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# Basil seed gum as a novel stabilizer for structure formation and reduction of ice recrystallization in ice cream

Maryam BahramParvar · H. Douglas Goff

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**Abstract** Basil seed gum (BSG), as a novel source of hydrocolloid, was used at two concentrations (0.1% or 0.2%) to stabilize ice cream, and its impact on selected physical and structural properties, especially ice crystal size, was compared to a commercial blend of carboxymethyl cellulose and guar gums (0.1% or 0.2%) and to an unstabilized control. Samples were temperature cycled at subzero temperatures and ice crystal size was measured before and after cycling. There was no significant difference in ice crystal size after hardening, but the presence of BSG reduced ice recrystallization compared to commercial gums and no stabilizer. The addition of BSG reduced the rate of ice crystal growth by 30–40% compared to the commercially stabilized ice creams. BSG also decreased the meltdown rate and increased the particle size, thus suggesting that BSG produced a different structure compared to the controls, possibly by lowering the air and fat interfacial tensions. More studies are needed to understand the mechanisms of action of BSG in cryoprotection and its role as a stabilizer and as an emulsifier in ice cream.

**Keywords** Cryoprotection · Frozen dessert · Heat shock · Stabilizer · Structure

## 1 Introduction

Stabilizers in ice cream impart specific and important functions, such as increasing the viscosity of the ice cream mix, enhancing smoothness, improving aeration, reducing ice recrystallization, and reducing the rate of structural collapse during melting (Marshall et al. 2003; BahramParvar and Mazaheri Tehrani 2011). Guar

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gum, locust bean gum, sodium carboxymethyl cellulose (CMC), xanthan, and carrageenan are the most common hydrocolloids in ice cream formulations. However, in many countries of the world, there are a number of local sources of hydrocolloid gums that could also be suitable for ice cream applications (BahramParvar and Mazaheri Tehrani 2011). For example, the ability of *Lallemantia royleana*, with vernacular name of Balangu, seed gum to stabilize soft ice cream has recently been reported (BahramParvar et al. 2009, 2010).

Basil (*Ocimum basilicum* L.) is one of the endemic plants in Iran and is mainly used as a pharmaceutical plant (Naghbi et al. 2005). This plant is grown in many parts of the world especially in warm regions of Asia, Africa, and Central and South America (Paton et al. 1999). Besides its use as a traditional medicine, basil seeds are commonly incorporated into food products, such as desserts and beverages, and are used as a source of dietary fiber in Iran and some regions of Asia. These seeds, when soaked in water, swell into a gelatinous mass, which has a reasonable amount of gum. It has been reported that the polysaccharides extracted from basil seed comprise two major fractions, glucomannan (43%) and (1→4)-linked xylan (24.29%), and a minor fraction, glucan (2.31%). The presence of a highly branched arabinogalactan, in addition to glucomannan and (1→4)-linked xylan, has also been shown (Hosseini-Parvar et al. 2010).

Basil seed gum (BSG) has good functional properties comparable to some commercial food hydrocolloids (Razavi et al. 2009; Hosseini-Parvar et al. 2010; BahramParvar and Razavi 2012). Hosseini-Parvar et al. (2010), in a study on the steady shear flow behavior of BSG, concluded that the existence of yield stress, high viscosity at low shear rates, shear thinning behavior, and the heat resistant nature of BSG make it a good stabilizer in some food formulations such as mayonnaise and salad dressing. BSG, by its effects on apparent viscosity of ice cream mix, draw temperature, meltdown behavior, and total acceptance, has just shown promising results in stabilizing a typical fresh ice cream (BahramParvar et al. 2012). However, its impact on ice crystallization and recrystallization and on fat structure in ice cream has not been investigated.

Therefore, the objectives of this research were to study the effects of different levels of BSG in ice cream formulations on physical properties of ice cream compared to a commercial combination of CMC and guar gum and to an unstabilized formulation. Rheological properties of ice cream mixes, ice crystal size in ice creams after hardening and after storage at fluctuating temperature, fat particle size in ice cream mix and melted ice cream, microstructure, and meltdown characteristics of ice creams were all examined.

## 2 Materials and methods

### 2.1 Ice cream manufacture

Ice cream formulations consisted of 10% fat (derived from 35% fat cream; Sealtest, Toronto, Canada), 11% milk solids-not-fat (derived from cream and skim milk powder; Coverdale Brand, Parmalat, Toronto, Canada), 15% sucrose (Lantic Sugar, Toronto, Canada), 0.3% vanilla (Food Specialties, Mississauga, Canada), 0.15%

monoglycerides and diglycerides (saturated; Danisco, Scarborough, Canada), 0.0%, 0.1%, or 0.2% stabilizers, and the balance from water. BSG or a mixture of 50% CMC/50% guar (Danisco) was used as stabilizer. BSG was prepared according to the method of Razavi et al. (2009). Water and cream were mixed and warmed to 50 °C. Pre-blended dry ingredients were added and mixed prior to batch pasteurization (74 °C for 10 min) and two-stage homogenization (17.5/3.5 MPa; 31MR Laboratory Homogenizer, APV Gaulin Inc., Everett, MA, USA). Mixes were cooled and aged overnight at 4 °C. Ice cream mixes were frozen in a 3-L batch freezer (Model 104, Taylor Company, Rockton, IL, USA) for 5 min and whipped for an additional 2 min. Extruded ice creams were collected into 250 mL containers and hardened at -25 °C. Draw temperature of ice creams, which was measured by means of a thermocouple integrated in the freezer barrel door, was ~ -4 °C. All ice cream formulations were produced in triplicate.

## 2.2 Storage conditions

Ice cream samples were stored at both constant and cycling temperature conditions after hardening. At least three containers of each formulation were reserved for each storage condition. For temperature cycling, each sample was subjected to a programmed heating and cooling cycle during which the freezer was kept at -20 °C for 12 h, then heated to -10 °C in 12 h, held at that temperature for 12 h, and cooled to -20 °C in 12 h. This 48 h heating-cooling cycle was repeated seven times on every sample (Regand and Goff 2006). In the case of constant temperature, samples were stored at -25 °C.

## 2.3 Rheological measurements

The steady shear rheological measurements of ice cream mixes after aging were performed at 5 °C using a controlled stress rheometer (TA Instruments, New Castle, DE, USA) equipped with a cone and plate geometry (2°, 60 mm diameter). Samples were loaded onto the lower plate of the rheometer, allowed to equilibrate, and subjected to pre-shear stress at 0.2 Pa·s for 2 min to erase thixotropy. Subsequently, a shear stress ramp (20 to 200 s<sup>-1</sup>) was applied to the samples. The flow behavior of such systems was examined using the power law model as follows:

$$\tau = K\dot{\gamma}^n$$

where  $\tau$  is the shear stress (Pa),  $K$  is the consistency coefficient (Pa·s<sup>n</sup>),  $\dot{\gamma}$  is the shear rate (s<sup>-1</sup>), and  $n$  is the flow behavior index (dimensionless). Furthermore, apparent viscosity ( $\eta_a$ ) at the shear rate of 50 s<sup>-1</sup> was determined because this has been reported as an effective oral shear rate (Rao 1999).

## 2.4 Fat particle size analysis

Fat globule size distributions of ice cream mix (4 °C) and melted ice cream after hardening (4 °C for 3–4 h) were measured by laser diffraction (Malvern Mastersizer 2000, Malvern Instruments Ltd., Malvern, Worcestershire, UK). Dilution of the samples in the Mastersizer chamber was approximately 1:1,000 with Milli-Q. The

refractive index for the fat and the dispersing medium was 1.46 and 1.33, respectively, with absorbance of 0.001. Mean particle size diameter,  $d_{4,3}$  (the volume/surface-weighted diameter), was recorded (Mendez-Velasco and Goff 2011).

## 2.5 Overrun measurement

Overrun of samples was calculated as follows (Marshall et al. 2003):

$$\% \text{ overrun} = ((\text{weight of unit volume of mix} - \text{weight of unit volume foam}) / \text{weight of unit volume foam}) \times 100$$

## 2.6 Melting characteristics

Meltdown characteristics of ice cream were investigated according to the method used by Mendez-Velasco and Goff (2011). Samples for the meltdown test (260 mL), which were stored at  $-25\text{ }^{\circ}\text{C}$ , were removed carefully from the containers and weighed on a scale. The samples were suspended on rectangular stainless steel wire mesh grids ( $15 \times 11.5\text{ cm}$ , hole size of  $2.5 \times 2.5\text{ mm}$ ) supported on tripods and allowed to melt at room temperature ( $\sim 22\text{ }^{\circ}\text{C}$ ). The weight of drained material through the wire mesh was recorded every 10 min for 100 min. This weight was plotted as a function of time. Meltdown rates were calculated from the slope of each meltdown chart.

## 2.7 Ice crystal size analysis: bright-field microscopy

Ice cream containers were transferred from the  $-25\text{ }^{\circ}\text{C}$  walk-in freezer to a  $-18\text{ }^{\circ}\text{C}$  storage room 1 h before microscopy analysis. All mechanical devices required for further treatment of the samples were precooled to  $-18\text{ }^{\circ}\text{C}$ . A thin slice of ice cream was cut from the core section at the center of the container using a sharp knife. This layer was placed on a drop of iso-amyl-butanol (previously cooled to  $-18\text{ }^{\circ}\text{C}$ ) on a standard glass microscope slide, and a few more drops of iso-amyl-butanol were added to the sample. The microscope slide was covered with a coverslip and placed above liquid nitrogen in an insulated Styrofoam container and immediately transported to the cold stage (Linkam Scientific Instruments, Surrey, UK), which was previously programmed to a constant temperature of  $-17\text{ }^{\circ}\text{C}$  (Flores and Goff 1999a).

Images from uncycled and cycled samples were acquired using an Olympus BH PLM light microscope. Several different fields were photographed from 2 different containers of ice cream to obtain at least 300 crystals per sample. These images were analyzed using the Image J Software (Version 1.46k, Wayne Rasband, National Institutes of Health, Bethesda, MD, USA) by manually tracing the perimeter of ice crystals with a computer mouse; the area of each crystal was automatically calculated by the software. Equivalent circular diameter of the crystals was determined using Microsoft Excel 2007. Logistic dose–response model with a cumulative distribution of equivalent circular diameters was used to distinguish ice crystal size distributions. The slope of the distribution ( $n$ ) and the  $X_{50}$  values were calculated by Curve Expert 1.3 program. The  $X_{50}$  value corresponds to the theoretical median value of the fitted data to the model at 50% of the cumulative distribution. The

slope parameter is an indication of the span of the population with lower slope representing a more narrow distribution.

The rate of ice crystal growth in the sample was calculated with the following equation:

$$\% \text{ Rate of growth} = (X_{50} \text{ after cycling} - X_{50} \text{ before cycling})100/X_{50} \text{ before cycling}$$

where the  $X_{50}$  values are taken from the averaged means of the triplicate runs (Regand and Goff 2002).

## 2.8 Cryo-scanning electron microscopy

Cryo-scanning electron microscopy (cryo-SEM; Hitachi S-570 SEM, Hitachi Ltd., Tokyo, Japan; with Emscope SP2000A Sputter-Cryo Cryogenic Preparation System, Emscope Ltd., Kent, UK) was used to visualize the microstructures of the systems. Sample preparation and observation was performed according to Flores and Goff (1999a) and digital images were collected using the Voyager Acquisition System (Noran Instruments, Middleton, WI, USA).

## 2.9 Statistical analysis

All samples were prepared in triplicate. A completely randomized design was used and all analyses were performed in three to nine replications. Data were analyzed by MSTATC Statistical Software (version 1.42; MSTATC Director, Michigan State University, East Lansing, MI, USA). Means were compared using the least significant differences test at the significance level of 0.05.

# 3 Results and discussion

## 3.1 Rheological measurements

The power law model was successfully used due to the fact that its two parameters,  $n$  and  $K$ , showed excellent representation of the data ( $r^2=0.99$ ). All ice cream mixes exhibited non-Newtonian pseudoplastic flow behavior, with  $n$  values lower than 1 (Table 1). The flow behavior indices ranged from 0.59 to 0.80 for samples containing 0.2% BSG and 0% stabilizer, respectively. It has been reported that a low  $n$  value provides good mouthfeel characteristics (Szczesniak and Farkas 1962). The addition of stabilizers significantly increased the apparent viscosity and consistency coefficient values of ice cream mixes. BSG created higher viscosity at either 0.1% or 0.2% compared to the combination of CMC and guar at equivalent concentrations. The viscosity of an ice cream mix is considered a key attribute as it affects the body and texture of the finished product (Miller-Livney and Hartel 1997; Marshall et al. 2003). In some studies, the function of hydrocolloids in enhancing viscosity and decreasing molecular mobility has been correlated to control of ice crystal growth (BahramParvar and Mazaheri Tehrani 2011). Therefore, BSG, by producing high viscosity and low  $n$  values, provided sufficient rheological properties for ice cream.

**Table 1** Rheological properties of ice cream mixes containing different types and concentrations of stabilizers

Formulation	Apparent viscosity (Pa·s) at 50 s <sup>-1</sup>	<i>n</i>	<i>K</i> (Pa·s <sup><i>n</i></sup> )
No stabilizer	0.046±0.0019 <sup>c</sup>	0.80±0.028 <sup>a</sup>	0.098±0.0045 <sup>d</sup>
0.1% BSG	0.18±0.0070 <sup>a</sup>	0.63±0.003 <sup>bc</sup>	0.75±0.038 <sup>ab</sup>
0.1% CMC/guar	0.094±0.0036 <sup>b</sup>	0.73±0.052 <sup>ab</sup>	0.27±0.043 <sup>c</sup>
0.2% BSG	0.18±0.0096 <sup>a</sup>	0.59±0.011 <sup>c</sup>	0.90±0.031 <sup>a</sup>
0.2% CMC/guar	0.17±0.011 <sup>a</sup>	0.67±0.027 <sup>bc</sup>	0.61±0.02 <sup>b</sup>

Different letters in a column represent significant differences,  $P < 0.05$ ,  $n = 3$

BSG basil seed gum, CMC carboxymethyl cellulose

### 3.2 Overrun measurement

As shown in Table 2, there was no significant difference among overrun of unstabilized samples and the ones containing BSG ( $P > 0.05$ ). However, the blend of CMC and guar increased the air incorporation into ice cream significantly ( $P < 0.05$ ). Lower overrun of ice creams containing BSG compared to commercial gums could be attributed to the rheological properties of the mixes and incapability of dashers of the batch freezer to incorporate as much air as in the lower viscosity samples.

### 3.3 Melting characteristics

The range of meltdown rate in our study matched other research very well (Bolliger et al. 2000; Karaca et al. 2009; BahramParvar et al. 2012). There was a significant difference in meltdown rate of samples ( $P < 0.05$ ). Ice creams containing 0.2% CMC and guar blend and 0.1% BSG showed the highest (1.58 g·min<sup>-1</sup>) and the lowest (0.28 g·min<sup>-1</sup>) values of meltdown rate, respectively (Table 2). The addition of BSG substantially reduced the meltdown rate of samples at either concentration compared to the CMC and guar blend. Such mixes had a greater resistance to flow and would not drip through the screen fast. Meltdown rate is usually a function of both fat structure formation and the rheological properties of the ice cream (Marshall et al. 2003). Muse and Hartel (2004) found that meltdown rate increased as the level of fat destabilization diminished, the consistency coefficient decreased, and the ice crystal size increased. Therefore, the higher viscosity of ice creams containing BSG compared to the CMC/guar blend was partly responsible for the reduced meltdown rate.

**Table 2** The effect of type and concentration of stabilizers on some physical properties of ice cream

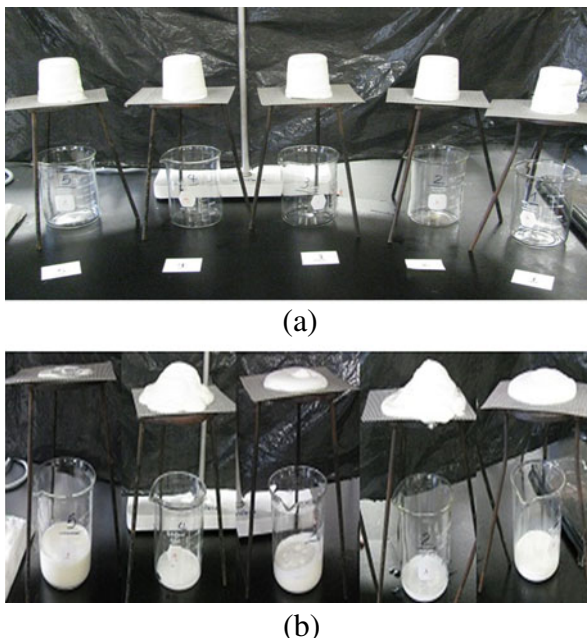
Different letters in a column represent significant differences,  $P < 0.05$ ,  $n = 3$  BSG basil seed gum, CMC carboxymethyl cellulose

Formulation	Overrun (%)	Meltdown rate (g·min <sup>-1</sup> )
No stabilizer	45.8±3.7 <sup>b</sup>	1.08±0.19 <sup>b</sup>
0.1% BSG	46.5±4.0 <sup>b</sup>	0.28±0.021 <sup>d</sup>
0.1% CMC/guar	59.5±4.6 <sup>a</sup>	0.72±0.033 <sup>bc</sup>
0.2% BSG	42.7±3.0 <sup>b</sup>	0.30±0.015 <sup>cd</sup>
0.2% CMC/guar	62.3±5.1 <sup>a</sup>	1.58±0.21 <sup>a</sup>

More insight into the structure of ice creams was gained by investigating the shape retention during thawing (Fig. 1). Samples that contained BSG retained more of their original shape than did any of the other ice creams, which is dependent on the degree of fat destabilization (Muse and Hartel 2004) and the increase in consistency (Muse and Hartel 2004; Alvarez et al. 2005). Smaller dispersed air cells in these ice creams could also contribute to slower draining and better holding of the original shape as reported by Eisner et al. (2005). During thawing, the remaining portion of samples with no stabilizer or 0.1% CMC/guar looked foamier than the others.

### 3.4 Fat agglomeration

A comparison of the particle size distributions in ice cream mix and ice cream is presented in Table 3. No significant difference ( $P>0.05$ ) was found in the extent of homogenization ( $d_{4,3}$  mix values) for mixes with either no stabilizer or the CMC/guar combination, with  $d_{4,3}$  values all  $<1\ \mu\text{m}$ . A range of fat globule diameter ( $d_{4,3}$ ) in the ice cream mix has been reported to be  $0.04\text{--}4.0\ \mu\text{m}$  (Caillet et al. 2003). However, the addition of BSG had a significant impact on the colloidal particle size distribution in the mix, resulting in substantially larger values at either 0.1% or 0.2% BSG compared to the commercial gums. To understand these values, solutions of either 0.2% BSG or 0.2% BSG, 15% sugar, and 11% skim milk powder were heated and homogenized under similar mix processing conditions, and they showed a large peak with a  $d_{4,3}$  value of 167 and 81  $\mu\text{m}$ , respectively. This indicates that BSG itself was forming large aggregates; consequently, the size distributions reported in Table 3 for mixes do not solely represent fat globules. Hence, further comparisons are difficult.



**Fig. 1** Shape of ice cream samples during meltdown test at start (a) and after 100 min (b). Samples from right to left are 0% stabilizer, 0.1% BSG, 0.1% CMC/guar, 0.2% BSG, and 0.2% CMC/guar



**Table 3** The effect of type and concentration of stabilizers on colloidal properties of ice cream mix and ice cream

Formulation	Fat globule size ( $d_{4,3}$ ) mix	Fat globule/aggregate size ( $d_{4,3}$ ) ice cream
No stabilizer	0.82±0.11 <sup>c</sup>	1.37±0.47 <sup>c</sup>
0.1% BSG	23.6±5.71 <sup>b</sup>	6.37±2.09 <sup>b</sup>
0.1% CMC/guar	0.69±0.053 <sup>c</sup>	1.10±0.26 <sup>c</sup>
0.2% BSG	53.7±7.79 <sup>a</sup>	22.49±3.76 <sup>a</sup>
0.2% CMC/guar	0.73±0.092 <sup>c</sup>	1.18±0.13 <sup>c</sup>

Different letters in a column represent significant differences,  $P < 0.05$ ,  $n = 3$

BSG basil seed gum, CMC carboxymethyl cellulose

Ice cream samples containing either no stabilizer or CMC/guar at either concentration showed similar  $d_{4,3}$  values (Table 3), which were slightly higher than their respective mixes, indicating that some fat destabilization had occurred during freezing. In general, during freezing of ice cream, the emulsion undergoes partial coalescence or fat destabilization in which clumps and clusters of fat globules form an internal fat structure into frozen product by entrapping air within the coalesced fat, typically leading to larger  $d_{4,3}$  values in ice cream than the ice cream mix (Goff 1997; Bolliger et al. 2000; Eisner et al. 2005).

Samples containing BSG showed considerably higher values than the unstabilized or CMC/guar-containing ice creams, with 0.2% BSG being considerable higher than 0.1% BSG. Due to the presence of the BSG aggregates seen in the mix, it is not possible to determine the extent of fat destabilization per se. However, what is evident is that the BSG is also establishing a network structure in the ice cream, perhaps through interactions with fat or protein, leading to larger particle size distributions, slower rates of meltdown, and higher mix viscosity. Adsorption of BSG at oil–water interfaces in emulsion model systems and its ability to lower the interfacial tension at the interface have been recently reported (Osano et al. 2010). A number of other polysaccharides also show emulsifying properties besides their functions as texture modifiers or stabilizers. Their surface-active properties can be attributed to either hydrophobic groups or proteinaceous moieties associated with them (Dickinson 2003).

The effect of increased emulsification level and structure formation by using BSG in the ice cream was confirmed using cryo-SEM (Fig 2). As emulsification increased, more fat globules could be seen at the air interface and these globules seemed to penetrate further into the air bubble with increased BSG concentration. This behavior of fat globules could be expected based on increased hydrophobicity of the fat globule surface (Bolliger et al. 2000).

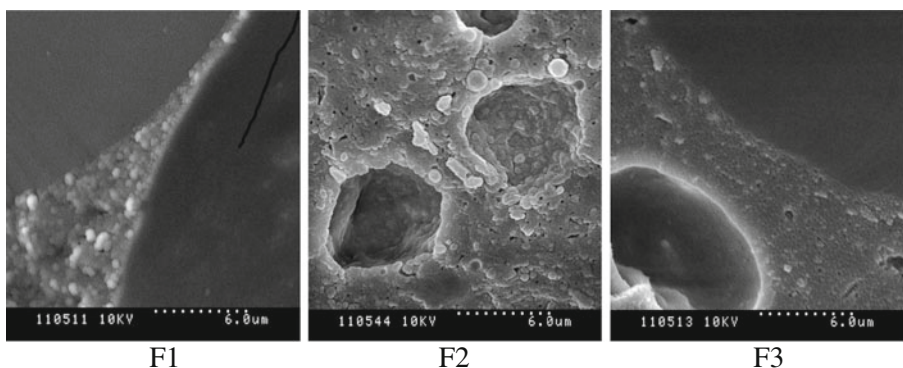
### 3.5 Ice crystal size analysis

Values of ice crystal equivalent diameter at 50% of the cumulative distribution ( $X_{50}$ ) and slope at these  $X_{50}$  values were used to characterize ice crystal size distributions (Table 4). There were no significant differences in these values before heat shock ( $P > 0.05$ ), which showed that the presence of stabilizers in ice cream had no direct effect on ice crystal distribution after hardening, as has been reported by other studies (Miller-Livney and

Hartel 1997; Sutton and Wilcox 1998; Flores and Goff 1999b; Regand and Goff 2002). Regand and Goff (2002) related this finding to the fact that stabilizers have no influence on the initial freezing properties of an ice cream mix.

Temperature cycling caused a significant increase ( $P < 0.05$ ) in  $X_{50}$  values and broadened the distribution of the population characterized by a decrease of slope at the inflection point. Flores and Goff (1999a) reported the values of 9.3–11.8 and 25.2–29.8  $\mu\text{m}$  for  $X_{50}$  after hardening and nine cycles, in ice creams containing CMC, guar gum, xanthan gum, or no stabilizer, respectively. In the present study, BSG resulted in the lowest values of ice crystal size and the highest values of slope at  $X_{50}$  after heat shock. This difference was significant compared to ice creams without stabilizer or containing a blend of CMC and guar ( $P < 0.05$ ). This may be related to the water-holding and network formation properties of BSG, a microviscosity enhancement in the surroundings of the ice crystals, and possibly a gel-like structure resulting in a reduction in the kinetics of the ice recrystallization phenomena. An enhancement of melt–regrow recrystallization, in which the crystal shrinks but does not disappear during warming and regrows on cooling, instead of melt–diffuse–grow recrystallization, in which water from crystals that melt during warming must redeposit on other existing crystals during cooling, preserves the ice crystal size and in a small span of the ice crystal size distribution (Regand and Goff 2002). The capacity of BSG to form gels at high temperature has been recently confirmed (Rafe et al. 2013), but there is no data concerning this capability at frozen conditions. The exact mechanisms of action of this hydrocolloid in cryoprotection of ice cream should be investigated in further detail. This decrease in  $X_{50}$ , especially in comparison with commercial stabilizers, is of special importance; ice crystal size is a critical attribute governing the texture of ice cream and large ice crystals result in coarse or grainy texture if present in sufficient number (Downhowe et al. 1991).

The rate of growth from before to after temperature cycling was also calculated (Table 4). The addition of BSG reduced the rate of ice crystal growth with reference to the unstabilized ice cream, which is in agreement with several researchers (Miller-Livney and Hartel 1997; Flores and Goff 1999b; Regand and Goff 2002; Soukoulis et al. 2008). In contrast, the CMC/guar blend had no particular effect on decreasing the ice recrystallization rate, which is similar to the finding of Flores and Goff (1999b)



**Fig. 2** Microstructure of air bubbles with fat globules at their interfaces in ice creams subjected to temperature cycling: *F1* no stabilizer, *F2* containing 0.1% BSG, *F3* containing 0.1% CMC/guar

**Table 4** Ice crystal diameter at 50% of the cumulative distribution function of the sample ( $X_{50}$ ) and slope at  $X_{50}$  for ice cream after hardening and after temperature cycling and rate of ice crystal growth (in percent)

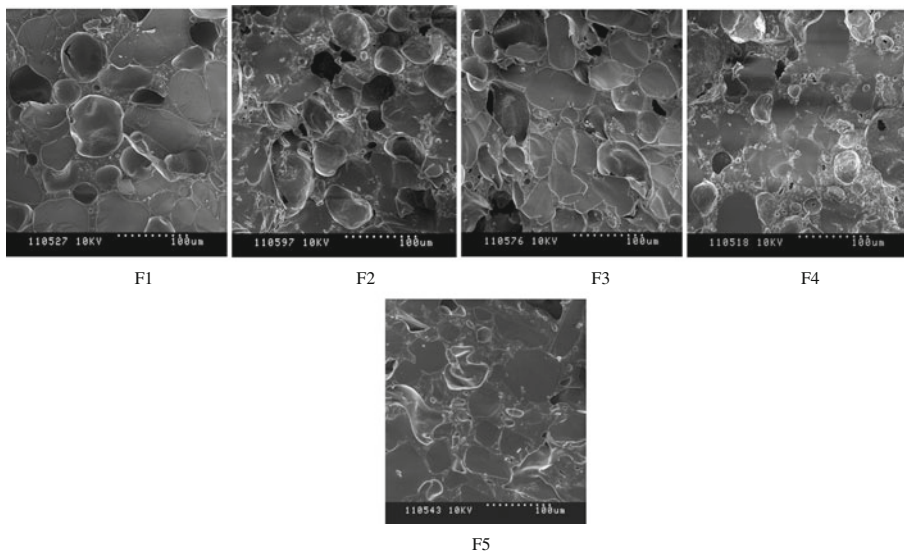
Formulation	Before cycling		After cycling		Ice crystal growth (%)
	$X_{50}$ ( $\mu\text{m}$ )	Slope ( $\% \cdot \mu\text{m}^{-1}$ )	$X_{50}$ ( $\mu\text{m}$ )	Slope ( $\% \cdot \mu\text{m}^{-1}$ )	
No stabilizer	10.8 $\pm$ 0.78 <sup>d</sup>	5.52 <sup>d</sup>	28.8 $\pm$ 0.9 <sup>b</sup>	3.86 <sup>h</sup>	167.7
0.1% BSG	11.1 $\pm$ 0.24 <sup>d</sup>	6.78 <sup>a</sup>	25.3 $\pm$ 1.2 <sup>c</sup>	5.56 <sup>e</sup>	127.4
0.1% CMC/guar	12.1 $\pm$ 0.47 <sup>d</sup>	5.29 <sup>f</sup>	33.4 $\pm$ 1.6 <sup>a</sup>	3.30 <sup>i</sup>	176.3
0.2% BSG	11.5 $\pm$ 0.41 <sup>d</sup>	6.19 <sup>b</sup>	23.2 $\pm$ 1.5 <sup>c</sup>	5.50 <sup>e</sup>	102.3
0.2% CMC/guar	11.4 $\pm$ 0.96 <sup>d</sup>	5.22 <sup>g</sup>	32.5 $\pm$ 2.9 <sup>a</sup>	3.18 <sup>i</sup>	185.5

Different letters in columns and rows (for  $X_{50}$  or for slope) represent significant differences,  $P < 0.05$ ,  $n = 3$   
 BSG basil seed gum, CMC carboxymethyl cellulose

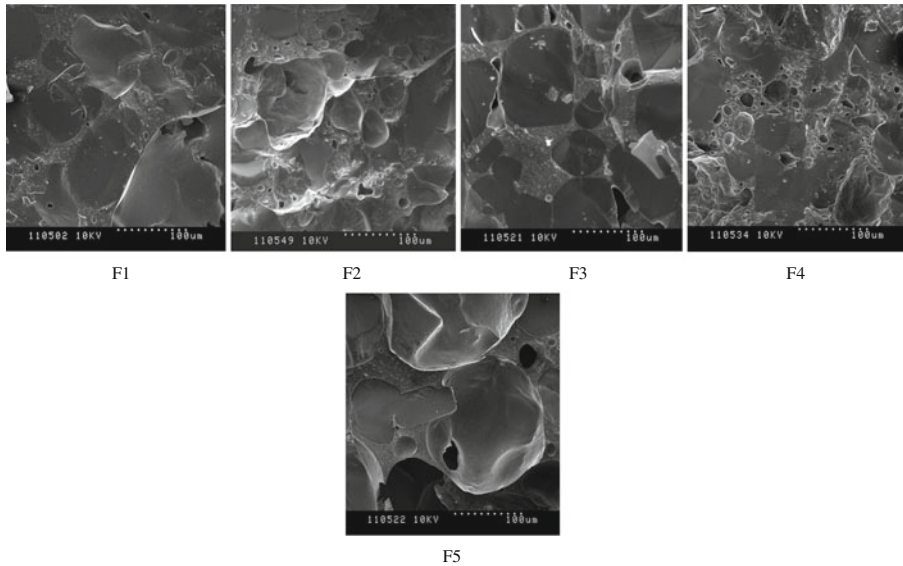
who reported nonsignificant difference in ice crystal size between unstabilized samples and ice creams including CMC after temperature cycling. They concluded that stabilizers could not control ice recrystallization when migratory recrystallization and accretion were predominant mechanisms; however, they did show a protective influence after a prolonged heat shock in which melt–refreeze recrystallization was probably the main mechanism.

### 3.6 Microstructure

The microstructure of ice creams without stabilizer or containing two levels of stabilizers before and after temperature cycling as seen by cryo-SEM is shown in



**Fig. 3** Microstructure of ice cream samples without stabilizer (*F1*) and containing 0.1% BSG (*F2*), 0.1% CMC/guar (*F3*), 0.2% BSG (*F4*), or 0.2% CMC/guar (*F5*) after hardening



**Fig. 4** Microstructure of ice cream samples without stabilizer (*F1*) and containing 0.1% BSG (*F2*), 0.1% CMC/guar (*F3*), 0.2% BSG (*F4*), or 0.2% CMC/guar (*F5*) after temperature cycling

Figs. 3 and 4. Smaller size of ice crystals after heat shock in samples containing BSG compared to others was obvious in these images, which confirmed the results of bright-field microscopy. Air cells were also smaller in ice cream containing BSG, which may be due to either its high viscosity or its emulsification properties, as discussed previously. Because the air cell dispersion is controlled by the ratio of disruption and coalescence in the freezer barrel, a higher viscosity produces smaller air cells. This smaller size has positive impacts on the stability of the foam and on the perception of creaminess during consumption (Eisner et al. 2005). The air bubbles in ice cream are usually partially coated with fat globules and the fat globules are coated with a protein/emulsifier layer (Goff 1997). More fat globules could be seen in ice creams stabilized by BSG, which is related to more air cells as well as the emulsifying capacity of this hydrocolloid. Measurement of air bubble size distribution or composition of the air interface could help in better understanding of BSG function in ice cream.

#### 4 Conclusions

Selected physical properties were examined to show the effects of BSG as an ice cream stabilizer compared to an unstabilized sample or a combination of CMC and guar at two concentrations. To determine the cryoprotective function of BSG, ice creams were subjected to heat shock and ice crystal size before and after cycling were measured and compared. This hydrocolloid significantly reduced the values of  $X_{50}$  and the width of the ice crystal size distribution compared to the commercial gums. The mechanisms of action of BSG in reducing ice crystal growth, e.g., the possible ability of BSG to form a cryo-gel during freezing and thawing, should be studied in

further detail. Besides the ice structures, BSG incorporation also induced changes in the colloidal structure of the ice cream, specifically the fat and air structures. Large aggregates were shown by particle size analysis, which may be related to the network structure formation of BSG through its emulsifying capacity. Cryo-SEM images demonstrated smaller air cells in the presence of BSG. Further investigations, such as rheological behavior during thawing (viscoelastic properties as a function of temperature), fat and protein analysis in drip and remaining portions during meltdown test, and air bubble size in ice cream, are required for better understanding of the structural changes that occurred with incorporation of BSG. Finally, sensory analyses of ice creams containing BSG need to be conducted.

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