As. J. Food Ag-Ind. 2008, 1(01), 51-61

Asian Journal of Food and Agro-Industry

ISSN 1905-

Available online at www.ajofai.info

Research Article

Comparison of commercial stabilizers with modified tapioca starches on foam stability and overrun of ice cream

Siwatt Thaiudom[1*], Khoon Singchan[2] and Thanomduang Saeli[1]

[1] School of Food Technology, Institute of Agricultural Technology,
Suranaree University of Technology,
Nakhon Ratchasima 30000, Thailand

[2]Innofresh Co., Ltd.
Nakhon Naiyok 26110, Thailand

*Author to whom correspondence should be addressed, email: thaiudom@sut.ac.th
This paper was originally presented at Food Innovation Asia 2007.

Abstract: The influence of commercial stabilizers (Fulfil 400, locust bean gum; LBG and guar gum) and modified tapioca starches (octenyl succinic anhydride starch; OSA, acetylated starch; AS and hydroxypropylated starch; HPS) on foam stability and the overrun of ice cream system was investigated. The apparent viscosity of each stabilizer solution at various concentrations was evaluated in order to compare their ability for retarding foam collapse, resulting in higher foam stability. Twenty-four hours aging process of ice cream mixes which contained 10% butter oil and different stabilizers was studied to estimate the effect of stabilizer hydration on the mix viscosity. Foam stability, as a function of duration time, of ice cream mixes with different stabilizers was also examined and recorded in terms of air volume fraction. The overrun of ice cream mixes after whipping and freezing in an ice cream batch maker was determined. The results showed that the viscosity of stabilizer and modified starch solutions increased in the following order: LBG > guar gum > OSA > fulfil 400 > AS, HPS, indicating that LBG was hydrated more completely than the other stabilizers. Foams of ice cream mixes which contained LBG or guar gum were the most stable, while foams of the mixes containing other stabilizers rapidly decreased in the duration of time from 0 to 90 min. Foams of ice cream mix made from Fulfil 400 seemed to be the least stable, while foam stabilities of ice cream mixes with different modified tapioca starches were not significantly different ($p>0.05$). Overrun of ice cream containing commercial stabilizers or modified tapioca starches were not significantly different ($p>0.05$) except the overrun of ice cream comprising AS which showed the least overrun. Overall, these results indicated that commercial stabilizers such as LBG and guar gum contributed more viscosity and foam stability to the ice cream mixes and modified tapioca starches such as OSA and HPS showed no significant difference ($p>0.05$) in the overrun.

Keywords: ice cream, stabilizer, modified tapioca starch, foam stability, overrun

Introduction

Dairy food products which are whipped in order to add air bubbles into the products are known as a complicated colloid system. Ice cream is one such product which contains air bubbles or foams dispersing in the unfrozen phase. Air bubbles or foams contribute to a soft texture, light body of ice cream and retardation of ice cream melting. (Sofjan and Hartel, 2004). The volume of air bubbles or foams in ice cream relates to the overrun which is normally reported in percentage (Marshell *et al*., 2003). The higher the overrun the softer the ice cream, resulting in a higher profit. However, higher overrun with many small air bubbles may cause a fluffy texture which is less acceptable to consumers (Marshell *et al*., 2003). On the other hand, even a small amount of large foaming can cause ice cream collapse from Ostwald repining (Dutta *et al*., 2004). To solve these problems and stabilize the air bubbles, quite a number of studies have been undertaken employing stabilizers to inhibit or limit the movement of air bubbles (Camacho, *et* al., 1998, 2001; Chang and Hartel, 2002a, b; Goff, 2002; Klitzing and Muller, 2002; Baez *et al*., 2005).

Stabilizers used in ice cream are normally polysaccharide gums, which serve to enhance viscosity in the ice cream mix and in the unfrozen phase of the ice cream following frozen process (Berger, 1997). They contribute to ice cream structure and alter textural characteristics (Thaiudom and Goff, 2003). The stabilizers mostly used in ice cream production are locust bean gum (LBG), guar gum, κ-carrgeenan and other commercial stabilizers e.g. Fulfil 400 which contains a mix of gums and emulsifier. However, Smith and co-workers (2000) found that stabilizers such as LBG caused lower overrun in whipped cream compared with those without stabilizers. In contrast, foam stability of whipped cream comprising stabilizers was higher than those without. Marshell and co-workers (2003) reported that stabilizers contribute to a smaller size of air bubbles or foams in ice cream. However, these stabilizers may result in a higher cost of ice cream production.

Using stabilizer replacers such as modified tapioca starch does not only lower the cost, but might also result in a better texture and lower melting point since they have been proven to inhibit freeze-thawing very well (Wu and Seib, 1990; Raina *et al*., 2006). Such modified starches i.e. octenyl succinic anhydride starch (OSA), acetylated starch (AS) and hydroxypropylated starch (HPS), are thus widely used in frozen food products. OSA is a starch derivative, prepared by a standard esterification reaction in which cyclic dicarboxylic acid anhydride and starch are suspended in water and mixed under alkaline conditions. OSA was reported to be an effective emulsifier due to the dual functional hydrophilic and hydrophobic groups. OSA has been used in a variety of oil-in-water *As. J.*

emulsions, in some water-in-oil systems and in pharmaceutical and industrial areas, especially in food production, due to its good filming properties and excellent emulsion-stabilizing properties (Trubiano, 1995; Viswanathan, 1999; Bao *et al*., 2003). HPS is a starch which is prepared by reacting starch with propylene oxide in order to produce a low level of etherification (BiMiller and Whistler, 1996). HPS reduces gelatinization temperature, forms clear paste and withstands freeze-thaw process (BeMiller and Whistler, 1996; Raina *et al*., 2006; Schmitz *et* al., 2006). AS is a starch produced by an acetylation process. This imparts the thickening needed in food application. The acryl groups in AS improve properties over the native form in storage stability, high swelling, high solubility, viscosity, low gelatinizaton, freeze-thaw stability and resistance to retrogadation (BeMiller and Whistler, 1996; Raina *et al*., 2006).

With the goal of examining the quality of ice cream i.e. foam stability and overrun using modified tapioca starches instead of commercial stabilizers, the objectives of this work were to examine the viscosity of commercial stabilizers (LBG, gaur gum and Fulfil 400) compared with that of modified tapioca starches (OSA, AS and HPS) as a function of their concentrations; to determine the viscosity and foam stability of ice cream mixes containing commercial stabilizers or modified tapioca starch in the presence of κ-carrageenan and milk proteins; and to examine the overrun of such mixes after freezing and aeration process in an ice cream freezer.

Materials and Methods

Materials and Chemicals

Food grade skim milk powder (SMP) was obtained from Murray Goulburn Co-operative Co., Ltd. (Brunswick, Victoria, Australia). The skim milk powder contained 99% (w/w) total protein (by Kjeldahl analysis). Commercial stabilizers: LBG, guar gum, and Fulfil 400, as well as κ-carrageenan were purchased from SKW Biosystems Co., Ltd. (Boulogne-Billancourt, France). Octenyl succinic anhydride starch (OSA), Acetylated Starch (AS) and Hydroxypropylated Starch (HPS) were obtained from Sanguanwong Co. (Nakhon Ratchasima, Thailand). Sucrose (food grade) was purchased from Mitrphol Co., Ltd. (Suphanburi, Thailand). Anhydrous butter was purchased from Murray Goulburn Co-operative Co., Ltd. (Brunswick, Victoria, Australia).

Preparation of stabilizer solutions and ice cream mixes

Commercial stabilizer and modified tapioca starch solutions were prepared at 40°C in deionized water by stirring with a magnetic bar for 10 min. All solutions at various concentrations: 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0 % were heated on a hot plate at 75°C for 25 min. All solutions were stirred with a magnetic bar and covered with a watch glass during heating before cooling down to 25°C. The solution preparation was processed in duplicate.

Ice cream mix formulations contained 10% butterfat, 10.5% SMP, 10% sucrose, 0.015% κ-carrageenan and 0.02% stabilizer or modified tapioca starch. These 6 formulations were processed in duplicate for a total of 12 mixes. The mixes were batch pasteurized at 75°C for 15 min, then homogenized at 2500/500 psi using Gaulin homogenizer (15 MR-8TA; APV Gaulin, Everett, MA, USA), aged at 5°C for 24 h before analyses.

Viscosity measurement

Viscosity measurements of solutions and mixes, before and after aging, were determined using Brookfield viscometer (D III Ultra; Brookfield Engineering Laboratory Inc., Middleboro, MA, USA) at 5°C with spindle no. 21 at 150 rpm. Readings were recorded after 5 sec of a measurement process. Viscosity measurements were performed in triplicate.

Foam stability measurements

A food mixer (Moulinex BM9; Jebsen & Jessen, Bangkok, Thailand) with a 2.7*l* stationary bowl and rotating beaters was used for foam formation. 200*l* of ice cream mix were whipped at a turbo speed setting (planetary rpm of 220 and 5 cm diameter beaters rpm of 730) for 15 min. The whipping was performed at room temperature. Foam and mix were poured to a scaled cylinder to measure total volume of foam. Foam stability was carried out by plotting graph between total volume of foam and time of observation from 0 to 240 min.

Overrun measurement

Overrun measurements were begun immediately after the mixes were batch frozen in an ice cream batch freezer (Taylor 103-34; Taylor Rockton, IL, USA). The freezer was run under whipping and cooling conditions until the temperature of ice cream was lowered to the desired draw temperature (-5°C) and until the running process reached 15 min. Once the end point was reached the overrun in the ice cream was measured and calculated by comparing the weight of a known volume of ice cream to the weight of the same volume of unfrozen ice cream mix.

Microstructure study

The microstructure of ice cream mixes were determined using Transmission Electron Microscope (TEM-2010; JEOL Ltd., Tokyo, Japan) following the procedure as described in Thaiudom and Goff (2003).

Statistics

All statistical analyses were performed on a personal computer running SAS for Windows v.6.12 (SAS Institute Inc., NC, USA) and SPSS v.13.0 (SPSS Inc., IL, USA). Analysis of variance was performed using the routine Proc ANOVA and multiple comparisons of means were conducted using a Duncan's New Multiple Range Test.

Results and Discussion

Viscosities of stabilizer and modified starch solutions

Fig. 1 shows viscosities of stabilizer and modified starch solutions as a function of their concentrations. Viscosity of each solution obviously increased with an increase in concentration, except the viscosity of AS and HPS. LBG and guar gum solutions showed a higher viscosity when increasing their concentrations. This may be because LBG and guar gum are hydrocolloid, which could hydrate water better than other stabilizers or modified starches at the same level of concentration. High viscosity of LBG and gaur gum solutions could be attributed to more linear conformation of their structure, compared with Fulfil 400 and modified starches, resulting in a high free volume of gyration when they rotated themselves in water (Glicksman, 1982; BeMiller and Whistler, 1996). However, Fulfil 400 and OSA solutions also showed an increased viscosity when increasing their concentrations throughout this study. A solution of OSA was more viscous than Fulfil 400 even though both of them have emulsifying properties. This may be due to OSA having stronger hydrophilic and hydrophobic groups compared with Fulfil 400, which might have interference from its component ingredients. AS and HPS solutions showed a slight change of their viscosity even though their concentration was increased. This is probably due to AS and HPS having compacted branch chains which resist absorbing water and swelling compared to other stabilizers, resulting in less free volume of gyration. However, AS and HPS are popular for frozen food products they can improve the freeze-thaw or cold storage stability of frozen food (Wu and Seib, 1990; Raina *et al*., 2006).

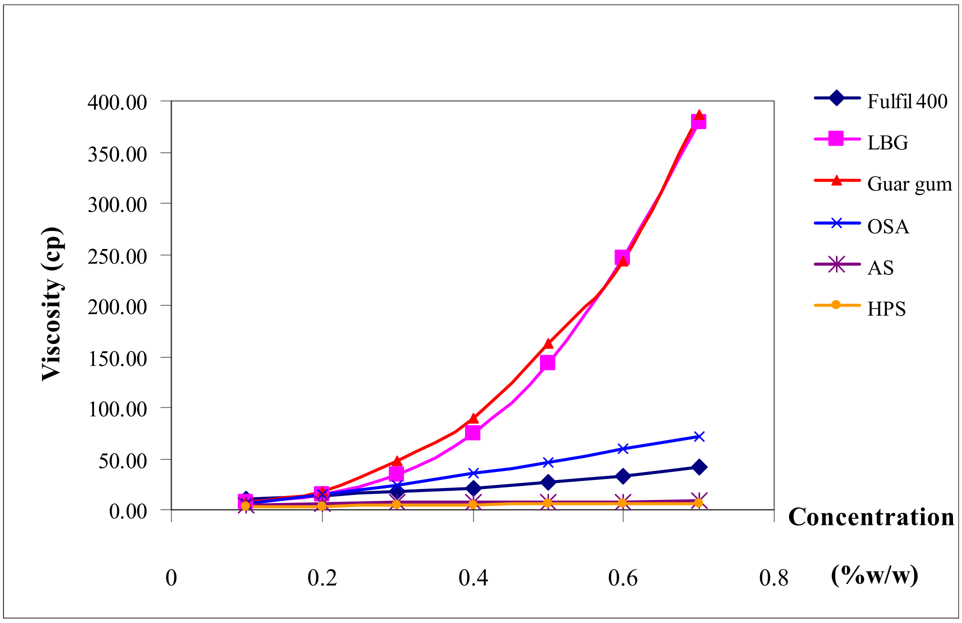

Fig. 1. Viscosities of solutions of commercial stabilizers and modified tapioca starches as a function of concentration.

Viscosities of ice cream mixes containing different commercial stabilizers or modified starches are shown in Table 1. This demonstrates that the viscosity of ice cream mixes before aging increased in the order of guar gum > LBG > AS > HPS, fulfil 400 > OSA, while after aging the viscosity of mixes increased in the order of LBG > guar gum > HPS, fulfil 400, AS > OSA. However, aging caused an increased viscosity of all ice cream mixes except the one containing guar gum. This may be due to an alteration of its conformation which was attributed to self association of guar gum and phase separation between guar gum and milk proteins (Bourriot *et al.*, 1999). These could cause a less free volume of gyration of guar gum in aqueous solution, resulting in a lower viscosity after aging process. In addition, after the mix aging, the system containing guar gum showed less fat partial coalescence, detected by TEM (Fig. 2), compared to the systems with other stabilizers or modified starches. The fat partial coalescence contributes to fat networks which can resist flow in a system, resulting in higher viscosity in the order of LBG > guar gum > HPS, fulfil 400, AS > OSA.

However, after aging, the ice cream mix containing LBG showed the highest viscosity compared with other mixes. This may be due not only to a high level of fat partial coalescence (Fig. 2a) but also the synergistic effect between LBG and κ-carrageenan which could enhance the resistance to flow (Chen *et* al., 2001; Goncalves *et al.*, 1997; Spagnuolo *et al.*, 2005; Stading and Hermansson, 1993; Vega *et al.*, 2005; Williams and Langdon, 1996).

Table 1. Viscosities of ice cream mixes comprising different stabilizers or modified starches.

Stabilizers/ Modified starch	Viscosity (cp)	
	before aging[1]	After aging[1]
Fulfil400[2]	41.17±1.13 [D, b]	43.00±0.91 [CD, a]
LBG	90.33±1.19 [B, b]	112.06±8.30 [A, a]
Guar gum	97.11±0.83 [A, a]	92.72±1.16 [B, b]
OSA	34.33±0.76 [E, b]	42.22±0.49 [D, a]
AS	43.89±1.47 [C, b]	46.78±1.47 [C, a]
HPS	39.95±1.29 [D, b]	42.56±1.41 [CD, a]

Note : [1)] within columns, values (mean ± standard deviation) followed by the same capital letter do not differ significantly from each other ($p > 0.05$)
[2)] within rows, values (mean ± standard deviation) followed by the same small letter do not differ significantly from each other ($p > 0.05$)

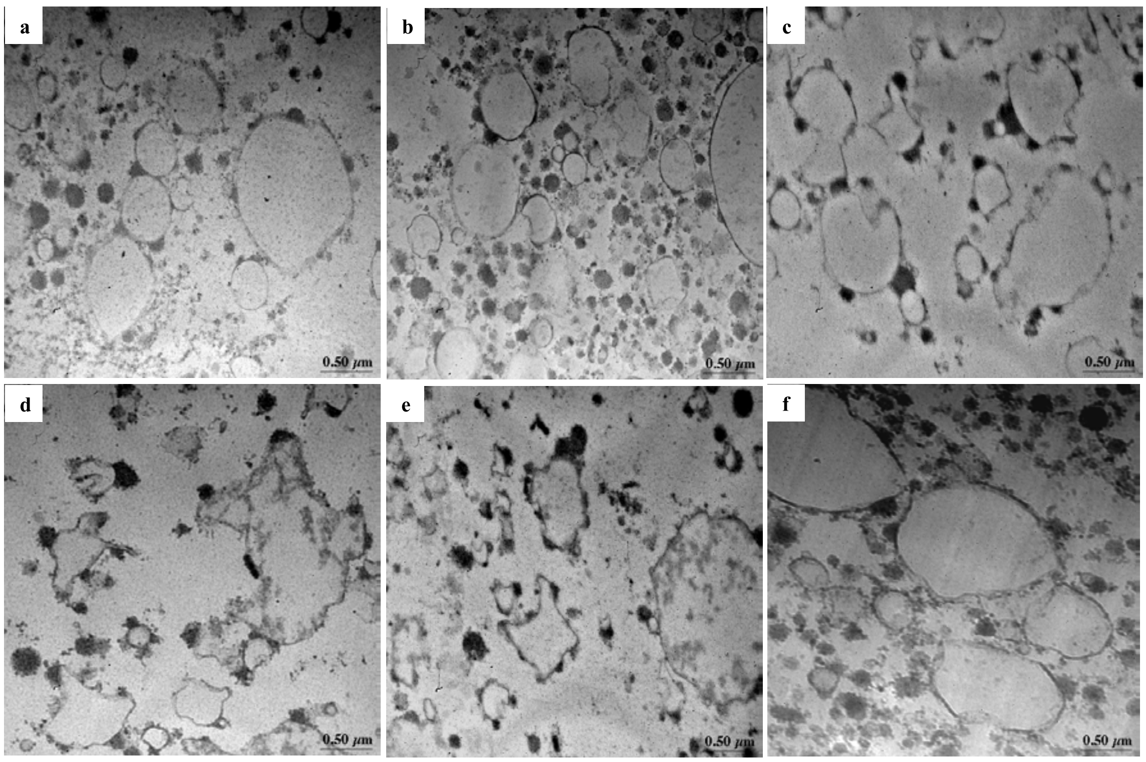

Fig. 2. Microstructure of ice cream mixes containing: (a) LBG, (b) guar gum, (c) Fulfil 400, (d) OSA, (e) AS and (f) HPS. Casein micelles are C and fat particles are F.

A far greater difference in viscosities before and after aging of ice cream mix containing OSA was evident (Table 1). This might be because OSA has a higher emulsifying property which induces more fat partial coalescence by competing with milk proteins to adsorb at the interface between fat globule surface and serum or aqueous phase over increasing time. During competition between OSA and milk proteins, surfaces of fat globules are free from any adsorbed particles. This can induce the occurrence of partial coalescence by closed fat globules (Fig. 2d). This phenomenon was not as evident in ice cream mixes comprising AS or HPS (Fig. 2e or f, respectively), consequently the difference in viscosities before and after aging of these mixes was less than OSA. This may be due to the lack of emulsifying properties in HPS and AS.

Interestingly, the shape and distribution of fat globules in ice cream mixes comprised LBG or guar gum seemed to be rounded and quite uniform compared with the others (Fig. 2). This might be due to the effect of higher viscosity of LBG or guar gum which were absent in the systems containing Fulfil 400 or modified tapioca starches.

Foam stability of ice cream mixes

The stability of whipped foams in ice cream mixes were determined. The results showed that foams of ice cream mixes comprising LBG or guar gum were the most stable, while foams of the mixes containing other stabilizers or modified starches rapidly decreased in the duration time from 0 to 90 min (Fig. 3). It is suggested that the viscosity of LBG or guar gum contributed to these results. The higher the viscosity of the mixes, the more stability of foams, since air bubbles in the mixes were limited in their movement. This resulted in less air bubbles combining, called Ostwald repining, and less foam collapse.

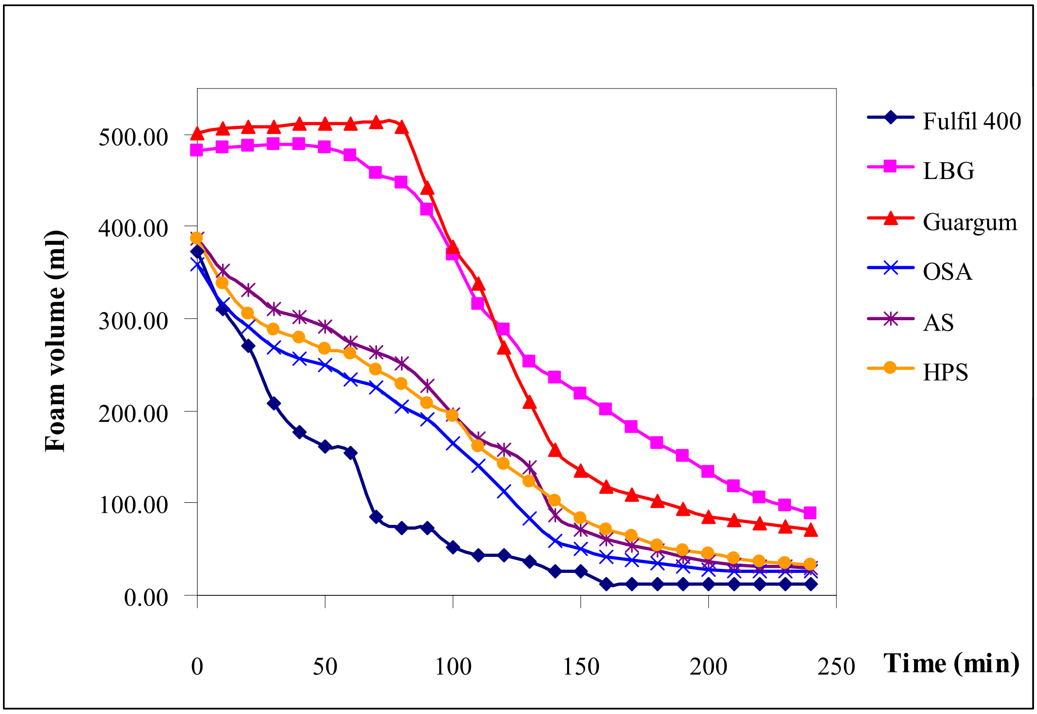

Fig. 3. Foam stability of ice cream mixes containing different stabilizers or modified tapioca starches.

Foam stabilities of ice cream mixes with different modified tapioca starches were not significantly different (p>0.05) (Fig. 3) but significantly less than the ones with LBG or guar gum (p<0.05). The effect of viscosity contributed to this result. Ice cream mixes containing these starches had a lower viscosity which might not hold air bubbles as constantly as the mixes containing LBG or guar gum, resulting in more air bubble movement and collision. Interestingly, foams of ice cream mix containing Fulfil 400 seemed to be the least stable even though this sample exhibited higher viscosity after aging than the modified starch samples. The reason for this is not known as yet, however, the foam stability of all ice cream mixes decreased with increasing time of observation.

Overrun of ice cream

Overruns of ice cream containing commercial stabilizers or modified tapioca starches were not significantly different (p>0.05), except the overrun of ice cream comprising AS which showed the least overrun (Table 2). This meant that the type of stabilizer or modified starch did not affect the overrun of ice cream except AS. This may be because the whipping force, applied to the mix during freezing and aeration process in the ice cream freezer, was strong enough to break and distribute air bubbles into the same shape and size in all ice cream mixes except the mix comprising AS. The bubbles in these mixes were immediately trapped in unfrozen serum phase by crystallized fat partial coalescence and fixed by ice crystals (Goff, 1997). However, the air bubbles of ice cream containing AS might experience less trapping and fixing than by those previously mentioned. Consequently, the overrun of ice cream comprising AS was lower than the others. This demonstrated that HPS and OSA are not different from commercial stabilizers for the ice cream overrun, while AS is.

Table 2. Overrun of ice cream mixes comprising different stabilizers or modified starches.

Stabilizers	Overrun (%)[1]
Fulfil400	45.08 ± 6.00^{A}
Guar	42.31 ± 2.66^{A}
LBG	45.91 ± 3.42^{A}
OSA	42.98 ± 1.46^{A}
AS	36.94 ± 0.05^{B}
HPS	46.18 ± 1.52^{A}

Note : [1)] within columns, values (mean ± standard deviation) followed by the same letter do not differ significantly from each other (p > 0.05).

Conclusions

Commercial stabilizers, i.e. LBG or guar gum provided a higher viscosity in both solution and ice cream mix when compared with Fulfil 400 and modified starches. This is due to a higher free volume of gyration which was found in LBG or guar gum than Fulfil 400 and modified starches. The higher the viscosity of ice cream mixes, the higher the foam stability. The retardation of the air bubble movement in ice cream mixes, affected by higher viscosity, contributed to higher foam stability. In whipped ice cream mixes, modified tapioca starches did not stabilize foam as well as LBG and guar gum. Modified tapioca starches such as OSA and HPS showed no significant difference to LBG and guar gum ($p>0.05$) in the overrun. This research provides further evidence that modified tapioca starches, i.e. OSA and HPS, have potential application in ice cream production.

Acknowledgments

Financial support for this research from the National Center for Genetic Engineering and Biotechnology (BIOTEC) Thailand is gratefully acknowledged. The authors would also like to thank the Center for Scientific and Technological Equipment, Suranaree University of Technology for the use of their laboratory facilities and Sanguanwong Co., Nakhon Ratchasima, Thailand for providing the modified tapioca starches.

References

1. Baez, R., Sanchez, C. C., Piilosof, A. M. R. and Patina Rodriguez, J. M. (2005). Interac-tions of polysaccharides wih b-lactoglobulin absorbed films at the air-water interface. Food Hydrocolloids. 19: 239-248.

2. Bao, J., Xing, J. Phillips, D. L. and Corke, H. (2003). Physical properties of octenyl succinic anhydride modified rice, wheat, and potato starches. Journal of Agricultural and Food Chemistry. 51: 2238-2287.

3. BeMiller, J. N. and Whistler, R. L. (1996). Charbohydrates. In: Food Chemistry. Fennema, O. R. (ed.). 3rd Ed., Marcel Dekker Inc. NY, p. 157-223.

4. Berger, K. G. (1997). Ice cream. In: Food Emulsions. Friberg, S. E. and Larsson, K. (eds.). 3rd Ed., Marcel Dekker, NY, p. 413-490.

5. Bourriot, S., Garnier, C. and Doublier, J. L. (1999). Phase separation rheology and structure of micellar casein-galactomannan mixtures. International Dairy Journal. 9: 353-357.

6. Camacho, M. M., Martinez-Navarrate, N. and Chiralt, A. (1998). Influence of locust bean gum/ λ-carrageenan mixtures on whipping and mechanical properties and stability of dairy cream. Food Research International. 31: 887-894.

7. Camacho, M. M., Martinez-Navarrate, N. and Chiralt, A. (2001). Stability of whipped dairy cream containing of locust bean gum/ λ-carrageenan mixtures during freezing-thawing process. Food Research International. 34: 653-658.

8. Chang, Y. and Hartel, R. W. (2002a). Stability of air cells in ice cream during hardening and storage. Journal of Food Engineering. 55: 59-70.

9. Chang, Y. and Hartel, R. W. (2002b). Development of air cells in a batch ice cream freezer. Journal of Food Engineering. 55: 71-78.

10. Chen, Y., Liao, M.-L., Boger, D. V. and Dunstan, D. E. (2001). Rheological characterization of κ-carrageenan/locust bean gum mixtures. Carbohydrate Polymers. 46: 117-124.

11. Dutta A.; Chengara A.; Nikolov A.D.; Wasan D.T.[1]; Chen K.; Campbell B. (2004). Destabilization of aerated food products: effects of Ostwald ripening and gas diffusion. Journal of Food Engineering. 62: 177-184.

12. Glicksman, M. (1982). Functional properties of hydrocolloids. In: Food Hydrocolloids. Glicksman M. (ed.). Vol.1, CRC Press, Boca Raton, FL, p. 47-99.

13. Goff, H. D. (1997). Colloidal aspects of ice cream - a review. International Dairy Journal. 7: 363-373.

14. Goff, H. D. (2002). Formation and stabilization of structure in ice cream and related products. Current Opinion in Colloid and Interface Science. 7: 432-437.

15. Goncalves, M. P., Gomaens, C., Langdon, M. J., Viebke, C. and Williams, P. A. (1997). Studies on κ-carrageenan/ locust bean gum mixures in the presence of sodium chloride and sodium iodide. Biopolymers. 41: 657-671.

16. Klitzing, R. V. and Muller, H. J. (2002). Film stability control. Current Opinion in Colloids and Interface Science. 7: 42-49.

17. Marshell, R. T., Goff, H. D. and Hartel, R. W. (2003). Ice cream. 6th ed. Kluwer Academic/ Plenum Publishers. New York. p. 34-36, 80-84.

18. Raina, C. S., Singh, S., Bawa, A. S. and Saxena, D. C. (2006). Some characteristics of acetyled, cross-linked and dual modified Indian rice starches, European Food Research Technology. 223: 561-570.

19. Schmitz, C. S., de Simas, K. N., Santos, K., Joao, J. J., de Mello Castanho Amboni, R. D. and Amante, E. R. (2006). Cassava starch functional properties by etherification-hydroxypropylation. International Journal of Food Science and Technology. 41: 681-687.

20. Segall, K. I. and Goff, H. D. (1999). Influence of adsorbed milk protein type and surface concentration on the quiescent and shear stability of butteroil emulsions. International Dairy Journal. 9: 683-691.

21. Smith, A. K., Goff, H. D. and Kakuda, Y. (2000). Microstructure and rheological properties of whipped cream as affected by heat treatment and addition of

stabilizer. International Dairy Journal. 10: 295-301.

22. Sofjan, R.P. and Hartel, R.W. (2004). Effects of overrun on structural and physical characteristics of ice cream. International Dairy Journal. 14: 255-262.

23. Spagnuolo, P.A., Dalgleish, D.G., Goff, H.D. and Morris, E.R. (2005). Kappa-carrageenan interactions in systems containing casein micelles and polysaccharide stabilizers. Food Hydrocolloids. 19: 371-377.

24. Stading, M. and Hermansson, A.M. (1993). Rheological behaviour of mixed gels of κ- carrageenan-locust bean gum. Carbohydrate Polymers. 22: 49-56.

25. Thaiudom, S. and Goff, H.D. (2003). Effect of κ-carrageenan on milk protein polysaccharide mixtures. International Dairy Journal. 13: 763-771.

26. Trubiano, P.C. (1995). The role of specialty food starches in flavor emulsions. In Flavor Technology: Physical Chemistry, Modification, and Processing. American Chemical Society, Washington DC. P. 199-209.

27. Vega, C., Dalgleish, D. G. and Goff, H. D. (2005). Effect of κ-carrageenan addition to dairy emulsions containing sodium caseinate and locust bean gum. Food Hydrocolloids. 19: 187-195.

28. Viswanathan, A. (1999). Effect of degree of substitution of octenyl succinate starch on the emulsification activity on different oil phases. Journal of Environmental Polymer Degradation. 7: 191-196.

29. Williams, P.A. and Langdon, M.J. (1996). The influence of locust bean gum and dextran on the gelation of κ-carrageenan. Biopolymers. 38: 655-664.

30. Wu, Y. and Seib, P.A. (1990). Acetylated and hydroxypropylated distarch phosphates from waxy barley: paste properties and freeze-thaw stability. Cereal Chemistry. 67: 202-208.