 x_k x_l$$

Relates to linear and non-linear effects of mixture components, and

$$\left[\sum_{k=1}^q y_k^i x_k + \sum_{k=1}^{q-1} \sum_{l=k+1}^q y_{kl}^i x_k x_l \right] Z_i$$

Relates to linear and non-linear effects of process components, and

$$\sum_{k=1}^{m-1} \sum_{l=i+1}^m \left[\sum_{k=1}^q y_k^{ij} x_k + \sum_{k=1}^{q-1} \sum_{l=k+1}^q y_{kl}^{ij} x_k x_l \right] Z_i Z_j$$

Relates to linear interactions of mixture components and process variables.

Then, using the analysis of variance (ANOVA), the significance of linear effects, quadratic, and interaction regression model coefficients for each response at the levels of 0.05, 0.01, and 0.001 was investigated.

Results and discussion

Model establishment

The equations obtained for predicting the dependent variables using the mixture-process experiments for the significant variables are given in Table (2). The coefficient of determination (R²), coefficient of variation (CV), and lack of fit values were used to check the accuracy of the model.

Table 2. Predicted models for the physical, textural, and rheological properties of camel milk whipped creams

Dependent variable	Equation	Model type	F-value	P-value Probe>F	R ²	CV	Lack of fit
Overrun	$Y_1=428.58.26A+36.68B-6112AB-43.03AC+14.32AC+14.32AD-5.62BC+31.39BD+696ABD+181.58ABD$	Quadratic× Linear	11.92	0.0019	0.93	23	n.s.
Foam stability	$Y_2=96.63A-5.58C+4.82D+0.93BD-0.79D^2$	Mean× Quadratic	15.56	0.0003	0.86	3.2	n.s.
Hardness	$Y_3=-25.12A+31.93B+3.59AC+4.67A+2.20BC-10.90BD-0.60ACD+0.57BCD-0.59BC^2+0.65BD^2$	Linear× Quadratic	10.50	0.0001	0.951	16.30	n.s.
Adhesiveness	$Y_4=2.366A-1.93B+113.85AB+0.218AC+3.52AD-2.88BC-0.66ACD+22.77B^2C$	Linear× Quadratic	4.50	0.045	0.81	6.64	n.s.
Flow behavior index	$Y_5=2.58A+2.08B+0.08AC-0.01AD+0.08BC-648/2BC+4161ABC+1057AC^2+4533AC^2$	Quadratic× Linear	12.34	0.0003	0.84	5.45	n.s.
Consistency coefficient	$Y_6=9.43A+10.65B-0.16C+0.30D$	Linear× Linear	4.79	0.022	0.99	9.21	n.s.
Relaxation time	$Y_7=0.11A+0.14B+0.28AB-0.01AC+0.02AD-0.65ABC+0.41ABD$	Linear× Linear	12.92	0.0015	0.93	9.21	n.s.
Zero shear rate viscosity	$Y_8=2.19A+2.65B+700.76AB-0.32AC+1.03AD-0.20BC+0.47BD-81.20ABC-60.09ABD$	Quadratic× Linear	18.50	0.0011	0.96	26.61	n.s.
Infinite shear rate viscosity	$Y_9=0.42A+0.40B+89.61AB+0.03AC+0.03AD+0.03BC+0.01BD-9.32ABC-8.52ABD$	Linear× Linear	138	0.0001	0.99	7.67	n.s.
Cross model flow behavior index	$Y_{10}=7.71A+9.27B+0.11AC-0.54AD-0.30BD$	Quadratic× Linear	4.98	0.029	0.78	13.6	n.s.
Hysteresis area	$Y_{11}=+3479.33A+4621.98B+76148.33AB+3488AC+1597.33AD-932.86BC+2048.62BD-25351.2ABC$	Quadratic× Linear	73.31	0.0024	0.99	14.03	n.s.

A: Carboxymethyl cellulose; B: cress seed gum; C: Whey protein concentrate; D: whipping time

As shown in Table (2), the R² values for all measured properties were higher than 0.8 and the lack of fit values were not significant for all measured properties at a 95% confidence level. Therefore, high R², non-significance of lack of fit, and C.V. value less than 10% for all answers confirm the accuracy of the selected models for predicting the responses (Montgomery, 2017).

Overrun

The percentage increase in volume depends on the efficiency of air penetration into the cream texture (Jakubczyk & Niranjana, 2006). The overrun of the tested samples varied between 2.3 and 89.75%. The linear

effects of CSG and CMC and the interactions of CMC-CSG, CMC-WPC, CSG-WT, and CMC-CSG-WPC on the overrun of the samples were significant at the level of 99% based on the overrun of samples. Fig. (1) shows the effect of WT, CSG, and CMC on the overrun of camel cream samples (4% WPC) according to equation Y₁ shown in Table (2). It can be seen that the overrun increased with increasing the WP. Increasing the WP leads to more air entering the foam system and trapping them inside the system. Also, increasing the WP can increase the overrun by increasing the denaturation of proteins and decreasing the surface tension (Delahaije *et al.*, 2019).

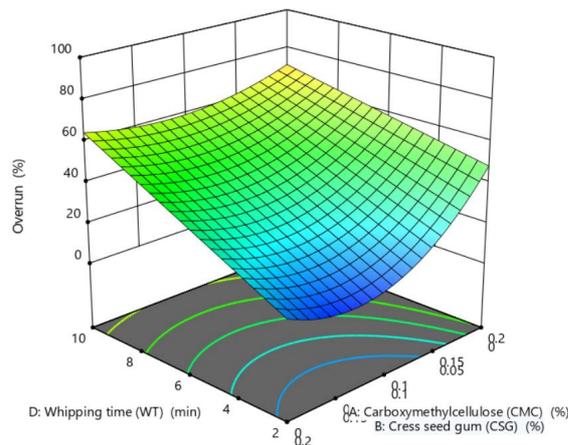


Fig. 1. The effect of WT, CSG, and CMC on the overrun of camel milk whipped cream samples (4% WPC)

Similar results have been reported for cow milk whipped cream (Farahmandfar *et al.*, 2019). Also, the samples with higher CMC had higher overrun than samples with higher CSG (Fig. 1). The lowest overrun was observed for the samples with the same amount of both CMC and CSG gums. The viscosity of the samples plays an important role in the amount of overrun and a certain level of viscosity is required to create the appropriate amount of overrun (Dickinson & Stainsby, 1988). Therefore, increasing the viscosity prevents air from entering the system and reduces the maximum amount of air trapped in the mixture, thus reducing the overrun. Hydrocolloids exert their thickening effects by binding to water and are therefore expected to form heavier foams. Similar results have been reported for WPC foam (Liszka-Skoczylas *et al.*, 2014) and cow milk whipped cream (Farahmandfar *et al.*, 2019). CSG has a higher zero-shear viscosity and a higher consistency coefficient than CMC gum in equal concentrations (Alghooneh *et al.*, 2019). Therefore, CSG has increased the viscosity of the system more, thus reducing the entry of air into the system and as a result, less overrun of the samples. Smith *et al.* (2000) also stated that the addition of a combination of gums and emulsifiers in two temperature treatments, rapid pasteurization, and sterilization of whipped cream, due to the increase in serum

viscosity, reduced the percentage increase in volume. The results also showed that the effect of different values of WPC on the overrun of the samples was highly dependent on the whipping time and different concentrations of gums, so that at low whipping time and under conditions where both CMC and SSG gums are almost the same, with increasing the WPC level, the overrun of samples increased. However, at high whipping time and when CMC gum was at maximum, the overrun of the samples reduced with increasing the WPC concentration. With increasing the WPC, the overrun increased. However, at high WT level and when CMC concentration was at its maximum level, the overrun of the samples decreased with increasing the WPC level. This difference in the effect of WPC on the overrun of the samples can be due to changes in the viscosity of the samples and the different protective effects of whey proteins from air bubbles against the pressure exerted by fat and air molecules. Because the nature of fat and air are similar, fat molecules are absorbed into the air bubbles and will burst (Harper *et al.*, 1980). In fact, with increasing the WPC level, the fat percentage of the samples has also decreased. Therefore, the simultaneous increase of WPC and WP reduces the absorption of fat globules on the surface of air bubbles, which also reduces the amount of overrun. Izadi *et al.* (2020) also showed that with increasing WPC from one to three percent, cheese overrun increased but the further increase of WPC up to 5% had no significant effect on the overrun.

Foam stability

Foam stability is known as the structure's resistance to disintegration. This stability is strongly dependent on the characteristics of the continuous aqueous phase as well as the viscoelastic properties of the interfacial film layer. Foam disintegration manifests itself in three forms: water leaking or leaking out of the foam structure, the joining of air bubbles, and the non-uniformity of the structure by creating large air bubbles in different parts of the

structure (Wilde & Clark, 1996). As a result, by measuring the water content of whipped cream, it is possible to evaluate its foam stability and the properties of the interfacial film layer (Padiernos *et al.*, 2009). The foam stability of the tested samples ranged from 0.8 to 28.24%. Based on the ANOVA results of model Y_2 (Table 2), the linear effects of WPC and WT and the WPC-WT interaction were significant at a 99% level on the foam stability of the samples and the change in the ratio of CSG and CMC gums had no significant effect on the foam stability. Fig. (2) shows the effect of WPC and WT on the foam stability of camel whipped cream samples (0.1% CSG, 0.1% CMC) according to equation Y_2 in Table (2).

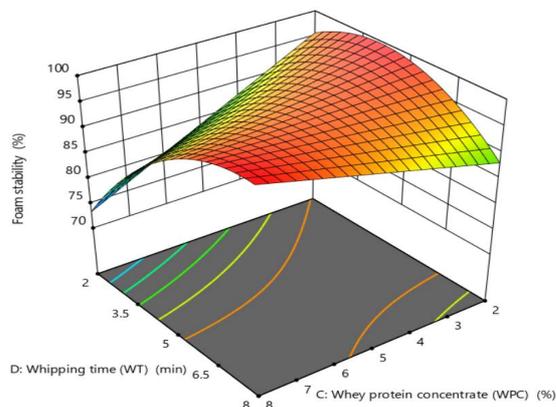


Fig. 2. The effect of WPC and WT on the foam stability of camel milk whipped cream samples (0.1% CSG & CMC)

As seen in Fig. (2), at low WPC values, the foam stability of the samples increases with increasing WT (from 2 to 4 min), but with a further increase in WT (from 4 to 8 min), the foam stability of the samples decreases, while at high values of WPC, as the WT increases, the foam stability of the samples also increases. Whey proteins are spherical proteins that form a highly steady foam due to the formation of a viscous film (Phillips *et al.*, 1990). As the percentage of WPC increases, the viscosity and yield stress of the continuous phase increases, in which case a steadier foam will be formed. Because in this case, the preserved middle wall is not easily broken (Bag *et al.*, 2011). In protein-stabilized foams, proteins are

adsorbed on the interface, react with lamellae in various ways, and form hydrogen, covalent, hydrophobic, and electrostatic bonds. This enhances the viscoelasticity of the lamella and as a result, its stability and strength. The stabilizing mechanism associated with the protein is called the viscoelastic stabilizing mechanism (Wilde & Clark, 1996). Also, the higher values of foam stability created by WPC may be due to the high ability of this protein to form high-rigidity protein films around air bubbles resulting from the formation of intermolecular disulfide bonds. Besides, coacervate between protein-polysaccharide at the interface between air and water can be an efficient process to increase foam stability. Increasing the WT also denatures more whey proteins and increases the hydrophilic groups on the surface, resulting in more foam stability. However, higher WTs destroy the viscoelastic and elastic properties of the lamella, in which case the bubble wall strength decreases, leading to a decrease in the strength of the foam structure and the collapse of the joint wall between the bubbles (Raharitsifa *et al.*, 2006).

Textural attributes

The hardness and adhesiveness of the samples varied between 0.25 and 3.48 N and 0.1 to 4 mJ, respectively. Based on the ANOVA results of models Y_3 and Y_4 (Table 2), the interactions of CMC-WT, CSG-WPC, CSG-WT, and CMC-WT-WPC at a 99% level on the hardness and linear effects CSG and CMC and the interactions of CMC-CSG, CMC-WPC, CSG-WT, and CMC-CSG-WPC were significant at the level of 99% on the adhesiveness of samples. Fig. (3) shows the effect of WT, CSG, and CMC on the hardness of camel whipped cream samples (4%WPC) according to equation Y_3 in Table (2).

As seen in Fig. (3), in conditions where the WPC value of the samples is constant at 4%, with increasing WT and CSG, the hardness of the samples increases.

Farahmandfar *et al.* (2019) also showed that in whipped cream, with increasing percentage CSG from 0.1 to 0.3, the hardness and adhesiveness parameters increase from 51 and 30.65 to 69.5 g and 47.5 mJ, respectively. The appropriate whipping time is the time when the sample reaches the maximum stiffness. As whipping time increases, the volume of the product and its stiffness increase, and after reaching the maximum volume and stiffness, these properties reduce with further increase in whipping time (Turgeon & Beaulieu, 2001). The results showed that changes in the levels of the gums, WPC, and WT had almost the same effect on changes in adhesion and stiffness of samples. The adhesiveness is the force required to overcome the friction between particles (Bylund, 1995), so the adhesiveness, like the hardness, is affected by the weak network created by the interfacial film layer.

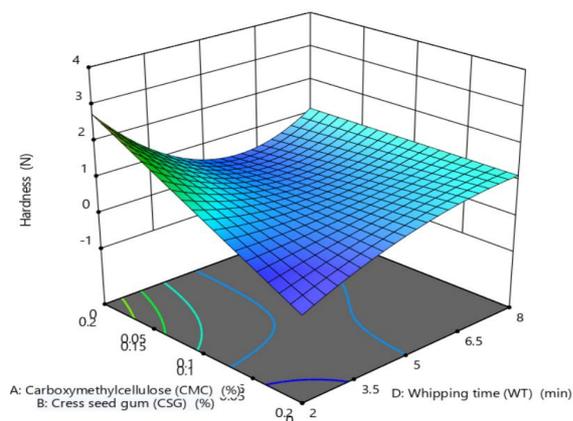


Fig. 3. The effect of WT, CSG, and CMC on the hardness of camel milk whipped cream samples (4% WPC)

Rheological properties

Fig. (4) shows the flow behavior of the sample containing 0.2% CMC, 0% CSG, 0.2 % WPC and produced with 2 min WT in terms of the shear stress-shear rate. Since the relationship between shear stress and shear rate of all treatments was as nonlinear as that of treatment No. 5, all the whipped creams are rheologically classified as non-Newtonian fluids. The presence of a hysteresis loop for all

treatments also indicates their time-dependent behavior (Steffe, 1996).

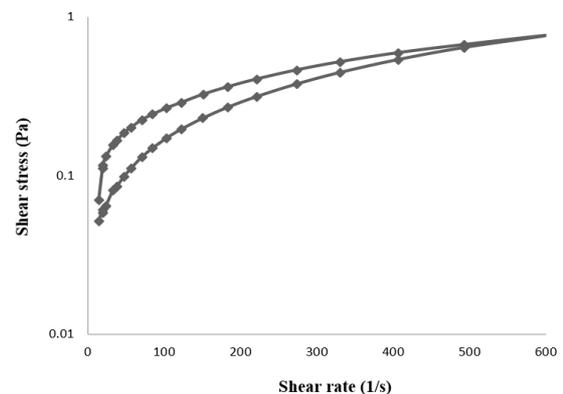


Fig. 4. The flow behavior of the sample containing 0.2% CMC, 0% CSG, 0.2 % WPC and produced with 2 min WT

In this study, the Power-law and Cross models were used to describe the time-independent rheological behavior of the samples. According to the results, the high R^2 in the modeling showed a good fit for both models on the tested data. The hysteresis loop area was also calculated to measure and compare the time-dependent flow behavior of the samples. The results obtained from the fitting of the Power-law and Cross models as well as the hysteresis area determined for the whipped cream samples in the shear rate range of 14-600 s^{-1} and at 4 °C are shown in Table (3).

Power-law model parameters

According to Table (3), the flow behavior index (n) of the tested samples varied between 0.43 and 0.64. The n value less than 1 indicates the shear thinning behavior (pseudoplastic) of the whipped creams. The reason for the pseudoplastic behavior of all samples is that the molecules are irregularly arranged at low shear rates and are only partially aligned, which leads to high viscosity in the mixture. However, with increasing shear rate, the molecules are aligned and as a result, the internal friction, and the viscosity of the mixture decreases (Agyei-Amponsah *et al.*, 2019). McClements (2015) also stated that the reason for this flow is that with increasing the shear rate to the extent required to

overcome the Brownian motion, the emulsion particles are more in the direction of flow and will have less resistance to flow, so the viscosity is reduced. Also, camel cream contains agglomerated fat globules, which can show a relaxing behavior due to shearing. CSG and CMC gums, like most high molecular weight polymers, show a shear-thinning behavior (Alghooneh *et al.*, 2019). Similar results have been reported for cow milk whipped cream in the presence of basil seed gum, cress seed gum, and Quince seed gum (Farahmandfar *et al.*, 2019).

According to ANOVA results of model Y_5 (Table 2), the linear effects of CSG and CMC and the interactions of CMC-WPC and CSG-WPC were significant at a 99% level on the flow behavior index but WT had no significant effect on the pseudoplasticity. The results showed that with increasing the WPC and CMC levels, the flow behavior index of the samples increased (Table 3).

The consistency coefficient of the tested samples varied between 0.68 and 18.15 Pa.s (Table 3). Based on the ANOVA results of Y_6 (Table 2), the linear effects of

CSG and CMC and the interactions of CMC-WPC-WT and CSG-WPC-CMC were significant at the 99% level on the consistency coefficient of the samples. The results showed that at low values of WPC and WT, the highest consistency of samples is related to the samples that have the same amount of both gums, which indicates the synergistic effect of these two gums on the consistency coefficient of samples. The consistency coefficient is a criterion for measuring the viscous nature of food and a factor similar to the apparent viscosity (Sopade & Kassum, 1992). To create high viscosity and a suitable and desirable oral sensation, the consistency coefficient of the samples should be high and the flow behavior index should be low (Izidoro *et al.*, 2007). Therefore, since CSG could reduce the flow behavior index and the simultaneous use of CSG and CMC also increased the consistency of the samples, it seems that using CSG-CMC blend in creating a good oral feeling and favorable conditions in the samples with low WPC and WT levels will be very effective.

Table 3. The parameters of the Power-law and Cross models and the hysteresis area determined for the camel milk whipped creams in the shear rate range of 14-600 s^{-1} and at 10 °C

Sample codes	Power-law			Cross			Hysteresis area		
	k (Pa.s ^{<i>n</i>})	<i>n</i>	R ²	η_0 (Pa.s)	η_∞ (Pa.s)	<i>z</i> (s)	<i>m</i>	R ²	(Pa)
1	18.15	0.46	0.99	4.86	0.64	0.02	1.50	0.95	2304
2	2.82	0.59	0.98	1.71	0.15	0.16	0.70	0.91	4278
3	3.29	0.43	0.95	0.88	0.10	0.02	1.63	0.90	4355
4	4.70	0.50	0.99	2.17	0.16	0.06	1.19	0.98	4646
5	1.56	0.58	0.99	0.59	0.11	0.02	1.33	0.98	4029
6	1.90	0.57	0.97	0.60	0.13	0.01	1.79	0.97	3775
7	4.21	0.53	0.99	4.44	0.85	0.01	1.72	0.99	3404
8	4.12	0.49	0.98	1.20	0.14	0.02	1.27	0.98	5995
9	2.62	0.64	0.99	1.48	0.20	0.04	0.88	0.93	8831
10	1.63	0.63	0.96	0.57	0.15	0.01	1.52	0.96	5370
11	2.22	0.63	0.99	0.90	0.18	0.01	1.11	0.99	6568
12	0.68	0.58	0.99	0.24	0.06	0.01	1.17	0.96	1093
13	4.21	0.49	0.97	1.23	0.16	0.02	1.30	0.97	6761
14	4.16	0.50	0.99	2.16	0.16	0.06	1.07	0.99	4491
15	1.82	0.49	0.99	0.50	0.07	0.02	1.60	0.90	3599
16	3.15	0.49	0.95	0.96	0.12	0.02	1.36	0.95	4951
17	3.17	0.55	0.99	0.93	0.17	0.01	1.41	0.90	4666

Cross model parameters

In this research, the cross model was used to describe the highly shear-thinning behavior of the samples in the wide shear rate range in terms of the parameters of zero-shear rate viscosity (η_0) and infinite-shear rate viscosity (η_∞). The relaxation time of the tested samples varied between 0.01 and 0.16 seconds, respectively (Table 3). Relaxation time (τ) is defined as the time required for macromolecules to reach equilibrium in the shearing medium (Schoff & Kamarchik Jr., 2000), so a higher relaxation time indicates a faster breakdown of agglomerates. Based on ANOVA results of Y_7 (Table 2), the linear effects of CSG and CMC and the interactions of CMC-WT, CMC-WPC, CSG-WT, CMC-CSG-WPC, and CMC-CSG-WT were significant at the 99% level on the relaxation time. The results showed that in conditions where both gums are present in equal amounts, the relaxation time decreases with increasing WPC while increasing WT increased the relaxation time of the samples. The zero and infinite shear rate viscosities of the samples varied between 0.24 to 4.86 and 0.06 to 0.85 Pa.s, respectively (Table 2). Based on the ANOVA results (Table 2), for both infinite and zero shear rate viscosities (Y_8 and Y_9 models), linear effects of CMC, CSG, and interactions of CMC-WT, CMC-CSG-WPC, and CMC-CSG-WT were significant at the 99% level, while the CMC-WPC interaction was significant only for infinite shear rate viscosity. The results showed that at high CMC concentrations, with increasing WPC and WT, the infinite and zero shear rate viscosities increased and in the low values of WPC and WT, the highest infinite and zero shear rate viscosities of the samples were related to the samples that contained both gums. The same amount was indicating the synergistic effect of these two gums on the zero-shear rate viscosity of the samples. The magnitude of η_0

depends on the microstructure of the biopolymer during storage and larger η_0 indicates the greater number of the bonds between the sample network molecules (Sun *et al.*, 2014), which establishes the required foam stability of the product during processes such as pumping, whipping, and spraying and its higher value reveals the need for more energy to perform the process (Razavi *et al.*, 2014). The flow behavior index (n) of the samples also ranged from 0.70 to 1.79 (Table 3). Based on the ANOVA results of Y_5 (Table 2), the linear effects of CSG and CMC and the CMC-WT interaction at the level of 99% on the flow behavior index of the samples were significant. According to the results of the present study, with increasing the CSG and WPC levels, the flow behavior index of the samples increased. This observation was in line with Alghooneh *et al.* (2018), who reported that at the same concentration (1%), CSG had a higher Cross model flow behavior index than CMC (0.73 vs. 0.40), indicating stronger pseudoplastic behavior of CSG compared with CMC.

Thixotropy

Hysteresis loop test is one of the methods used for evaluation of time dependence behavior, and the area between shear rate increase curve (up) and decrease in shear rate (down) is an index of the required energy for removing time effect on flow behavior (Chandra & Shamasundar, 2015). Although the hysteresis loop test is fast and qualitative, it also has a serious limitation. The shear rate and the shearing time are applied simultaneously in this test and it is not possible to separate the effects of these two variables (Mewis & Wagner, 2009). The hysteresis area of the tested samples ranged from 1093 to 8831 Pa.s⁻¹ (Table 3), which indicated the time-dependent behavior of all samples (Steffe, 1996). Based on the ANOVA results of Y_{11} (Table 2), the linear effects of CSG and CMC and

the interaction effect of CMC-CSG at the level of 99% on the hysteresis area of the samples were significant. Fig. (5) presents the effect of WPC, CSG, and CMC on the hysteresis area of camel whipped cream samples (WT 4 min) according to equation Y_{11} shown in Table (2).

As can be seen in Fig. (2), the highest area of hysteresis is related to samples that contain the same amount of both gums, and in this case, increasing the WPC led to a decrease in the area of hysteresis. Lower hysteresis area means more ability to regenerate texture and return to the original state. Due to the bonds created between the gum molecules and the milk proteins, the strength of the gel network increases, so with increasing WPC, the ability to return to the original state increases, and the hysteresis area decreases. Also, samples with the same amount of both gums probably had higher viscosity and more structured systems than other samples, which, with increasing shearing time, were relatively broken and showed a larger hysteresis area (Morell *et al.*, 2015). Tárrega *et al.* (2004) stated that solutions with high viscosity show a higher hysteresis area. Farahmandfar *et al.* (2019) also observed a greater hysteresis area with a simultaneous increase in the amount of basil seed gum, cress seed gum, and Quince seed gum, for cow milk whipped creams.

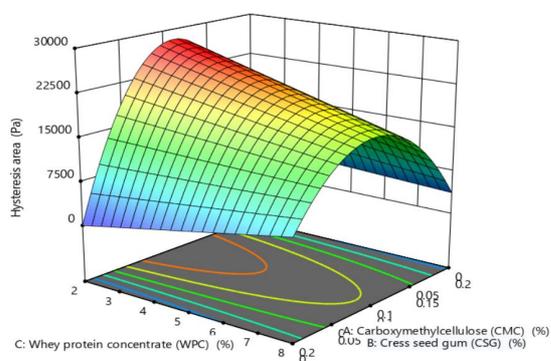


Fig. 5. The effect of WPC, CSG, and CMC on the hysteresis area of camel milk whipped cream samples (4 min WT)

Numerical optimization

Using the desirability function in the numerical optimization option of the Design-Expert software, an example of the exact conditions (CMC, CSG, WPC, and WT) on the studied properties of the samples were expressed. In this research, minimization of the Power-law flow behavior index and adhesiveness, and maximization of the overrun, foam stability, hardness, consistency coefficient, and zero and infinite shear rate viscosities were considered as the optimization goals. The optimum point calculated as 0.15% CMC, 0.05% CSG, 2% WPC and 7.2 min WT. It was found that such a product had an overrun of 60.50%, foam stability of 92.52%, hardness of 0.94 g, adhesiveness of 2.38 mJ, consistency coefficient of 7.54 Pa.sⁿ, flow behavior index of 0.51, infinite shear rate viscosity of 2.41 Pa.s, zero shear rate viscosity of 0.21 Pa.s, relaxation time of 0.06 s, Cross model flow behavior index of 0.95 and hysteresis area of 20685 Pa.s⁻¹ was obtained.

Conclusions

The production of camel milk fat products, including whipped cream, will provide a good market for producers, provided they maintain consumer-friendly characteristics. Therefore, considering the impact of process conditions and product formulations on the product characteristics such as whipping, foam stability, and rheological properties, which are most important features and the lack of sufficient information in this field, the effect of different values of CMC, CSG, WPC and WT and their interaction on the physical and rheological properties of camel milk whipped cream were investigated and the conditions were optimized. In general, the results showed that CSG, as an emerging hydrocolloid, improved the foaming, textural and rheological properties of camel milk whipped cream, so it can be considered as a suitable alternative to CMC. Furthermore, simultaneous use of the CMC

and CSG had a synergistic effect on most of the properties of camel milk whipped cream, including foam stability, hardness, and infinite and zero shear rate viscosities of samples, and therefore the mixture of these gums suggested being used in the industrial production of this product. The study results also showed that determining the optimal WPC is very important in improving overrun, foam stability, and rheological properties of camel milk whipped cream. The optimal WPC depends on the formulation (especially the gum) and whipping time. In conclusion, the optimal formulation in this study, with the lowest flow behavior index and highest overrun, foam stability, hardness, consistency coefficient, and zero and infinite shear rate viscosities, contained 0.15% CMC, 0.05% CSG, 2% WPC, and whipped for 7.2 min.

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Author contributions

Morteza Kashaninejad: Data collection, Data analysis and interpretation, Writing the draft of the manuscript; **Seyed Mohammad Ali Razavi:** Presenting the research idea and study design, Revising and editing the manuscript, Supervising the study, Approval of the final version; **Mohammad Reza Salahi:** Data collection, Data analysis.

Conflict of interest

There is no conflict of interest based on the writers.

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بررسی اثر کربوکسی‌متیل سلولز، صمغ دانه شاهی، کنسانتره پروتئین آب‌پنیر و مدت زمان هم‌زدن بر خواص فیزیکی، بافتی و رئولوژیکی خامه قنادی شیر شتر

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چکیده

در این پژوهش، اثرات صمغ دانه شاهی (0/2-0 درصد)، کربوکسی‌متیل سلولز (0/2-0 درصد)، کنسانتره پروتئین آب‌پنیر (2-8 درصد) و مدت زمان هم‌زدن (2-8 دقیقه) بر خصوصیات فیزیکی، بافتی و رئولوژیکی خامه قنادی شیر شتر بررسی شد. با افزایش کنسانتره پروتئین آب‌پنیر و مدت زمان هم‌زدن اورران افزایش یافت و نمونه‌های حاوی کربوکسی‌متیل سلولز بیشتر در مقایسه با نمونه‌های حاوی صمغ دانه شاهی بیشتر، اورران بیشتری داشتند. پایداری نمونه‌ها نیز با افزایش مدت زمان هم‌زدن و افزایش کنسانتره پروتئین آب‌پنیر افزایش یافت و تغییر نسبت کربوکسی‌متیل سلولز و صمغ دانه شاهی اثر معنی‌داری بر پایداری نداشت. آزمون اکستروژن برگشتی نشان داد که سختی و چسبندگی نمونه‌ها با افزایش صمغ دانه شاهی و زمان هم‌زدن افزایش یافت. با افزایش کنسانتره پروتئین آب‌پنیر و مدت زمان هم‌زدن، ویسکوزیته در درجه برش بی‌نهایت و صفر نمونه‌ها افزایش یافت درحالی‌که با افزایش کنسانتره پروتئین آب‌پنیر زمان رهاش کاهش یافت. بالاترین مساحت هیستریزس نیز مربوط به نمونه‌هایی بود که از هر دو صمغ به میزان یکسان داشتند و افزایش کنسانتره پروتئین آب‌پنیر منجر به کاهش مساحت هیستریزس شد. به‌منظور بهینه‌سازی، پایداری، اورران، سختی، ضریب قوام و ویسکوزیته در درجه برش بی‌نهایت حداکثر و رفتار جریان و چسبندگی حداقل در نظر گرفته شدند که براساس نتایج بهینه‌یابی، صمغ دانه شاهی 0/05 درصد، کربوکسی‌متیل سلولز 0/15 درصد، زمان هم‌زدن 7/2 دقیقه و کنسانتره پروتئین آب‌پنیر 2 درصد به‌دست آمد.

واژه‌های کلیدی: خامه، شیر شتر، صمغ دانه شاهی، کربوکسی‌متیل سلولز، کنسانتره پروتئین آب‌پنیر