Food Chemistry 116 (2009) 624–628

Contents lists available at ScienceDirect

Food Chemistry

journal homepage: www.elsevier.com/locate/foodchem

Effect of xanthan gum on the physical properties and textural characteristics of whipped cream

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ARTICLE INFO

Article history:
Received 12 December 2008
Received in revised form 7 January 2009
Accepted 25 February 2009

Keywords:
Whipped cream
Xanthan gum
Partial coalescence of fat
Textural characteristics
Particle size

ABSTRACT

Xanthan gum was used as thickening agent to prepare whipped cream in this work. A dose-dependent effect was observed on the average particle size ($d_{3,2}$) of whipped cream. At each xanthan gum level (0.025–0.125%) used, whipping time also showed a positive effect on the average particle size. With the increase of xanthan gum level or whipping time, the partial coalescence of fat in the whipped cream increased gradually. However, xanthan gum level showed no significant effect on the overrun of whipped cream. The textural characteristics of whipped cream were also investigated and the results indicated that a positive correlation was found between xanthan gum level and firmness, cohesiveness or viscosity of whipped cream. A different tendency was detected for consistency. The consistency of whipped cream increased with the increase of xanthan gum level to 0.100%, thereafter decreased.

1. Introduction

Xanthan gum is a natural polysaccharide which was discovered in the 1950s (Margaritis & Zajic, 1978). This heteropolysaccharide consists of glucose, mannose and glucuronic acid. Its main chain comprises β-1,4-D-glucose units, while the side chain is formed of one D-glucuronic acid unit between two D-mannose units. Approximately one-half of the terminal D-mannose units contain a pyruvic acid residue linked by keto group to the C-4 and C-6 positions. The presence of acetic acid and pyruvic acid make xanthan gum as an anionic polysaccharide (García-Ochoa, Santos, Casas, & Gómez, 2000). The xanthan gum molecule in aqueous solution has two conformations, helix and random coil, which depend on the dissolution temperature (García-Ochoa & Casas, 1994). Interaction with other polysaccharides is an important property of xanthan gum, which leads to a synergistic increase in viscosity (Casas & García-Ochoa, 1999). Xanthan gum has been used in the food industry due to its emulsion stabilisation, temperature stability, compatibility with food ingredients and pseudoplastic rheological properties.

Emulsion is a thermodynamically unstable system due to flocculation, creaming, coalescence, phase inversion and Ostwald riping (Thanasukarn, Pongsawatmanit, & McClements, 2004). Emulsifier is a surfactant which can stabilise the emulsion by absorption at the interface, thereby lowering the interfacial tension (Wollenweber, Makievski, Miller, & Daniels, 2000). It is usually used to improve the emulsion stability. Proteins and polysaccharides are often applied in emulsion as emulsifier. Proteins are usually used for their surfactant and gelling properties to improve the textural characteristics and stability of emulsion, while polysaccharides are usually added to increase the viscosity or to obtain a gel-like product (Hemar, Tamehana, & Singh, 2001; Péreza, Sánchezb, & Patino, 2007).

Whipping cream is a complex emulsion system because it is quiescently stable prior to freezing, and is unstable with the occurrence of partial coalescence when shearing (Goff, 1997a). Foam and emulsion properties are strongly influenced by the interfacial properties of emulsifier in the system (Dickinson, 2001). Xanthan gum is a potential emulsifier which may contribute to the quality of whipping cream. Till now, little information concerning the effect of xanthan gum on the physical properties and textual characteristics of whipped cream is available. Therefore, the objective of this work was to investigate the effects of xanthan gum on the physical properties and textural characteristics of whipped cream. The average particle size, partial coalescence of fat and overrun of whipped cream were determined to evaluate the interfacial properties. The changes in firmness, cohesiveness, consistency and viscosity of whipped cream at different xanthan gum levels were also measured.

2. Materials and methods

2.1. Materials

Sodium caseinate (95% of protein content) was obtained from New Zealand Milk Products Co. (Santa Rosa, CA). Xanthan gum

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doi:10.1016/j.foodchem.2009.02.079

(food grade) was kindly donated by Rhodia Group (Shanghai, China). Partially hydrogenated palm kernel oils (BL-39 and BS2000) with a Wiley melting point of 39–41 °C was donated by Southsea Oil & Fat Industrial Inc. (Shenzhen, China). Sugar was purchased from a local supermarket. Sucrose ester S170 and S1670 were purchased from Mitsubishi Chemical Company (Tokyo, Japan). Oil Red O was from AMRESCO (Ohio, USA). Phosphate consisting of 40% of trisodium orthophosphate and 60% of sodium dihydrogen orthophosphate was from Guangzhou Reagent Company (Guangzhou, China).

2.2. Emulsion preparation

The emulsion was prepared as follows: Phosphate (0.1 g), BL-39 (100 g), BS2000 (100 g), sodium caseinate (10 g), hydroxypropyl methylcellulose (0.9 g), S170 (0.39 g), S1670 (0.26 g), sugar (100 g) and xanthan gum (0.25, 0.50, 0.75, 1.0 or 1.25 g) were mixed. Distilled water was added to a final weight of 1000 g. The emulsion was mixed at 70 °C and held at 70 °C for 30 min, then immediately homogenised using a 2-stage single-piston homogenizer (APV-1000, Albertslund, Denmark) with 40 MPa of pressure at the first stage and 10 MPa at the second stage. After homogenisation, the mixture was cooled to 4 °C and aged at this temperature for 4 h. Then the sample was hardened at −18 °C. The emulsion was thawed at 4 °C for 24 h before whipping.

2.3. Measurement of average particle size

Average particle size of the sample was measured by an integrated-laser light scattering instrument (Mastersizer 2000, Malvern Instruments Co. Ltd., Worcestershire, UK). Relative refractive index and absorption were set as 1.414 and 0.001, respectively. The emulsion in the sample chamber was diluted 1000-fold with distilled water. The average particle size (volume–surface average diameter, $d_{3,2}$) was calculated by Eq. (1)

$$d_{3,2} = \sum n_i d_i^3 / \sum n_i d_i^2 \quad (1)$$

where n_i is the number of particles with the same diameter; d_i is the particle size.

2.4. Measurement of partial coalescence of fat

The amount of free fat in the emulsion was determined by the method of Palanuwech, Potineni, Roberts, and Coupland (2003). Oil Red O (0.1 μg/g) in soybean oil was prepared and stirred overnight using a magnetic stirrer (Meiyingpu Instrument Manufacturing Co., Ltd , Shanghai, China). The absorbance of the solution at 520 nm was measured using a UV–visible spectrophotometer (Perkin-Elmer, Lambda 3, Norwalk, CT). Soybean oil was taken as the blank. The principle of the dilution technique is that a dye solution in non-polar solvent is poured onto the surface of the emulsion, gently mixing, and allowing the colored oil to float at the surface under gentle centrifugation. Any free fat in the emulsion will be dissolved in the colored oil but the emulsified fat remains in the droplets. The diluted-dye solution fraction can be easily transferred from the surface and its absorbance was measured. The change in absorbance showed that the mass fraction that is not emulsified in the fat (φ_d) is given by the following Eq. (2)

$$\varphi_d = \frac{m_0(a-1)}{m_e \phi} \quad (2)$$

where φ_d is the mass fraction of fat in the emulsion, m_0 is the weight of added Red Oil O, m_e is the weight of emulsion, a is the ratio of absorbance of Red Oil O solution before and after centrifugation, and ϕ is the mass fraction of oil in the emulsion.

2.5. Measurement of overrun

The overrun was measured by the method of Scurlock (1986). It was performed by filling a tub to a set volume with the cream before and after whipping treatment. The overrun was related to the weight of this volume and the density of the cream before whipping. It was determined according to the following equation

$$\text{Overrun } (\text{m}^3 \text{ air}/100\ \text{m}^3 \text{ unwhipped cream}) = \frac{M_1 - M_2}{M_2} \times 100\%$$

where, M_1 is the weight of unwhipped cream with the set volume, and M_2 is the weight of whipped cream with the same volume.

2.6. Analysis of textural characteristics

Measurement of force in compression was performed using a TA-XT2i texturometer (Stable Microsystems, Surrey, UK) to determine the textural characteristics of whipped cream. The probe penetrated into the sample to a depth of 25 mm at a rate of 2.0 mm/s and the force exerted on the probe was automatically recorded. Four parameters (firmness, consistency, cohesiveness and viscosity) were recorded. The creams with different xanthan gum levels were whipped for 5 min. Three aliquots of 150 ml from each whipped cream were chosen for analysis at 10 °C.

2.7. Statistical analysis

All the tests were performed in triplicate. The result was expressed as mean ± standard deviation. Duncan's multiple-range test was used to evaluate significance of difference ($P < 0.05$) between results. The correlation coefficient was calculated by Microsoft Excel 2000 (Microsoft, Seattle, WA).

3. Results and discussion

3.1. Effect on average particle size of the emulsion

The average particle size of emulsions with different xanthan gum levels after designated whipping time are listed in Table 1. Five levels were chosen for the xanthan gum which were 0.025%, 0.050%, 0.075%, 0.100% and 0.125%, respectively. At each xanthan gum level used in this work, a whipping time-dependent manner was observed for the average particle size of whipped cream. In the range of 1–5 min, the increase of average particle size was faster at the late stage than at the early stage. The xanthan gum level also showed a positive effect on the average particle size of whipped cream. Whipping for 0 min represented the cream after thaw. The $d_{3,2}$ of this cream with xanthan gum level of 0.025% was 0.195 μm, significantly lower than that (0.237 μm) with xanthan gum level of 0.125%. For those creams after whipping treatment for different times, increase of xanthan gum level would give a further increase of average particle size.

Fat droplet size, the viscosity of their external phase, and the interfacial film properties are three factors that affect the emulsion stability. Average particle size is an indicator of droplet size in the cream. It strongly influences the emulsion stability and physical properties of whipped cream. In a system with large area of fat interface, large casein micelles are usually distributed between droplets to stabilise the system through charge force and emulsification (Halling, 1981). Xanthan gum is an anionic polysaccharide, which can exclude caseinates due to charge repulsion. Moreover, xanthan gum can increase the microviscosity of emulsion and reduce the water mobility of the system (Regand & Goff, 2003). The increase of the viscosity of the continuous phase due to xanthan that affects the emulsification procedure might lead to the

Table 1
Effect of xanthan gum level on the average particle size ($d_{3,2}$, μm) of whipped cream*.

Xanthan gum level	Whipping time (min)					
	0	1	2	3	4	5
0.025%	0.195 ± 0.015a	0.198 ± 0.011a	0.264 ± 0.011a	0.353 ± 0.013a	0.454 ± 0.010a	0.797 ± 0.019a
0.050%	0.205 ± 0.012ab	0.213 ± 0.008ab	0.261 ± 0.009a	0.355 ± 0.012a	0.561 ± 0.011b	0.872 ± 0.018b
0.075%	0.215 ± 0.010abc	0.226 ± 0.009bc	0.260 ± 0.005a	0.357 ± 0.009a	0.669 ± 0.012c	0.946 ± 0.019c
0.100%	0.226 ± 0.009bc	0.240 ± 0.012cd	0.302 ± 0.012b	0.429 ± 0.014b	0.764 ± 0.016d	1.365 ± 0.015d
0.125%	0.237 ± 0.015c	0.252 ± 0.012d	0.343 ± 0.016c	0.500 ± 0.017c	0.858 ± 0.011e	1.781 ± 0.018e

* The values with the same letter in each column were not significantly different ($P > 0.05$) according to Duncan's multiple-range test.

formation of larger particle size. During the whipping of natural and recombined cream, emulsion droplets are adhered to the air bubbles where they can partially coalesce, giving structural integrity to the air bubbles and increase of particle size. While in the whipped cream, a network of partially coalesced droplets connect fat clumps in the bulk and droplets adhere to the air bubble surface, giving structural integrity to the foam and further increase of $d_{3,2}$ (Vanapalli & Coupland, 2001). The interaction between emulsion droplets and air bubbles during aeration might be another mechanism for the increase of $d_{3,2}$ (Allen, Dickinson, & Murray, 2006). However, the dispersion of liquid fat at the air/water interface should be limited, because fat dispersion can result in thinning of the lamellae between bubbles, which may ultimately lead to film destabilisation and air bubble collapse (Hotrum, Stuart, van Vliet, & van Aken, 2004).

3.2. Effect on partial coalescence of fat

The partial coalescence of fat was determined by calculating the free fat in the emulsion. Effects of xanthan gum level and whipping time on the partial coalescence of fat are shown in Table 2. A dose-dependent effect was found for the partial coalescence of fat in the emulsion. With the increase of xanthan gum level, the partial coalescence of fat increased gradually. For those emulsions without whipping treatment (0 min of whipping time), xanthan gum could also facilitate the partial coalescence of fat droplets from 0.2% to 8.9% when the addition of xanthan gum was from 0.025% to 0.125%. A positive correlation was also shown between whipping time and partial coalescence of fat. Along with the extension of whipping time in the range of 0–5 min, the cream had an increased partial coalescence of fat. The correlation between average particle size and partial coalescence of fat was calculated. The correlation coefficient was 0.99 which indicated the highly positive correlation between them. Increase in the partial coalescence of fat could be the reason that average particle size increased.

Coalescence usually involves two or more droplets and results in coarsening of the foam structure. With the presence of air, the bubble size distribution is shifted to larger size (Sofjan & Hartel, 2004). Controlled destabilisation of an emulsion by partial coalescence of fat droplets is critical for emulsion stabilisation and important for perceivable quality (Goff, 1997b; Leser & Michel, 1999). The increase of partial coalescence is favourable to the stability of whipped cream. In the protein-polysaccharide system, proteins are always the most surface-active agents and govern the surface tension (Narchi, Vial, & Djelveh, 2009). In this work, xanthan gum mainly acted as a thickening agent. This might help droplets to approach one another more easily. However, if the increase of partial coalescence of fat is too fast, it can result in the destability of emulsion. Therefore, a relevant xanthan gum level needs to be determined.

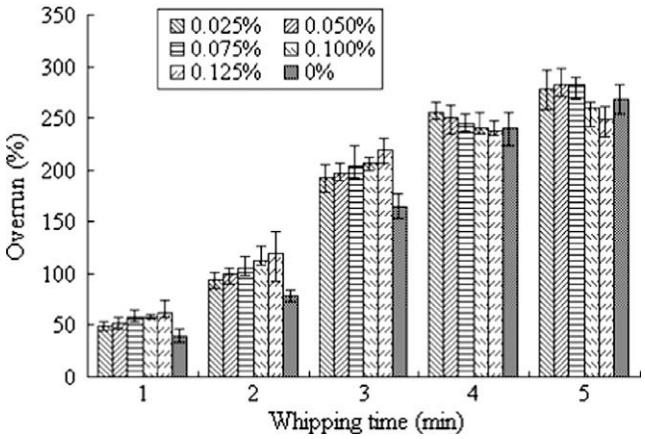

Fig. 1. Change in the overrun of whipped cream during whipping. The values are expressed as mean ± standard deviation.

3.3. Effect on overrun during whipping

Fig. 1 shows the effect of whipping time and xanthan gum level on the overrun of whipped cream. Xanthan gum level showed no significant effect on the overrun of whipped cream. This was different to the average particle size of whipped cream and partial coalescence of fat. From the results shown in Fig. 1, whipping time was an important factor affecting the overrun of whipped cream. A sharp increase of overrun was observed along with the extension of whipping time. The overrun of whipped cream with 0.025% xanthan gum after whipping for 1 min was 49%. It increased to 277% after 5 min of whipping treatment. Similar increases were also found for emulsion with other xanthan gum levels.

Table 2
Effect of xanthan gum level on the partial coalescence of fat (%)*.

Xanthan gum level	Whipping time					
	0	1	2	3	4	5
0.025%	0.2 ± 0.1a	1.6 ± 0.2a	2.4 ± 0.2a	10.6 ± 0.4a	23.2 ± 0.5a	42.3 ± 0.8a
0.050%	2.5 ± 0.2b	3.2 ± 0.1b	3.8 ± 0.3b	11.2 ± 0.5b	24.5 ± 0.7ab	46.7 ± 1.2b
0.075%	4.9 ± 0.2c	4.5 ± 0.3c	5.5 ± 0.2c	12.0 ± 0.4c	25.8 ± 0.7b	50.1 ± 0.9c
0.100%	6.8 ± 0.5d	8.5 ± 0.5d	9.2 ± 0.5d	16.7 ± 0.9d	31.4 ± 1.1c	58.0 ± 1.3d
0.125%	8.9 ± 0.6e	12.2 ± 0.4e	15.0 ± 0.6e	22.0 ± 0.8e	38.6 ± 0.8d	66.0 ± 1.0e

* The values with the same letter in each column were not significantly different ($P > 0.05$) according to Duncan's multiple-range test.

Table 3
Effects of xanthan gum level on the textural characteristics of whipped cream*.

Xanthan gum level	Firmness (*N*)	Consistency (*N* s)	Cohesiveness (*N*)	Viscosity (*N* s)
0.025%	4.32 ± 0.15a	44.95 ± 1.23a	3.70 ± 0.25a	32.74 ± 1.20a
0.050%	4.71 ± 0.24ab	47.61 ± 1.35a	4.11 ± 0.13ab	37.29 ± 1.00b
0.075%	5.08 ± 0.17b	54.07 ± 1.80b	4.44 ± 0.16b	37.58 ± 1.42b
0.100%	6.56 ± 0.22c	71.07 ± 1.52c	5.85 ± 0.21c	57.83 ± 1.21c
0.125%	7.67 ± 0.27d	56.19 ± 1.62b	6.58 ± 0.29d	49.26 ± 1.43d

* The values with the same letter in each column were not significantly different ($P > 0.05$) according to Duncan's multiple-range test.

The overrun is an indicator which gives information on the gas holdup or the percentage of gas in the whipped cream (Jakubczyk & Niranjan, 2006). Maximal overrun corresponds to maximal stability and stiffness of the foam. All the air bubbles at this case are encapsulated by coalesced fat droplets which distribute evenly at the air/slurry interface. The emulsion with xanthan gum is capable of incorporating large quantities of air during whipping. The thickening property of xanthan gum makes this air incorporate into the bubbles and it becomes hard to elapse. Once most of the air is incorporated into the emulsion, the emulsion shows strong combination and reinforces the stabilisation of the already incorporated air cells (Allen et al., 2006). It is easy to understand that extension of whipping time can facilitate more air being incorporated into the emulsion system, resulting in a higher overrun percentage. The xanthan gum level showed no apparent increase of overrun. It indicated that 0.025% of xanthan gum level was sufficient for the inhibition of air elapse.

3.4. Effect on the textural characteristics of whipped cream

As listed in Table 3, the firmness of whipped cream with xanthan gum level of 0.025–0.050% (4.32–4.71 *N*) was significantly lower than that with xanthan gum level of 0.075–0.125% (5.09–6.05 *N*). No significant difference ($P > 0.05$) in firmness was present between whipped cream with xanthan gum levels of 0.025% and 0.050%. However, a pronounced positive effect on firmness was observed for the sample with xanthan gum level in the range of 0.050–0.125%. Xanthan gum exhibited a dose-dependent effect on the cohesiveness of whipped cream. The cohesiveness value was 3.70 when 0.025% of xanthan gum level was used, significantly ($P < 0.05$) lower than 4.44 when using 0.075% of xanthan gum level. The addition of xanthan gum resulted in an increase of consistency. The higher the xanthan gum level in the range of 0.025–0.010% chosen, the higher the consistency of whipped cream obtained. Though no significant ($P > 0.05$) difference in consistency existed between samples with xanthan gum levels at 0.025% and 0.050%, a sharp increase was still observed when higher xanthan gum levels were used. However, the consistency decreased when 0.125% of xanthan gum level was used. The viscosity of whipped cream was improved by the addition of xanthan gum. Xanthan gum showed a dose-dependent effect on the viscosity. The viscosity difference between every xanthan gum levels was significant ($P < 0.05$).

Obtaining desirable textural characteristics is one of the goals for food production. (Stanley, Goff, & Smith, 1996). Firmness represents the force necessary to attain a given deformation (*N*). The strong thickening property of xanthan gum can explain this positive effect. Cohesiveness represents the strength of internal bonds making up the body of the products and is calculated as a ratio of positive force areas under first and second compression in the testing graph. Cohesiveness is the extent to which a material can be deformed before it ruptures (Szczesniak, 2002). The correlation between xanthan gum level and cohesiveness implied that the whipped cream with higher xanthan gum level was less crumbly and not as easily deformed. Consistency and viscosity are two important viscoelastic properties of whipped cream, which have great effect on the organoleptic quality and acceptability of the whipped cream. The consistency of whipped cream increased with the increase of xanthan gum level to 0.100%, thereafter decreased. This special phenomenon indicated that an optimal xanthan gum level existed to obtain the highest consistency. The possible mechanism regarding the decrease of consistency by increase of xanthan gum level is still not clear. Viscosity is the flow rate per unit force (Szczesniak, 2002). It plays an important role in the overall mouthfeel of whipped cream. Fat/water interface, air/water interface and proteins establish the texture of whipped cream. As a thickening agent, xanthan gum competes against caseinate at both the fat/water and air/water interfaces and is incorporated into whipped cream to provide a more desirable physical structure of the final product (Lal, O'Connor, & Eyres, 2006).

4. Conclusions

From the results obtained from this work, xanthan gum, as a thickening agent, could significantly affect the physical properties and textural characteristics of whipped cream. A dose-dependent effect was observed for the average particle size of whipped cream. At each xanthan gum level (0.025–0.125%) used, whipping time showed a positive effect on the average particle size. With the increase of xanthan gum level or whipping time, the partial coalescence of fat increased gradually. However, xanthan gum level showed no significant effect on the overrun of whipped cream. The textural characteristics of whipped cream were measured and the results indicated that a positive correlation was found between xanthan gum level and firmness, cohesiveness or viscosity. However, too high a xanthan gum level would result in a decrease of the consistency of whipped cream. All above results suggested the good application potential of xanthan gum in the formulation of whipped cream. The possible mechanism of these effects are still not clear. More work should be done focusing on this topic in the future.

Acknowledgement

The authors are grateful for the financial support from National Natural Science Foundation of China (No. 20806030).

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