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Influence of guar gum/furcellaran and guar gum/carrageenan stabilizer systems on the rheological and sensorial properties of ice cream during storage

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Abstract. The influence of furcellaran as a secondary stabilizer, together with guar gum, on ice cream rheological and sensorial properties during 13 months of storage was studied. The results were compared with various guar gum/carrageenan blends. While the addition of furcellaran to ice cream was found to slightly decrease the scores of colour, odour, and flavour characteristics, it also increased the creamy sensation and had a good stabilizing effect on the ice cream during extended storage.

Key words: ice cream, hydrocolloids, rheology, sensory.

1. INTRODUCTION

Ice cream is a product made of milk, sweeteners, stabilizers, emulsifiers, and flavours. During processing, the ice cream mix is pasteurized, homogenized, and then frozen. Freezing involves rapid removal of heat from the mix while agitating to incorporate air (Marshall et al., 2003). This process is crucial for a good quality product. Proper control of the formation and growth of ice crystals in the ice cream freezer results in a large number of small crystals, which in turn produces a smooth texture and good storage stability (Hagiwara and Hartel, 1996; Wildmoser et al., 2004). In addition, the size and distribution of air cells play an important role in ice cream quality, with specific influence on the sensorial aspect of creaminess (Wildmoser and Windhab, 2001; Windhab and Wildmoser, 2002): as the air bubbles become smaller, the creaminess becomes more pronounced. A strong correlation between ice cream mix viscosity and the resulting air bubble sizes was found by Chang and Hartel (2002) in a batch ice cream freezer. The freezing process is followed by hardening where the ice cream is frozen to −40 °C in a

specialized room, tunnel, or contact plate (Marshall et al., 2003). The final product is a complex multi-phase colloidal system consisting of protein, air cells, ice crystals, and fat globules.

During storage, several physical and chemical changes occur in ice cream. The growth of crystals and recrystallization are an important physical change, which occurs as water diffuses from the serum phase to the crystal surface (Adapa et al., 2000). This phenomenon has a pronounced effect on the texture of ice cream. The coarseness or iciness in ice cream increases dramatically under poor storage conditions, i.e., where temperature fluctuation occurs (Adapa et al., 2000). Stabilizers are added to ice cream to hinder the recrystallization phenomena, to increase the viscosity of the ice cream mix, to improve the texture and mouthfeel, and to enhance the shape retention of ice cream blocks (Marshall et al., 2003). Various hydrocolloids, such as guar gum, carboxymethyl cellulose, locust bean gum, carrageenan, and xanthan gum have been used as ice cream stabilizers with each stabilizer and stabilizer blend exhibiting unique functional properties (Hagiwara and Hartel, 1996; Miller-Livney and Hartel, 1997; Regand and Goff, 2003; Murtaza et al., 2004; Soukoulis et al., 2008; BahramParvar et al., 2010). Guar gum,

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locust bean gum, and xanthan gum are the most widely used hydrocolloids that inhibit the growth of ice crystals. These gums have high hydrating capacities even at low concentrations, and thus increase the viscosity of the serum phase in frozen ice creams. Carrageenan is the most commonly used secondary stabilizer; it helps to prevent wheying off in the mix. Furcellaran is a type of carrageenan that can be used as a stabilizing, thickening, and gelling agent in food (Thomas, 1997) without any side effects (Bender, 2005). The structure of furcellaran has been studied (Laos and Ring, 2005; Tuvikene et al., 2010) along with its gelling and sorption properties (Pritchkina and Chalykh, 1994; Michel et al., 1997; Truus et al., 1997; Laos et al., 2007b; Tuvikene et al., 2008) and interactions with different substances (Hughert and Sundelof, 2001; Laos et al., 2006, 2007a). However, there are no detailed accounts of either the effectiveness of furcellaran as a secondary ice cream stabilizer during storage or its impact on both the rheological and sensorial properties of ice cream.

The present study analyses the influence of guar gum, guar gum/furcellaran, and guar gum/carrageenan blends on the rheological and sensorial properties of ice cream in the course of 13 months of storage.

2. MATERIALS AND METHODS

2.1. Ice cream preparation

The ice cream used in this study consisted of 10% milk fat (provided as fresh cream 35%), 10.5% whey powder, 13% saccharose, 0.1% vanilla flavour, 0.2% emulsifier, and 66% water. Three hydrocolloids, κ/ι-carrageenan (Danisco A/S, Denmark), guar gum (Danisco A/S, Denmark), and furcellaran (Est-Agar AS, Estonia), were used as stabilizers (0.2%). The fluid and dry ingredients were mixed at 60 °C, homogenized in a double-stage homogenizer (Niro Soavi S.p.A, Italy) at the homogenization pressure of 15 MPa in the first stage and 40 MPa in the second stage. The ice cream mix was then pasteurized up to 85 °C for 20 s, then cooled to 5 °C, and aged for 24 h. The aged ice cream mixes were frozen using a freezer (Armfield FT25-BA, England) at a set draw temperature −5 °C, and packed into 500 mL containers and 40 mL plastic cups (Papstar, Germany). In this study the ice cream formulations had overrun values between 81% and 89%. The ice cream hardened at −40 °C for 24 h and was stored at −20 °C. The overall experimental design included a total of 9 formulations (Table 1). All ice cream formulations were measured once per month (every 30 days) for 13 months.

Table 1. Composition of the 10% vanilla ice cream samples used in the present study

Sample	Hydrocolloid, %		
	Carrageenan (C)	Guar gum (G)	Furcellaran (F)
G100	0	0.2	0
G80:C20	0.04	0.16	0
G50:C50	0.1	0.1	0
G20:C80	0.16	0.04	0
G95:F5	0	0.19	0.01
G90:F10	0	0.18	0.02
G75:F25	0	0.15	0.05
G65:F35	0	0.13	0.07
G50:F50	0	0.1	0.1

2.2. Mix viscosity

A viscometer (model RVDV-II+, Brookfield, USA) was used to measure the viscosity of 600 mL of each ice cream mix after 48 h of ageing. Spindle #2H was used to take viscosity measurements at 100, 50, 25, 10, 5, 2.5, 1.0, and 0.5 rpm at a temperature of 6 °C to create a flow curve. Each measurement was recorded 15 s after starting the viscometer. The shear stress (σ) and the shear rate (γ) of the mixes were calculated from the recorded viscosity data using Mitchka's equations (Mitschka, 1982). A power law model was used to determine the flow behaviour index (n) and consistency coefficient (K). The apparent viscosity was characterized using the equation: *Apparent viscosity* $= K * \gamma^{n-1}$.

2.3. Oscillatory rheometry

The rheological measurements were carried out applying an oscillatory thermo-rheometry method (Wildmoser et al., 2004). A rheometer (Physica MCR301, Austria) with a plate–plate geometry (diameter 25 mm) was used. Both plates were profiled in order to avoid wall slip. A movable hood covering the plate–plate geometry also reduced the rate of heat exchange with the environment. The measurement temperature was continuously increased from −20 °C to 10 °C at a heating rate of 1 °C/min. The test was performed at a constant angular frequency $\omega = 10\,\text{s}^{-1}$ and at a constant strain $\gamma = 0.02\%$. The gap width between the plates was adjusted to a constant value of 2 mm. Two replicate measurements were carried out for each ice cream blend. In the oscillation test, the storage modulus (G') and loss modulus (G'') were measured, which characterize the elastic and viscous behaviour of the measured sample. Storage modulus data were registered at −20 °C.

2.4. Sensory analyses

The ice creams were evaluated for sensory characteristics (colour intensity, odour, odour intensity, flavour, flavour intensity, creaminess, sweetness, softness, meltability, brittleness, overrun, and sandiness). The procedures for the training of the panelists and the establishment of the sensory attributes were based on the method presented in Meilgaard et al. (1999). All samples were served in 30 mL plastic containers with lids and the evaluation was performed in plain view under white lights. Three one-hour training sessions were held over a period of a month prior to the first characterization. In these sessions, definitions of attributes and assessment techniques were introduced and a practical sample evaluation was performed. Sensory evaluations were characterized using an 8-point scale and each sample was presented in random order. At least 6 trained panellists participated in this study.

2.5. Statistical analyses

Significant differences were defined at $p < 0.05$. An ANOVA was performed to evaluate the effects of the type and percentage of the hydrocolloids on the ice cream sensory properties (Duncan's mean values comparison test) using XL Stat version 10.0 (AddinSoft 2010, New York, NY, USA) statistical software. Sensory data are presented as the mean of three parallels.

3. RESULTS AND DISCUSSION

3.1. Mix viscosity

The consistency coefficient, flow behaviour index, and apparent viscosity for ice cream mixes with different stabilizers are shown in Table 2. The flow behaviour index of all mixes was observed to be less than one,

Table 2. Consistency coefficient, flow behaviour index, and apparent viscosity of the ice cream mixes (mean±SD, $n = 3$)

Ice cream mix	Consistency coefficient, Pa s^n	Flow behaviour index	Apparent viscosity at 25 rpm, mPa s
G100	0.52±0.10	0.51±0.01	798±22
G80:C20	0.66±0.10	0.21±0.01	1317±28
G50:C50	0.69±0.00	0.07±0.01	1557±19
G20:C80	0.69±0.01	0.04±0.00	1587±16
G95:F5	0.49±0.00	0.64±0.00	671±0
G90:F10	0.68±0.12	0.37±0.01	1178±18
G75:F25	0.59±0.12	0.34±0.01	1060±24
G65:F35	0.51±0.15	0.35±0.01	892±31
G50:F50	0.64±0.00	0.27±0.00	1213±0

which indicates pseudoplastic, shear thinning behaviour. Ice cream mixes with high consistency coefficients are more viscous. The consistency coefficients of guar gum/carrageenan mixes (G50:C50 and G20:C80) of $0.69±0.01$ Pa s^n were the highest among all the stabilizer systems studied. The guar gum/furcellaran mix (G90:F10) displayed the next highest consistency coefficient with a value of $0.68±0.12$ Pa s^n; however, these three measurements are not significantly different. The ice cream mix with guar gum/furcellaran (G95:F5) had both the lowest consistency coefficient ($0.49±0.00$ Pa s^n) and lowest apparent viscosity (671 mPa s).

3.2. Oscillatory rheometry

In the low temperature range ($-20°C$ to $-10°C$), the ice crystal microstructure governs the rheological behaviour. Wilbey et al. (1998) found a positive correlation between the hardness of ice cream and the amount of ice. Sakurai et al. (1996) also found that ice creams with large ice crystals are harder than those with smaller ice crystals. As ice crystals melt, the storage modulus (G') and loss modulus (G'') will decrease with increasing temperature.

The influence of different stabilizers on the ice cream storage modulus at $-20°C$ during 13 months of storage is presented in Fig. 1. The storage moduli of ice cream samples with guar gum/furcellaran blends in all ratios were the lowest of all measured samples (between $6.0±0.1$ MPa for G95:F5 and $7.7±0.1$ MPa for G50:F50) while the ice cream with guar gum/carrageenan blends in a ratio of 20:80 had the highest storage modulus ($14.6±0.1$ MPa). The storage moduli of all ice cream samples increased during storage, indicat-
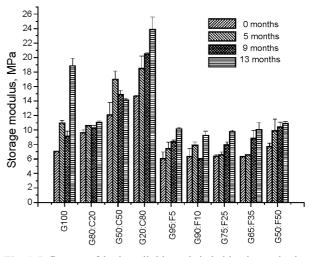

Fig. 1. Influence of hydrocolloids and their blends on the ice cream storage modulus during 13 months of storage (G – guar gum, C – carrageenan, F – furcellaran).

ing that ice recrystallization was occurring. The ice cream that consisted of a guar gum/carrageenan blend of 20 : 80 had the highest storage modulus values after 13 months of storage (23.8±1.8 MPa) followed by the ice cream with only guar gum (18.9±1.1 MPa). Addition of κ-carrageenan to ice cream mixes led to the reinforcement of pseudoplasticity, possibly caused by gelation phenomena. Thaiudom and Goff (2003) reported that the presence of κ-carrageenan in a protein/polysaccharides model solutions leads to a more heterogeneous distribution of casein micelles due to the formation of κ-carrageenan/casein complexes.

Storage time had a minor effect on the storage modulus of ice cream samples with a high guar gum content (G80 : C20, G : F blends in all measured ratios). The effect of guar gum to reduce ice crystal growth rates was reported elsewhere (Sutton and Wilcox, 1998a, 1998b). It was suggested earlier that this may be due to the modifications to the viscoelasticity of the unfrozen phase surrounding the ice crystals (Goff et al., 1995).

The influence of different stabilizers and their blends on ice cream loss modulus (G″) at 10°C during 13 months of storage is presented in Fig. 2. In the temperature range between 0°C and 10°C, all ice is melted, and only the dispersed air and fat phases have an impact on the rheological and quality characteristics. The loss modulus G″, which describes the viscous behaviour and flowability of ice cream, can be correlated with creaminess.

All fresh ice creams had high loss modulus values (between 405±7 Pa for G20 : C80 and 489±11 Pa for G75 : F25). During storage, the loss modulus decreased for all ice cream samples. The highest decrease was noted with ice cream G50 : C50, where the loss modulus value was 150±13 Pa after 13 months of storage. The ice creams with guar gum/furcellaran blends showed the highest loss modulus values, the highest being for G75 : F35 with a loss modulus of 297±8 Pa.
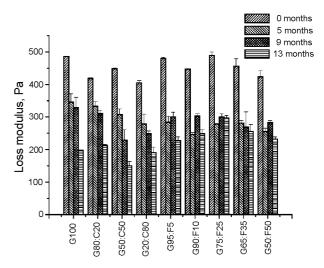

Fig. 2. Influence of hydrocolloids and their blends on ice cream loss modulus during 13 months of storage (G – guar gum, C – carrageenan, F – furcellaran).

3.3. Sensory analyses

Consumers consider textural and flavour perception of ice cream as the most important factors for the ice cream. A group of flavour and texture specified attributes was used to evaluate the influence of hydrocolloids over the 13-month storage period. The effect of hydrocolloids on the sensory attributes of each ice cream blend was determined both directly after preparation (Table 3) and after 13 months of storage (Table 4). The addition of furcellaran to ice cream slightly decreased the scores of colour, odour, and flavour characteristics but increased the creamy sensation. The softness of ice cream increased with the addition of guar gum. The highest scores of softness were obtained with the pure guar gum blend (8.00), followed by a guar gum/carrageenan blend 20 : 80 (7.78). The lowest softness score was obtained with the G90 : F10 guar gum/furcellaran ice cream blend (6.50).

Table 3. Effect of hydrocolloids on the sensory attributes (mean values) of ice creams directly after preparation

Sample	Colour intensity	Odour	Odour intensity	Flavour	Flavour intensity	Creaminess	Sweetness	Softness	Meltability	Brittleness	Overrun	Sandiness
G100	4.00[a]	8.00[a]	4.00[ab]	8.00[a]	4.00[ab]	4.00[c]	4.00[abc]	8.00[a]	7.50[ab]	0.40[bcd]	7.50[ab]	0.00[b]
G80 : C20	4.00[a]	8.00[a]	3.70[ab]	8.00[a]	3.80[ab]	4.00[c]	3.90[bc]	7.44[ab]	7.40[ab]	0.50[abcd]	7.40[abc]	0.00[b]
G50 : C50	4.00[a]	8.00[a]	3.80[ab]	8.00[a]	4.00[ab]	4.00[c]	4.00[abc]	7.00[bcde]	7.40[ab]	0.40[bcd]	7.50[ab]	0.00[b]
G20 : C80	4.00[a]	8.00[a]	3.70[ab]	8.00[a]	4.00[ab]	4.00[c]	3.80[c]	7.78[a]	7.80[a]	0.50[abcd]	7.60[ab]	0.00[b]
G95 : F5	3.80[b]	8.00[a]	4.30[a]	7.50[ab]	4.00[ab]	4.40[ab]	4.30[abc]	6.60[de]	6.70[c]	1.20[a]	6.50[c]	0.00[b]
G90 : F10	4.00[a]	7.20[b]	3.90[ab]	7.10[bc]	3.50[b]	4.20[bc]	4.20[abc]	6.50[e]	7.00[bc]	1.10[ab]	6.50[c]	0.00[b]
G75 : F25	4.00[a]	7.90[a]	3.80[ab]	7.10[bc]	3.70[ab]	4.50[a]	4.50[a]	6.70[cde]	7.10[abc]	0.80[abc]	6.50[c]	0.00[b]
G65 : F35	4.00[a]	7.90[a]	3.60[b]	7.50[ab]	3.90[ab]	4.30[ab]	4.10[abc]	7.30[abc]	7.50[ab]	0.50[abcd]	7.10[abc]	0.00[b]
G50 : F50	3.80[b]	8.00[a]	4.00[ab]	6.70[c]	3.60[b]	4.20[bc]	4.00[abc]	7.00[bcde]	7.60[ab]	0.90[abc]	7.00[abc]	0.00[b]

[a–e] Different letters between the rows indicate a significant difference ($p < 0.05$) among the ice cream samples according to Duncan's mean values comparison test.

Table 4. Effect of hydrocolloids on the sensory attributes (mean values) of ice creams after 13 months of storage

Sample	Colour intensity	Odour	Odour intensity	Flavour	Flavour intensity	Creami-ness	Sweet-ness	Soft-ness	Meltability	Brittle-ness	Overrun	Sandi-ness
G100	4.00[bc]	7.90[a]	3.60[ab]	4.70[bc]	4.00[a]	4.20[ab]	4.00[ab]	3.78[bc]	6.10[bcd]	1.50[c]	7.00[ab]	0.10[b]
G80:C20	4.00[bc]	7.80[ab]	3.70[ab]	6.20[ab]	4.00[a]	4.20[ab]	4.50[ab]	6.33[ab]	6.80[abcd]	2.40[b]	7.10[ab]	0.70[b]
G50:C50	4.00[bc]	7.30[ab]	3.70[ab]	5.90[ab]	3.80[a]	4.10[ab]	4.40[ab]	6.33[ab]	7.30[ab]	1.30[bc]	7.40[a]	0.30[b]
G20:C80	4.00[bc]	8.00[a]	3.50[ab]	5.60[ab]	3.70[a]	4.40[ab]	4.60[a]	5.00[ab]	7.20[ab]	1.20[bc]	7.50[a]	0.20[b]
G95:F5	4.10[b]	7.20[ab]	3.80[a]	5.00[abc]	3.80[a]	4.20[ab]	4.00[ab]	5.80[ab]	7.10[ab]	1.40[bc]	6.90[ab]	0.00[b]
G90:F10	4.00[bc]	7.80[ab]	3.60[ab]	6.40[ab]	3.80[a]	3.90[ab]	4.10[ab]	6.50[a]	7.20[ab]	1.10[bc]	7.20[ab]	0.00[b]
G75:F25	4.00[bc]	8.00[a]	3.60[ab]	6.80[ab]	3.80[a]	3.80[b]	4.10[ab]	6.90[a]	7.30[ab]	0.80[bc]	7.30[a]	0.00[b]
G65:F35	4.00[bc]	7.90[a]	3.70[ab]	7.00[a]	3.80[a]	3.80[b]	4.00[ab]	6.80[a]	7.40[a]	0.80[bc]	7.50[a]	0.00[b]
G50:F50	4.10[b]	8.00[a]	3.70[ab]	7.10[a]	3.70[a]	3.80[b]	4.10[ab]	6.10[ab]	7.20[ab]	1.20[bc]	7.20[ab]	0.00[b]

[a–d] Different letters between the rows indicate a significant difference ($p < 0.05$) among the ice cream samples according to Duncan's mean values comparison test.

During storage, the texture of ice cream gradually deteriorates. A strong decrease in softness, melting, and flavour properties was observed with increased brittleness in ice creams with only guar gum and a guar gum/carrageenan blend (80:20) after 13 months of storage. The ice creams with guar gum/furcellaran blends in ratios 90:10, 75:25, and 65:35 displayed the best stabilizing effect during 13 months of storage.

4. CONCLUSIONS

The results presented herein show that stabilizers have a strong effect on ice cream properties during extended storage. Furcellaran was found to be an effective secondary ice cream stabilizer together with guar gum. Although the addition of furcellaran to ice cream was found to slightly decrease the scores of colour, odour, and flavour characteristics, it increased the creamy sensation and had a good stabilizing effect on the ice cream during 13 months of storage.

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Stabilisaatorite guarkummi-furtsellaraani ja guarkummi-karragenaani segude mõju jäätise reoloogilistele ning sensoorsetele omadustele säilitamisel

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Jäätis on külmutatud toiduaine, mis koosneb piimast, magusainetest, stabilisaatoritest, emulgaatoritest ja maitse-ainetest. Stabilisaatorite ülesanne jäätises on takistada jää rekristalliseerumist, suurendada segude viskoossust ja parandada tekstuuri ning suutunnet. Igal stabilisaatoril on unikaalsed omadused. Guarkummi, jaanileivapuujahu ja ksantaani kõrval kasutatakse sekundaarse stabilisaatorina kõige enam karrageeni. Furtsellaraan on karrageenitüüp, mida toodetakse Eestis punavetikast *Furcellaria lumbricalis*. Siiani puuduvad avaldatud andmed furtsellaraani mõjust sekundaarse stabilisaatorina jäätises. Antud töös uuriti stabilisaatorite guarkummi-furtsellaraani segu mõju jäätise reoloogilistele ja sensoorsetele omadustele 13 kuu vältel. Andmeid võrreldi guarkummi-karragenaaniseguga. Tulemustest selgus, et juba väike furtsellaraanikogus sekundaarse stabilisaatorina alandas jäätise värvi-, lõhna- ja maitseomadusi. Samal ajal suurenes jäätise kreemisus ja paranes jäätise stabiilsus säilivusel.