國立臺灣海洋大學食品科學系碩士班
專題討論書面報告

蛋白質與多醣類對冰淇淋乳化安定性之影響

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摘要

本篇探討冰淇淋之乳化與安定特性。用單一蛋白質與蛋白質混合物配製冰淇淋，使總蛋白濃度達 4-10％。蛋白質來源、混合物或濃度對冰晶和氣室平均大小以及膨脹率沒有顯著影響。融化速率隨蛋白質含量的增加而增加，融化速率在所有的蛋白質濃度下均導致快速的融化。蛋白質種類、混合物和濃度會影響乳化界面特性導致脂肪部分聚集和融化速率不同。多醣類（PS）作穩定劑以改善結構和質地，但多醣類會與蛋白質交互作用導致乳化不安定。蛋白質和兩種膠〔羧甲基纖維素（CMC）和關華豆膠（GG）〕之間相互作用對由 11％脫脂奶粉（SMP）和 10％椰子油組成的冰淇淋模型的穩定性的影響；取決於多醣類的種類和濃度。SMP / GG 混合乳化與具有相同比例 SMP / CMC 混合模型相比乳化率更高，SMP / CMC 混合模型中相分離的臨界含量以下的較低乳化率與牛奶蛋白和 CMC 之間的吸引力交互作用以及視黏度提高有關。用混合物設計方法研究兩種穩定劑在兩種濃度下的不同混合物。混合物中高比例的羅勒籽膠會增加冰淇淋混合物的視黏度並降低其融化速率，添加 0.15％的多醣類時以 84.43％羅勒籽膠(BSG)和 15.57％關華豆膠(GG) 為最佳比例。綜合上述，增加蛋白質含量對冰淇淋理化性質不安定可添加 0.15％多醣類(BSG84.43％和 GG15.57％)改良。

一、 前言

製作冰淇淋多以乳製品及乳化及安定劑等成分製成，其中中蛋白質含量對結構產生深遠影響，特別是在冷凍過程中形成部分凝聚的脂肪(Segall & Goff, 1999)。酪蛋白膠束與冰淇淋混合物中一些常用的多醣類安定劑會有熱力學不穩定性（Spagnuolo *et al.*, 2005）。冰淇淋安定劑中關華豆膠（GG）、刺槐豆膠（LBG）、羧甲基纖維素鈉（CMC）、三仙膠和鹿角菜膠是最常見的，此外一些地方性非商業性膠也已被證明可以用作冰淇淋安定劑(BahramParvar & Mazaheri, 2011)。

二、 單一蛋白質來源或混合物對冰淇淋的微觀結構和融化速率的影響

Daw and Hartel. (2015)研究單一蛋白質源和蛋白質混合物配製的冰淇淋測量各種反應，包括陳化冰淇淋混合物的黏度、平均冰晶和氣泡尺寸、部分聚集程度和融化速率。雙因子變異數分析顯示蛋白質來源和類型之間的相互作用會顯著影響一致性係數（P <0.0001），而杜凱確實差異測試顯示出各個數據點之間的統計差異。冰淇淋混合物中蛋白質含量的增加，稠度係數增加，但用乳清分離蛋白製成的冰淇淋混合物除外。蛋白質來源與含量之間的交互作用對流動行為指數具有顯著影響（P <0.0001），而杜凱確實差異測試顯示這些值之間存在顯著差異。冰淇淋混合物的稠度係數之間存在統計學差異。蛋白質來源和蛋白質濃度之間的相互作用對平均冰晶尺寸影響較小（P =0.0026）。隨著蛋白質含量的增加，平均冰晶尺寸也會增加。用 10％的奶油製成的冰淇淋具有最大的冰晶，而用乳清分離蛋白製成的冰淇淋通常具有最小的冰晶。對照冰淇淋僅含 4％蛋白質的脫脂奶粉平均冰晶尺寸最小，與所有製得的冰淇淋的所有其他平均冰晶尺寸相比有統計學差異（P <0.05）與蛋白質混合物。蛋白質來源和濃度之間的相互作用對不同冰淇淋的平均氣泡尺寸沒有顯著統計學影響（P = 0.1638）。僅含 4％蛋白質的脫脂奶粉的對照冰淇淋的平均氣泡尺寸最小。蛋白質來源和蛋白質濃度之間的相互作用對膨脹率沒有顯著影響（P = 0.6666）。膨脹率範圍從 32.0％到 45.5％。通過單因

子變異數分析（P = 0.0109）和杜凱確實差異檢定分析得出的膨脹率沒有顯著差異，範圍為 27.3 至 38.6%。蛋白質來源和濃度之間的相互作用非常顯著（P = 0.0021），各種冰淇淋配方與部分聚結的脂肪量之間存在差異。用脫脂奶粉和乳清分離蛋白製成的冰淇淋在所有蛋白質濃度上的脂肪不穩定化程度均明顯高於用牛奶濃縮蛋白和 procream 製成的冰淇淋。隨著蛋白質含量的增加，用牛奶濃縮蛋白、乳清分離蛋白和 procream 製成的冰淇淋的部分聚結脂肪的數量減少。在脫脂奶粉對照冰淇淋中添加前乳脂和乳清分離蛋白均會部分降低脂肪含量。在含有 4%脫脂奶粉蛋白質的對照配方中發現的部分聚結脂肪（39.4%）的量與在所有蛋白質濃度下用蛋白質混合物製成的冰淇淋在統計學上不同（P <0.005）。不同蛋白質來源和濃度的融化速率之間的統計差異。一致的是用 procream 製成的冰淇淋在所有濃度下的融化率最高，範圍從 1.55 至 1.62 g min^{-1}，兩者均無統計學差異（P> 0.05）。用脫脂奶粉中 4%的蛋白質製成的對照配方的熔解速度最慢（0.32 g min-1），而所有其他樣品的熔解速度都更快。用蛋白質混合物製成的所有冰淇淋都在約 80 分鐘內非常迅速且完全融化。融化速率與部分聚集的脂肪的程度具有很好的相關性。

三、 牛奶蛋白質-多醣類的交互作用對冰淇淋混合模型系統之穩定性的影響

Cheng *et al.* (2015)發現 CMC 在整個濃度範圍內都沒有表面/界面活性。在水中添加 SMP 顯著降低了空氣/水的表面張力和椰子油/水的界面張力，分別降至 49.17±0.10 mN / m 和 9.57±0.03 mN / m。脫脂奶粉(SMP)溶液的表面張力和界面張力受到 CMC 濃度的顯著影響（p <0.05）。隨著熔點的降低，塗有 SMP 的油滴顯示出逐漸降低的負界達電位值，最終在牛奶以下變為正值的等電點。加入 CMC 顯示出 pH 和濃度依賴於界達電位的影響。在整個 pH 範圍內存在 GG 搭配 SMP 時乳化界達電位，因此沒有明顯的交互作用。對於 SMP / CMC 冰淇淋混合模型乳液，CMC 濃度顯著影響表面蛋白濃度（p <0.05）。平均粒徑（D4,3）隨著 CMC

的增加而逐漸減小。共聚焦顯微照片還顯示，在不存在 CMC 的情況下，存在相對大量的大液滴。包含不同濃度的 CMC 的冰淇淋混合物乳化模型的微觀結構。在不存在或存在 0.05％（w / w）CMC 的情況下乳化是均勻的。在長時間範圍內的相分離行為以 4℃下 21 天後的未凍結體積分數為特徵，顯示沒有乳化現象。稠度指數取決於多醣濃度。在相同條件下，發現 SMP / CMC 混合系統的值高於 SMP / GG 系統。在 0.40％（w / w）的濃度下，CMC 水溶液的視黏度明顯低於 GG 溶液的視黏度。

四、應用單體重心混合設計最適化的穩定劑組合於冰淇淋的製造

BahramParvar *et al.* (2015)選擇二次模型來分析視黏度和融化速率數據，同時使用完全二次模型來分析擠出溫度和膨脹率。BSG 的增加的比例顯示出與視黏度的正相關關係。因此 BSG、CMC 和 GG 的組合可以提高它們的黏度。BSG 含量的增加使擠出溫度降低了 0.15％。相反地混合物中高比例的 CMC 會提高擠出溫度。膨脹率介於 30.60（多醣類濃度為 0.35％的 50％BSG 和 50％CMC 的樣品）和 65.22％（0.15％的 GG 樣品）之間。濃度為 0.15％時混合物中 BSG 和 GG 的比例增加，會增加樣品的膨脹率。融化速率值隨混合物中 CMC 和 GG 比例的增加而增加；相反地 BSG 降低了融化速率。具有較高黏度、膨脹率和融化速率以及較低擠出溫度的冰淇淋是優選的。最佳比例為多醣濃度為 0.15％時 84.43％BSG 和 15.57％GG。這個結果也能夠用 BSG 作為冰淇淋及相關產品產業的一個非常有效的安定劑，並且比市售的安定劑表現更好。視黏度、擠出溫度、膨脹率和融化速率的平均觀測值分別為 0.40±0.012 Pa.s，-5.65±0.212℃，62.38±3.246％和 0.57±0.007 g / min。發現預測反應和觀察反應之間沒有顯著差異（$P > 0.05$）。

五、 結論

1. 增加蛋白質含量會對冰淇淋的各種理化的特性造成不良影響，特別是與脂肪

不穩定化和融化速率有關。

2. 於混合物穩定劑系統中用 CMC 與牛奶蛋白相互作用並降低乳脂蛋白的作用。

3. 以 0.15%的多醣類濃度混合 84.43%羅勒籽膠和 15.57%關華豆膠為最佳配方。

六、Q & A

1.蛋白質應該可以增加黏度，為何增加蛋白質含量反而會對冰淇淋的各種理化的特性造成不良影響?

增加超過一定的量反而增加蛋白質間交互作用造成冰淇淋的各種理化特性的不良影響。

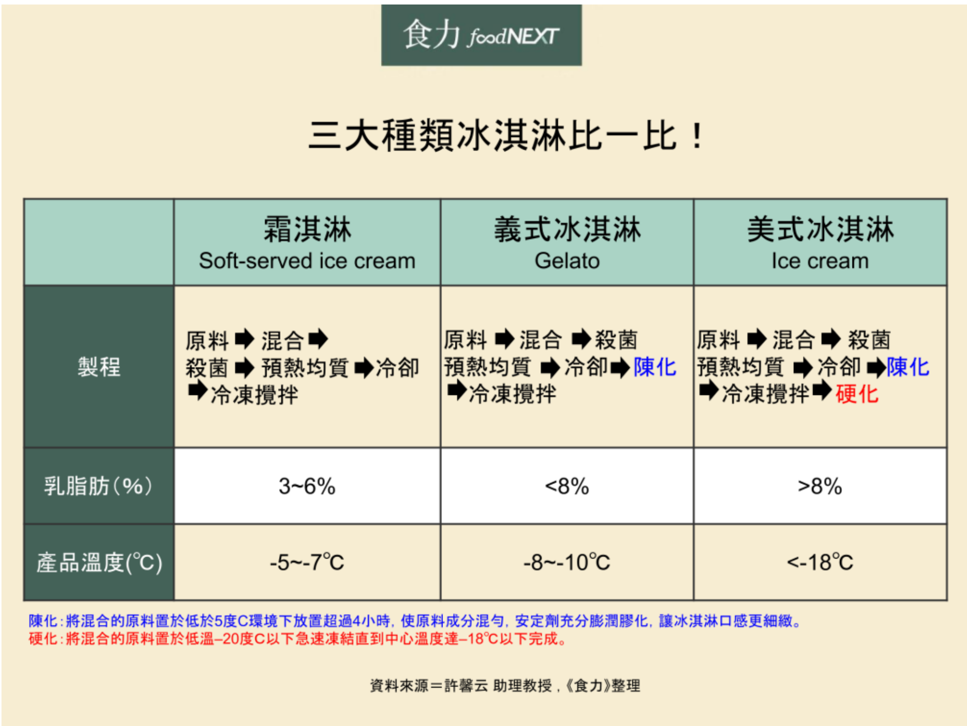
2.多醣類指的是?

膠體安定劑

七、 補充資料

1. 界達電位（zeta potential）在膠體化學中，是指膠體粒子上累積的離子所引發的靜電壓；膠體粒子由電雙層構成，包含固定層和擴散層。

2. 三種冰淇淋比較


食力 foodNEXT

三大種類冰淇淋比一比！

	霜淇淋 Soft-served ice cream	義式冰淇淋 Gelato	美式冰淇淋 Ice cream
製程	原料 ➡ 混合 ➡ 殺菌 ➡ 預熱均質 ➡冷卻 ➡冷凍攪拌	原料 ➡ 混合 ➡殺菌 預熱均質 ➡冷卻➡陳化 ➡冷凍攪拌	原料 ➡ 混合 ➡ 殺菌 預熱均質 ➡冷卻 ➡陳化 ➡冷凍攪拌➡硬化
乳脂肪(%)	3~6%	<8%	>8%
產品溫度(℃)	-5~-7℃	-8~-10℃	<-18℃

陳化：將混合的原料置於低於5度C環境下放置超過4小時，使原料成分混勻，安定劑充分膨潤膠化，讓冰淇淋口感更細緻。
硬化：將混合的原料置於低溫–20度C以下急速凍結直到中心溫度達–18℃以下完成。

資料來源＝許馨云 助理教授，《食力》整理

八、 參考文獻

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九、 圖表

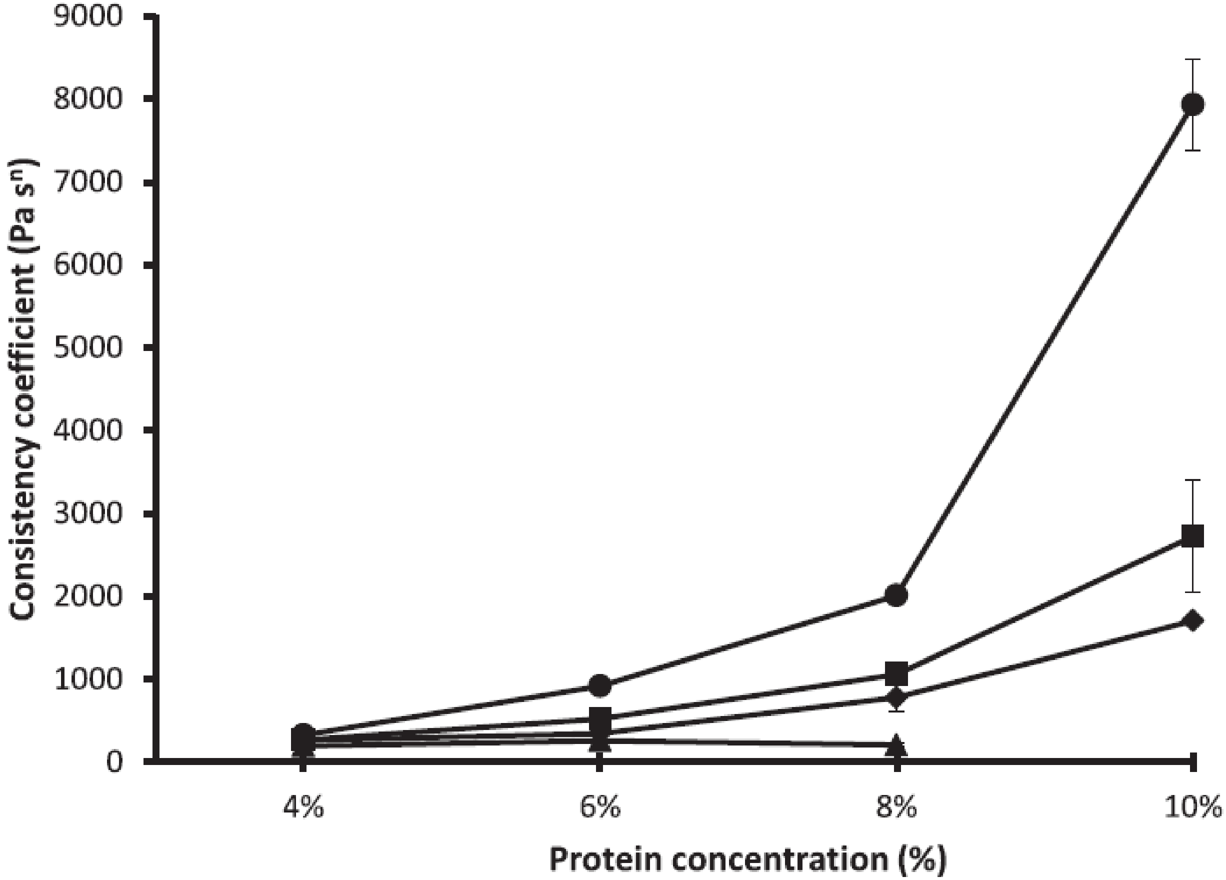


Fig. 1. Consistency coefficient of ice cream mixes as protein concentration increased: ■, nonfat dry milk; ◆, milk protein concentrate; ▲, whey protein isolate; ●, pro-cream. The error bars represent standard deviations between replicate measurements. (Daw and Hartel, 2015)

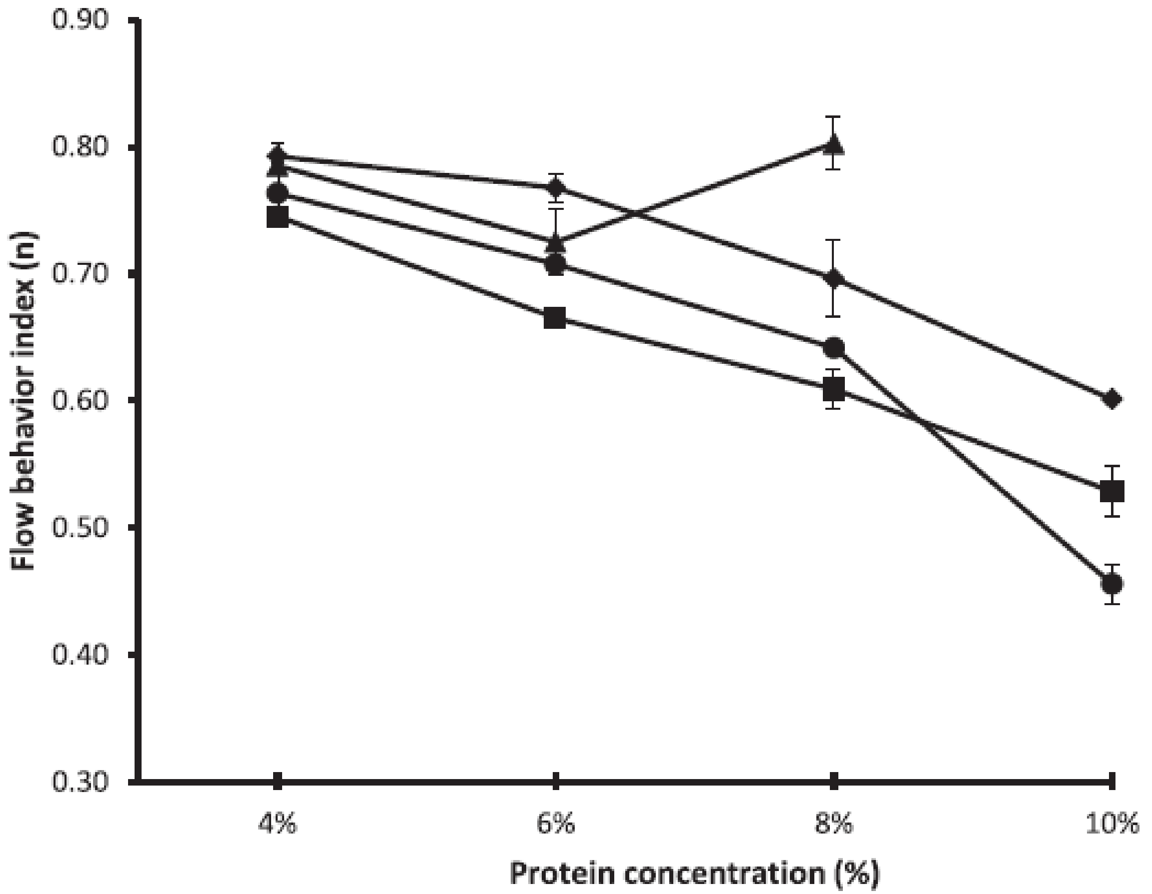


Fig. 2. Flow behavior index in ice cream mixes as protein concentration increased: ■, nonfat dry milk; ◆, milk protein concentrate; ▲, whey protein isolate; ●, procream. The error bars represent standard deviations between replicate measurements. (Daw and Hartel, 2015)

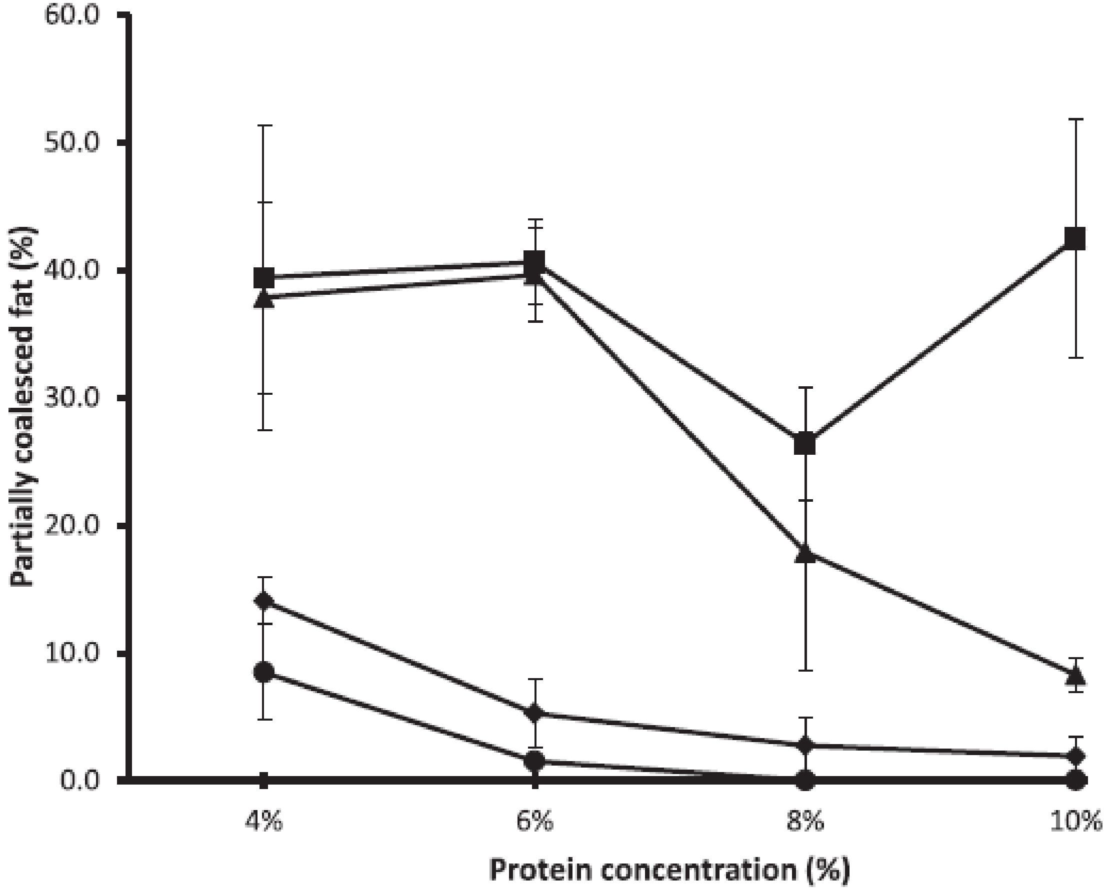


Fig. 3. Partial coalescence in ice cream mixes as protein concentration increased: ■, nonfat dry milk; ◆, milk protein concentrate; ▲, whey protein isolate; ●, procream. The error bars represent standard deviations between replicate measurements. (Daw and Hartel, 2015)

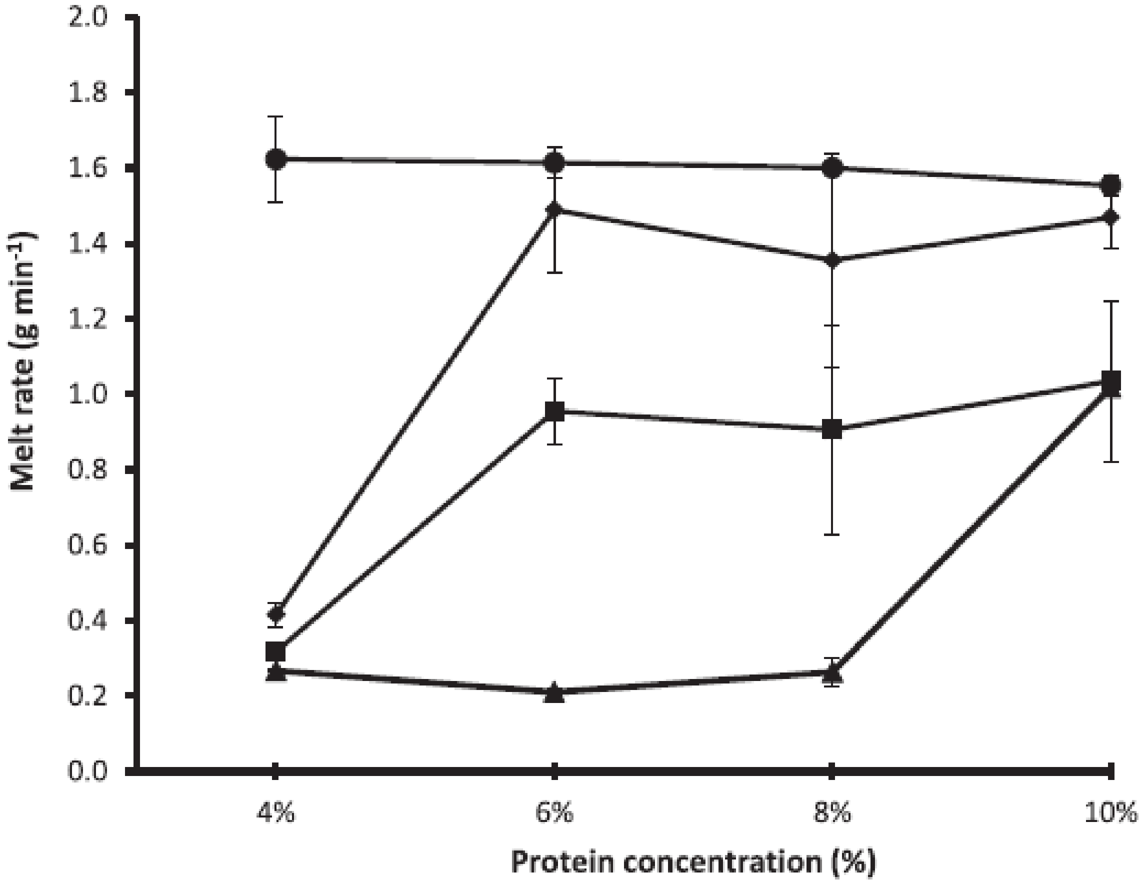


Fig. 4. Melt rate (g min-1624) of ice creams as protein concentration increased: ■, nonfat dry milk; ◆, milk protein concentrate; ▲, whey protein isolate; ●, procream. The error bars represent standard deviations between replicate measurements. (Daw and Hartel, 2015)

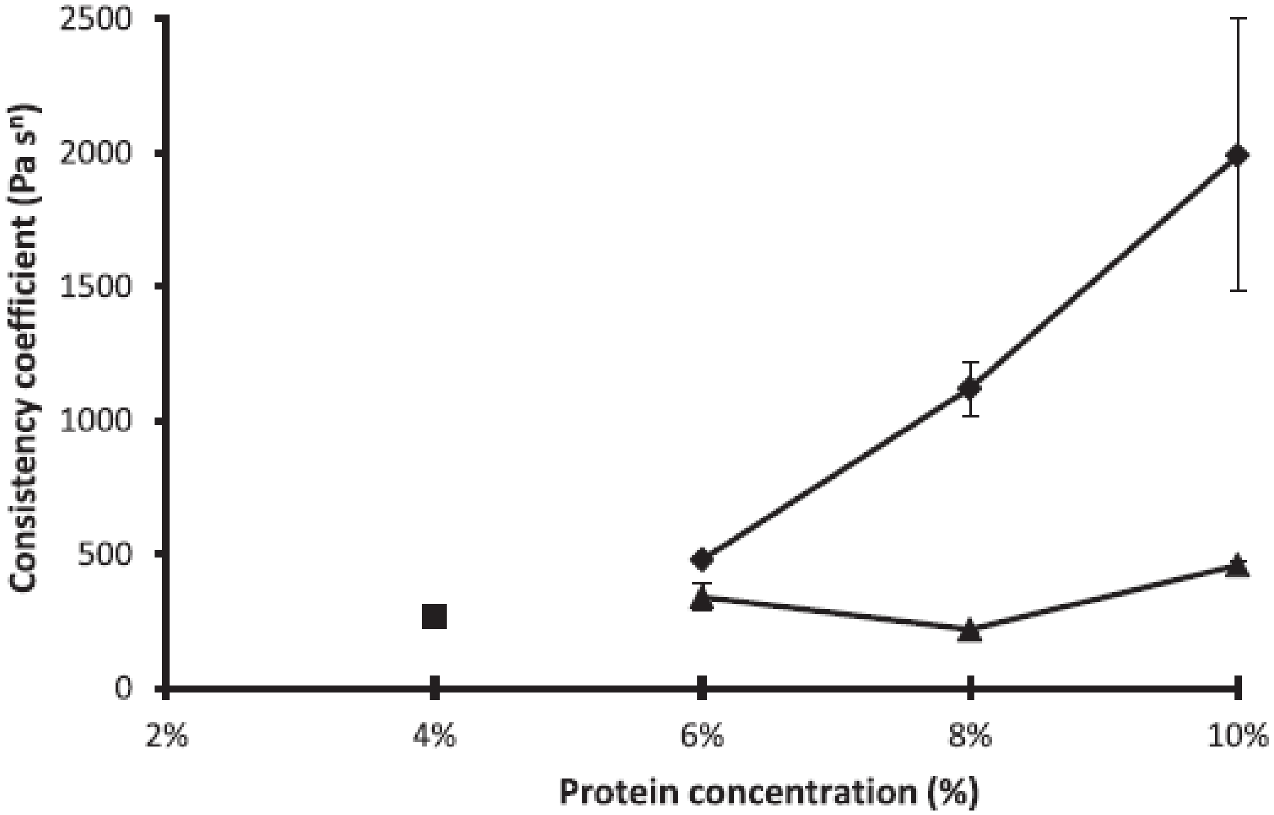


Fig. 5. Consistency coefficient of ice cream mixes made with protein blends as protein concentration increased: ■, nonfat dry milk 4%; ◆, nonfat dry milk and whey protein isolate; ▲, nonfat dry milk and procream. The error bars represent standard deviations between replicate measurements.

(Daw and Hartel, 2015)

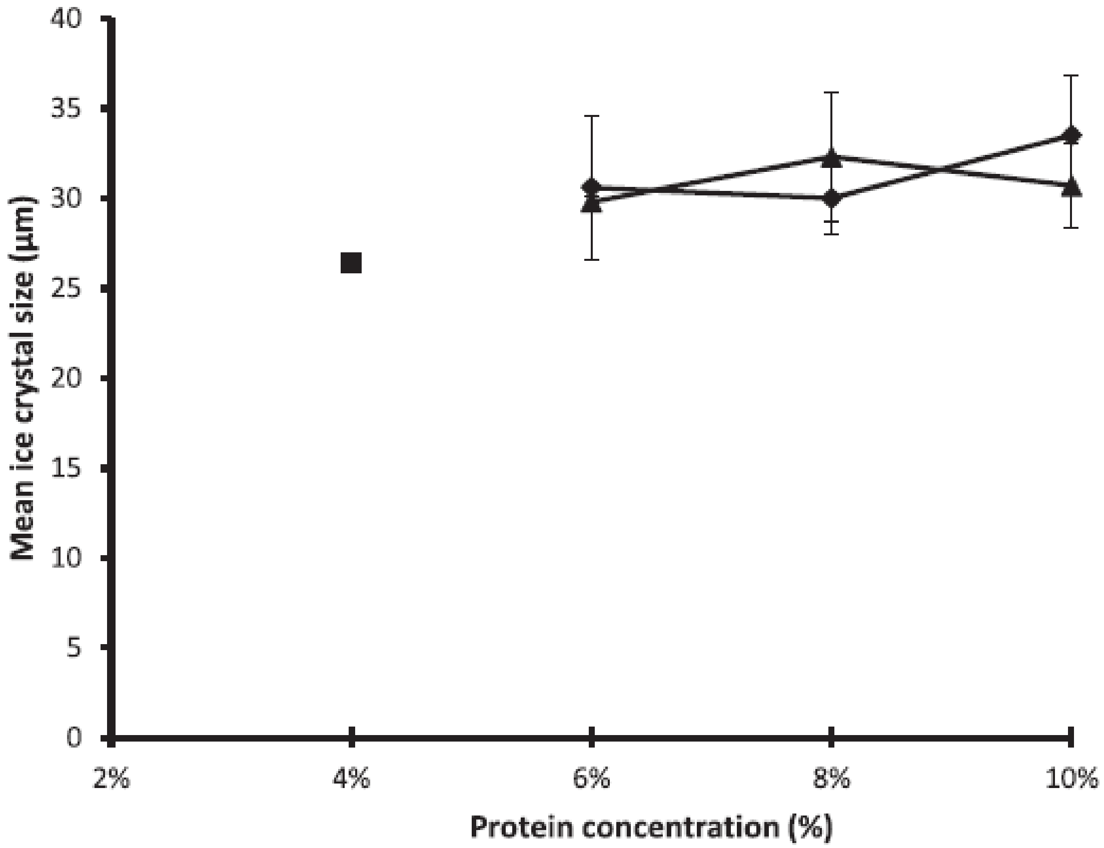


Fig. 6. Mean ice crystal size of ice cream mixes made with protein blends as protein concentration increased: ■, nonfat dry milk 4%; ◆, nonfat dry milk and whey protein isolate; ▲, nonfat dry milk and procream. The error bars represent standard deviations between replicate measurements.

(Daw and Hartel, 2015)

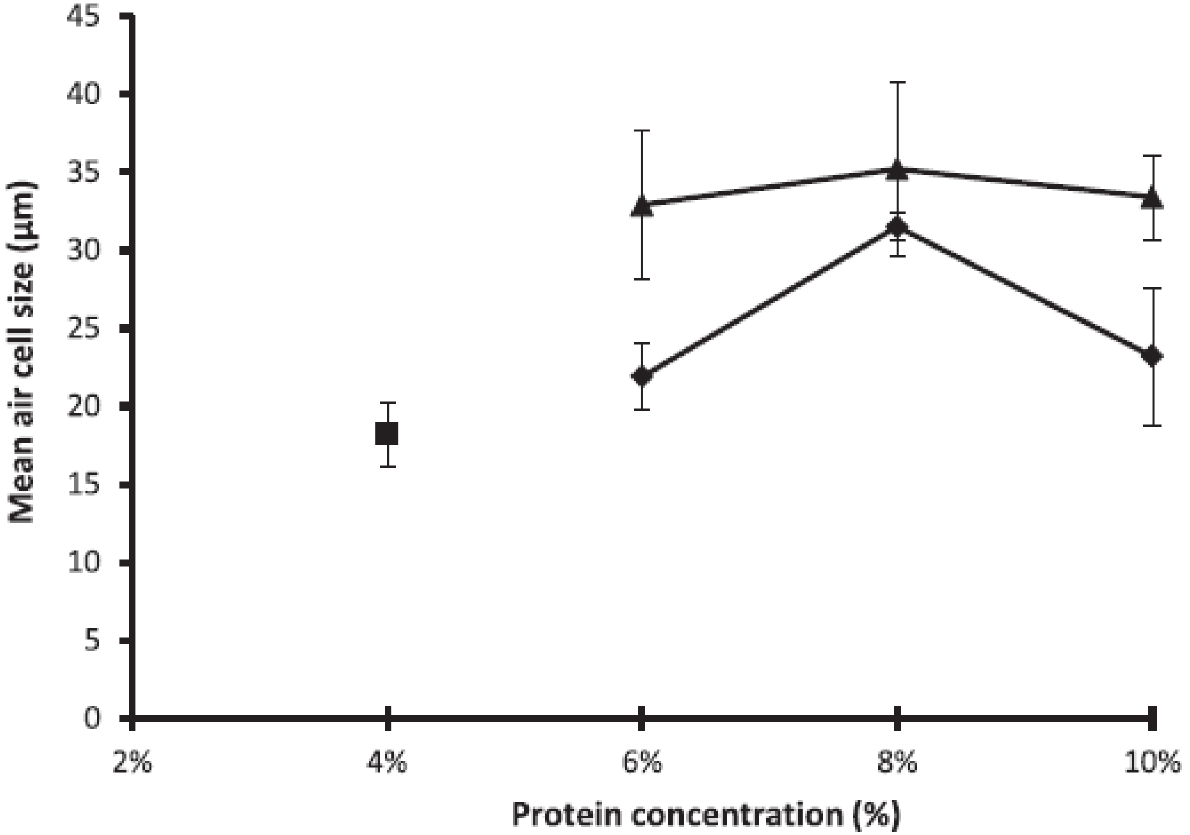


Fig. 7. Mean air cell size of ice cream mixes made with protein blends as protein concentration increased: ■, nonfat dry milk 4%; ◆, nonfat dry milk and whey protein isolate; ▲, nonfat dry milk and procream. The error bars represent standard deviations between replicate measurements. (Daw and Hartel, 2015)

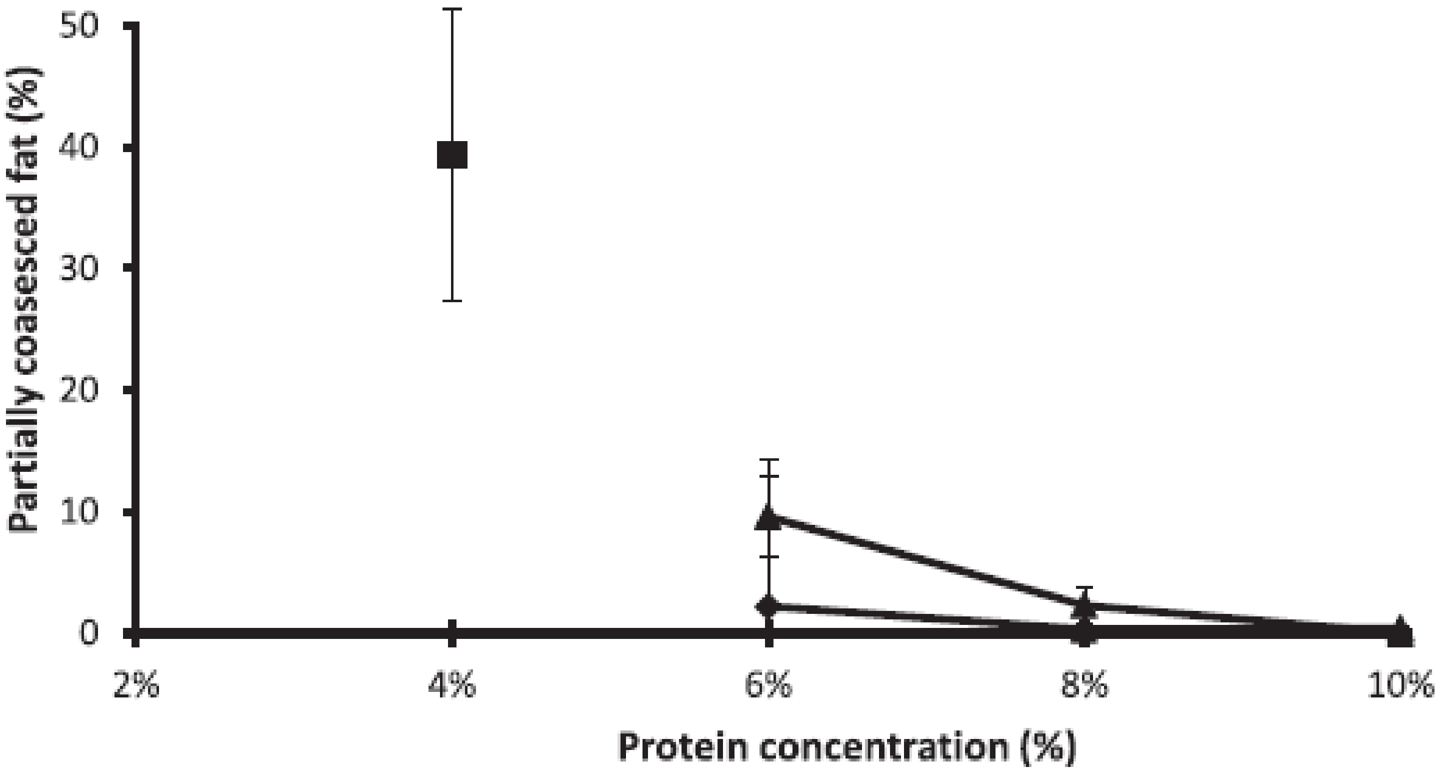


Fig. 8. Amount of partially coalesced fat of ice cream mixes made with protein blends as protein concentration increased: ■, nonfat dry milk 4%; ◆, nonfat dry milk and whey protein isolate; ▲, nonfat dry milk and procream. The error bars represent standard deviations between replicate measurements.

(Daw and Hartel, 2015)

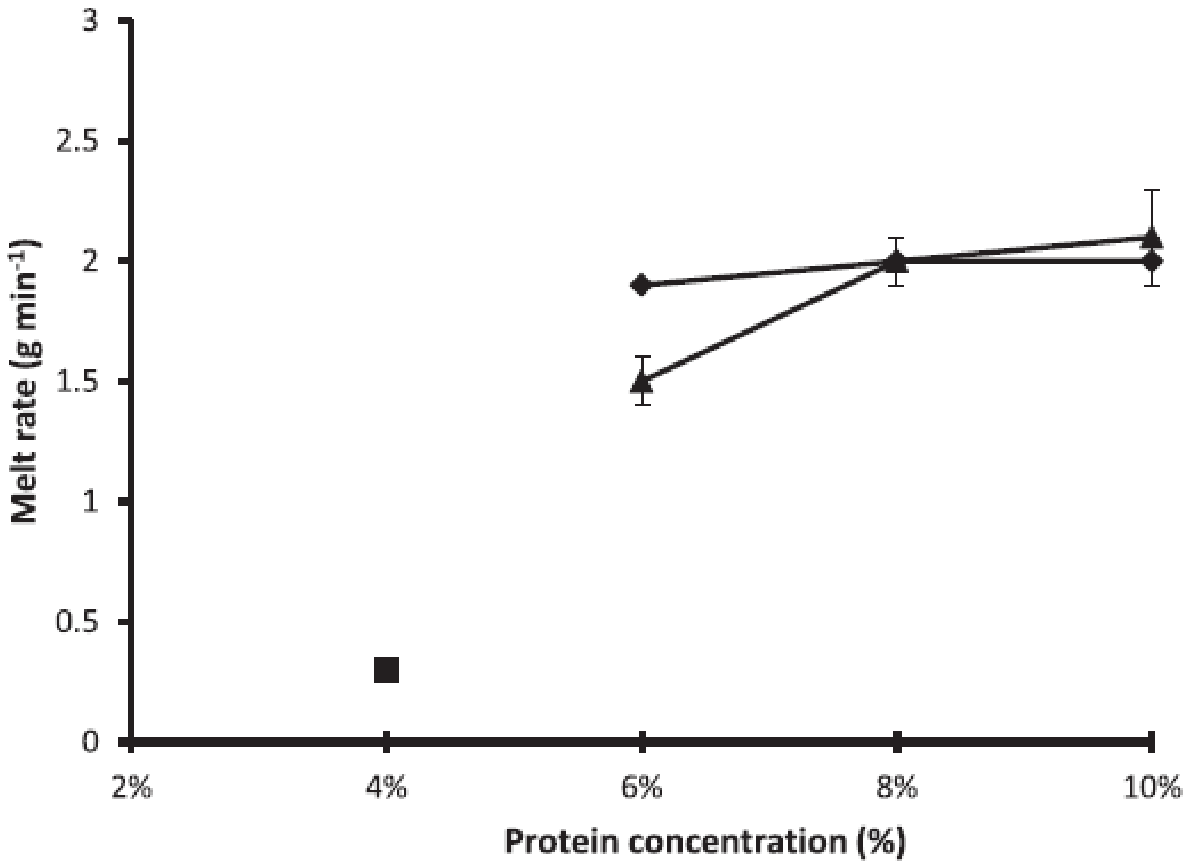


Fig. 9. Melt rate of ice cream mixes made with protein blends as protein concentration increased: ■, nonfat dry milk 4%; ◆, nonfat dry milk and whey protein isolate; ▲, nonfat dry milk and procream.

(Daw and Hartel, 2015)

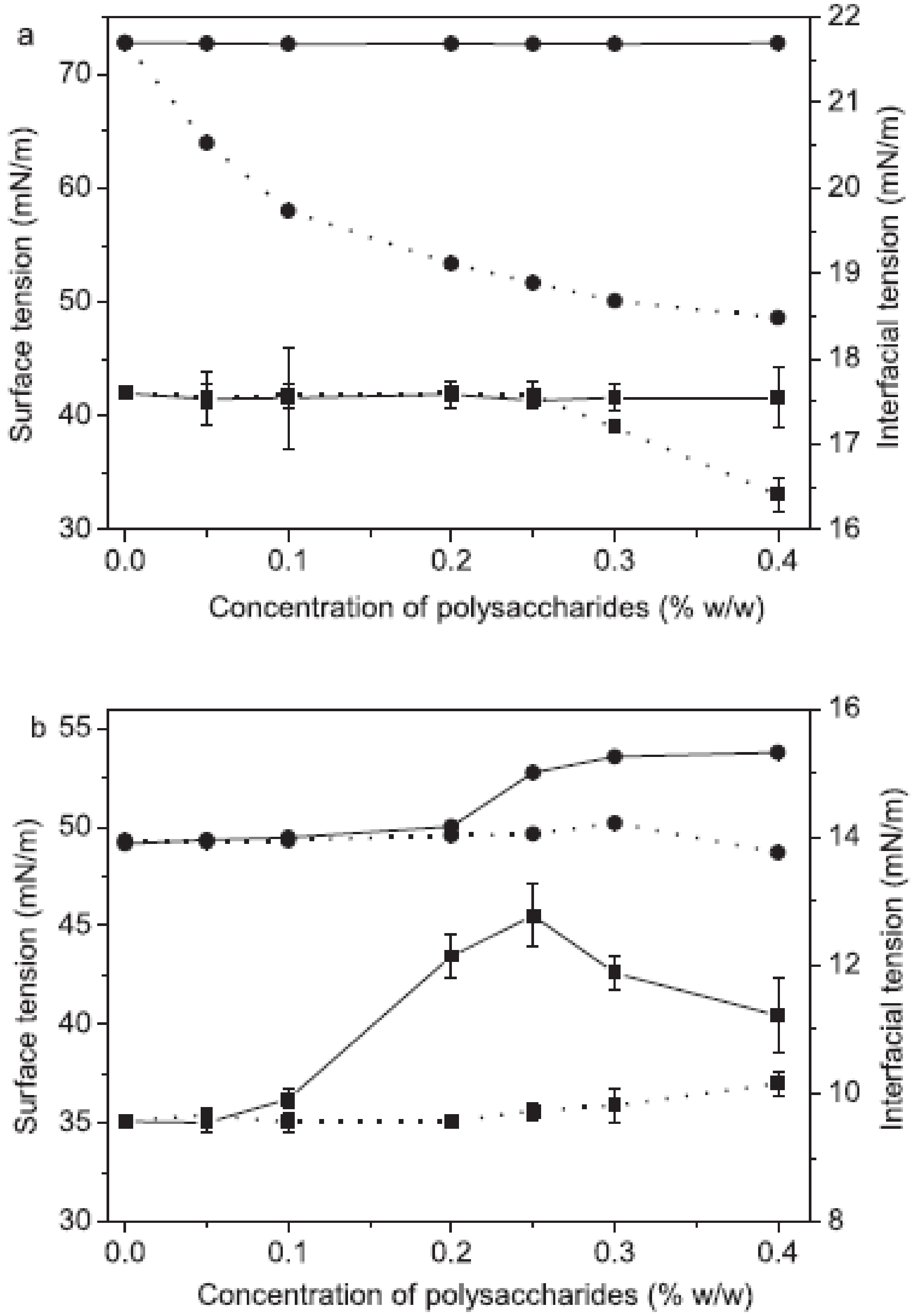


Fig. 10. Effect of CMC (—) and GG (·····) concentrations on the surface tension of PS solutions/air (●) and interfacial tension of PS solutions/coconut oil interfaces (■) in the absence (a) and presence (b) of SMP.

(Cheng *et al.*, 2015)

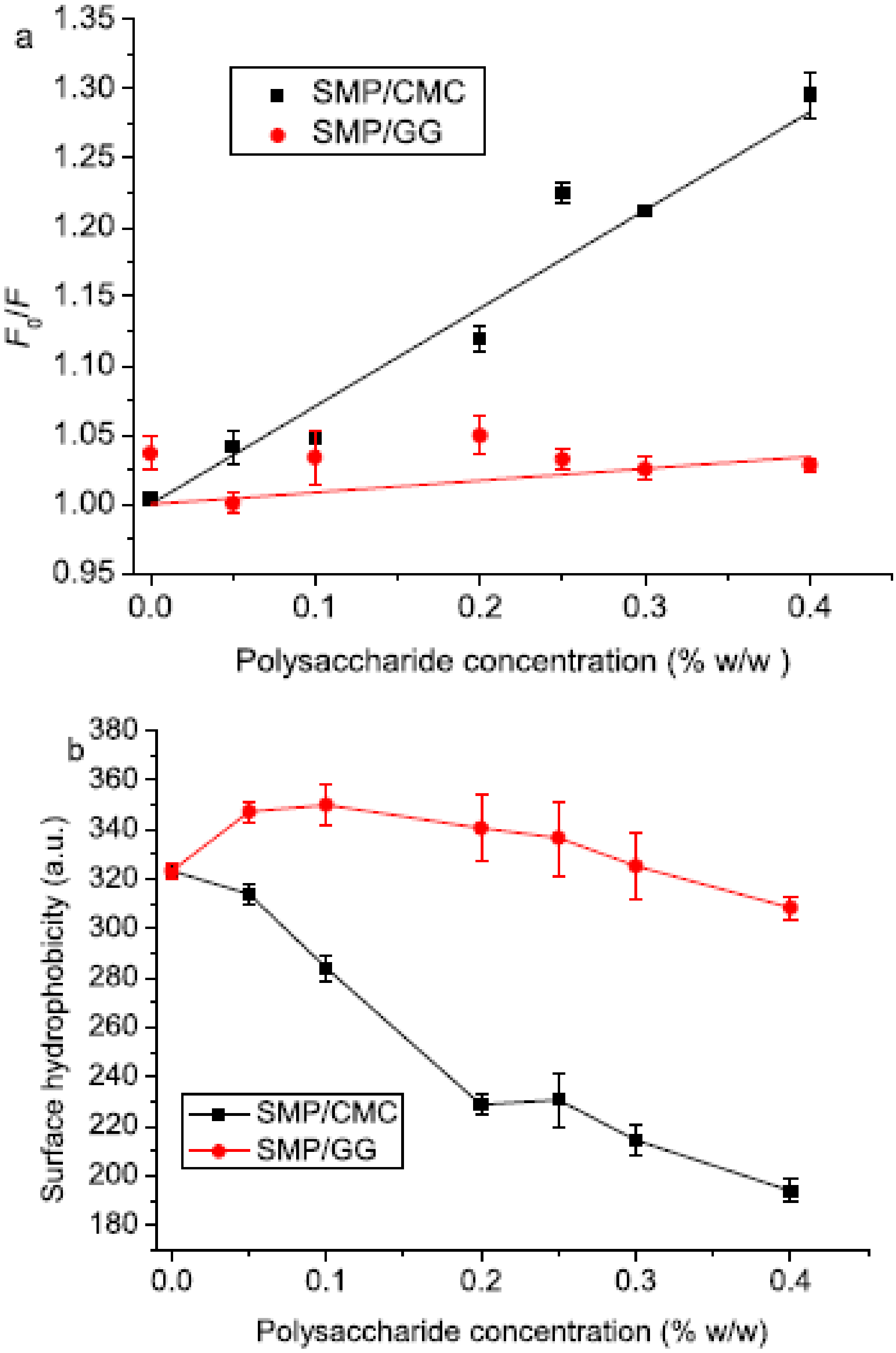


Fig. 11. Stern–volmer plots for SMP/PS systems (a); Effect of PS concentration on the protein surface hydrophobicity (b).

(Cheng *et al.*, 2015)

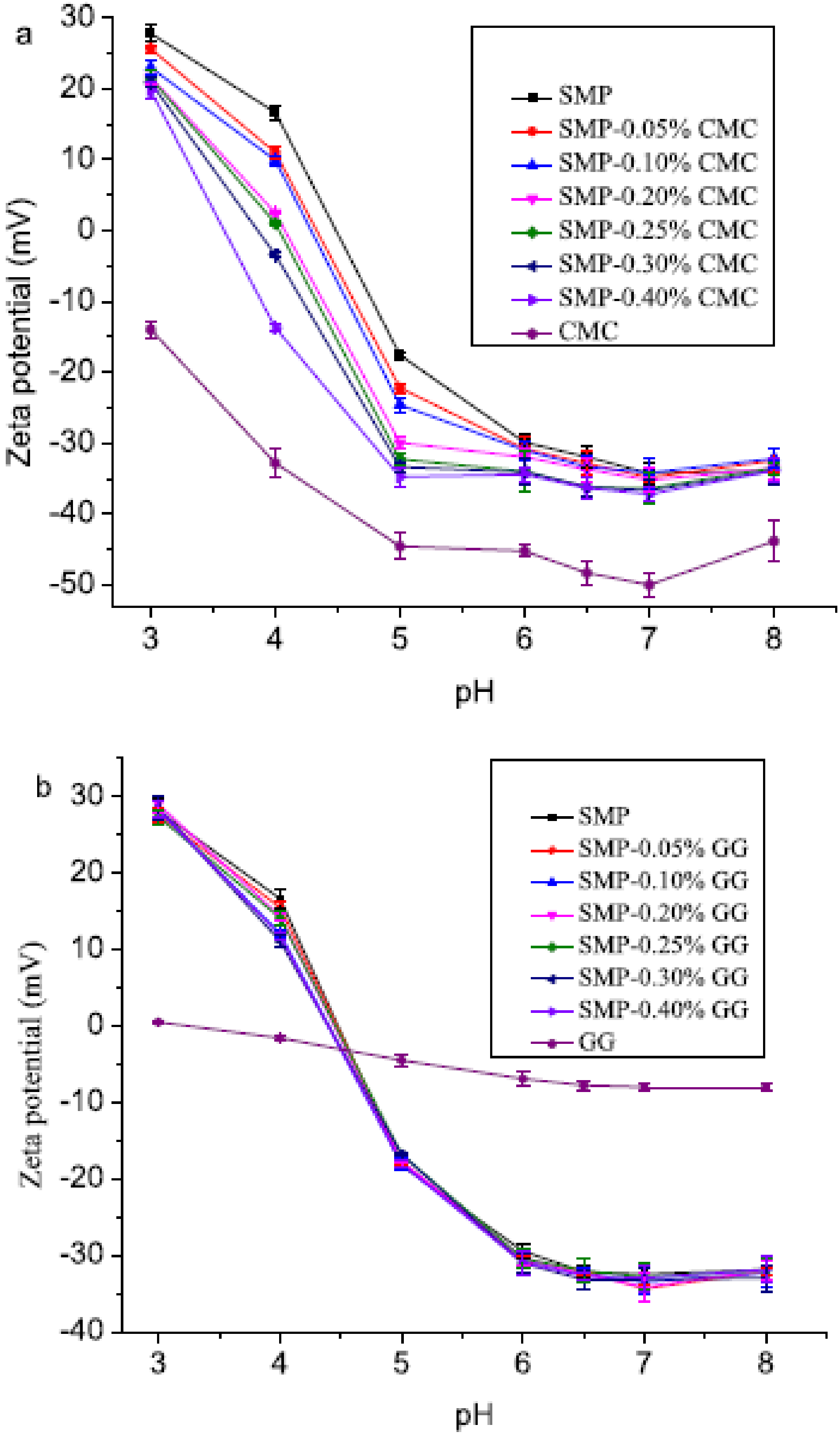


Fig. 12. Effect of CMC (a) and GG (b) concentrations on the zeta potential values of emulsions as a function of pH.

(Cheng *et al.*, 2015)

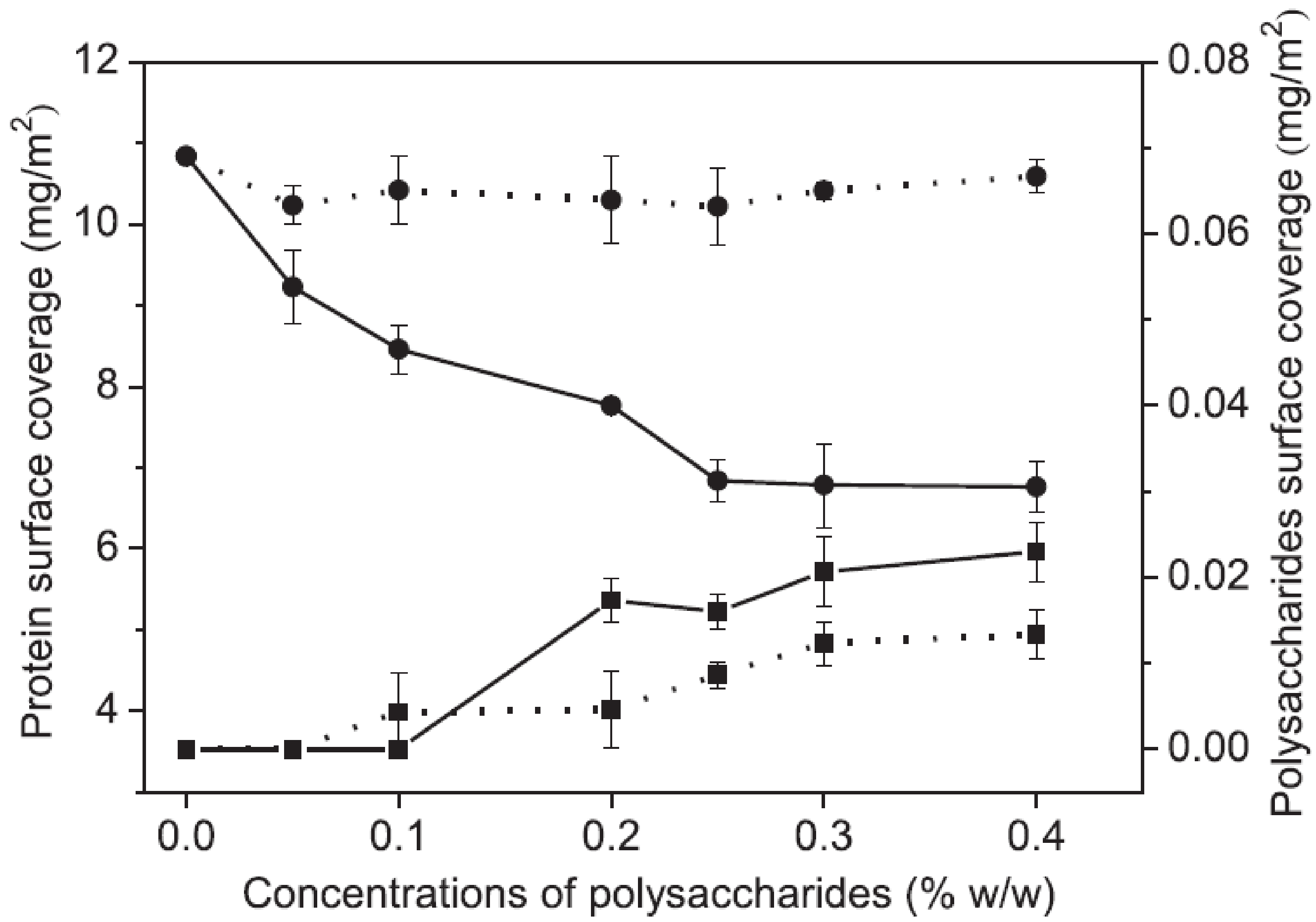
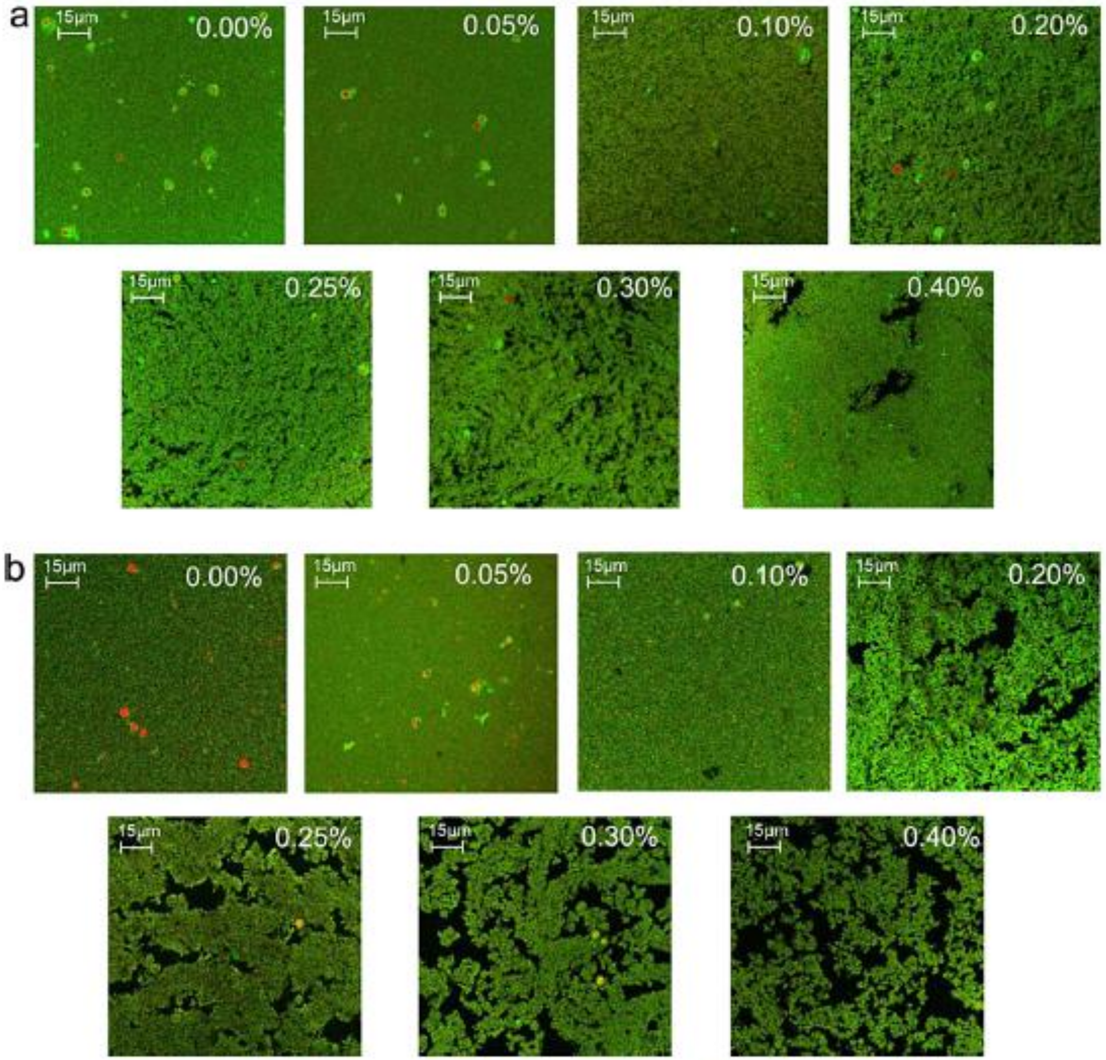


Fig. 13. Effect of CMC (—) and GG (·····) concentrations on the protein surface coverage (●) and polysaccharide stabilizers surface coverage (■) of emulsions. (Cheng *et al.*, 2015)



(Cheng *et al.*, 2015)

Fig. 14. Confocal micrographs of ice cream model emulsions prepared with different concentrations of CMC (a) and GG (b).

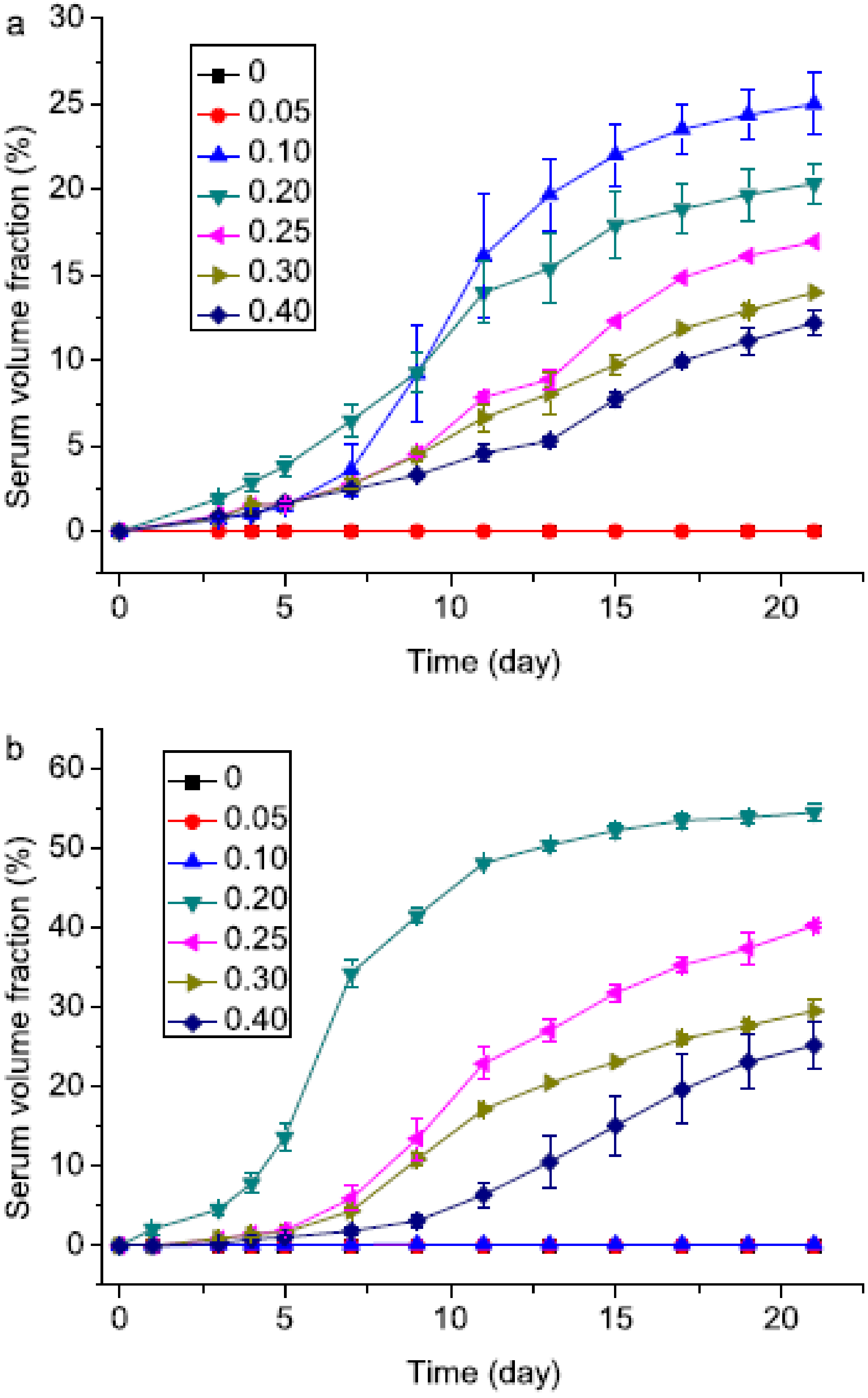
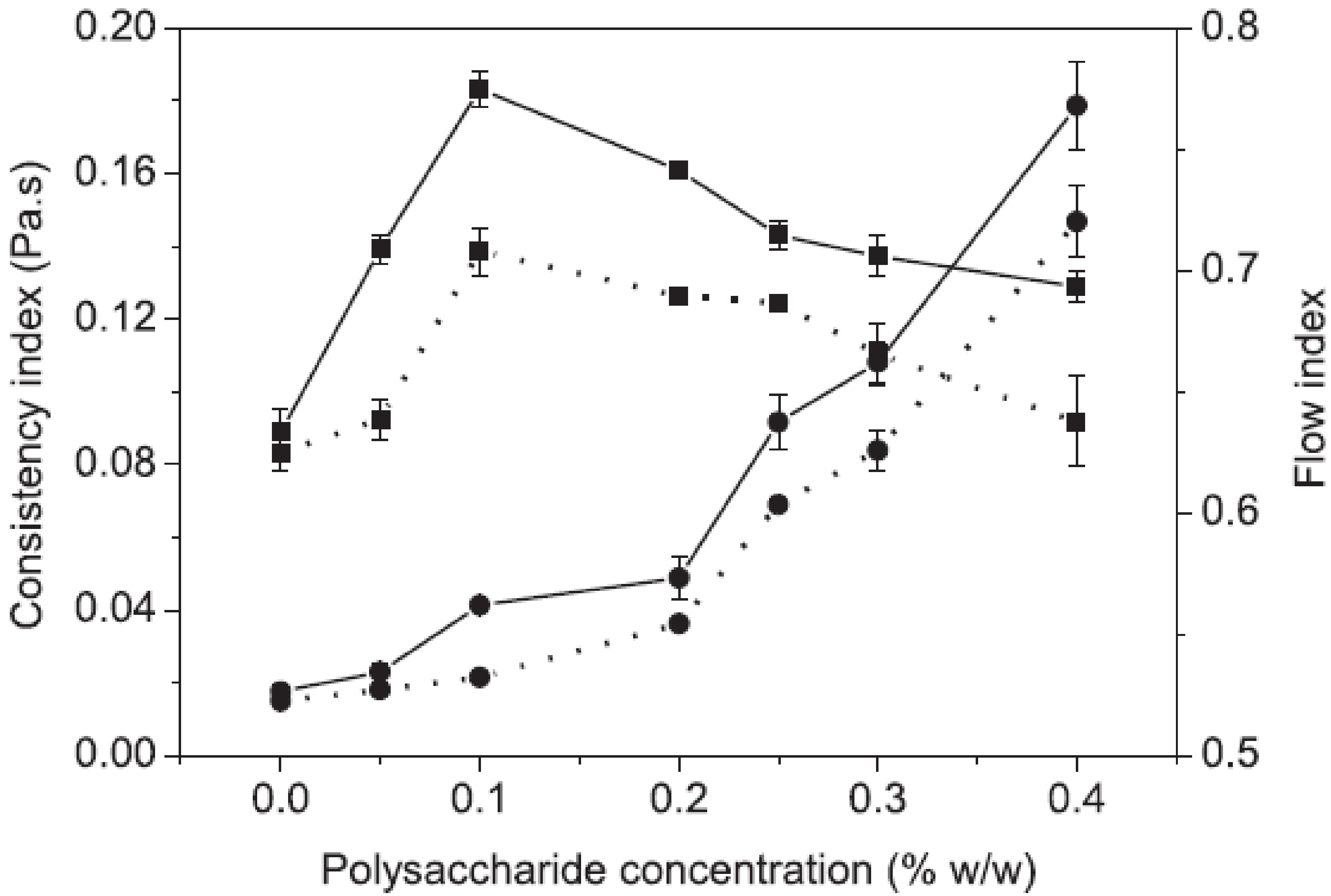


Fig. 15. Effect of CMC (a) and GG (b) concentrations on the creaming stability of emulsions.

(Cheng *et al.*, 2015)



(Cheng *et al.*, 2015)

Fig. 16. Effect of CMC (—) and GG (·····) concentrations on parameters of the Herschel–Bulkley model. Symbols: (●) consistency index; (■) flow index.

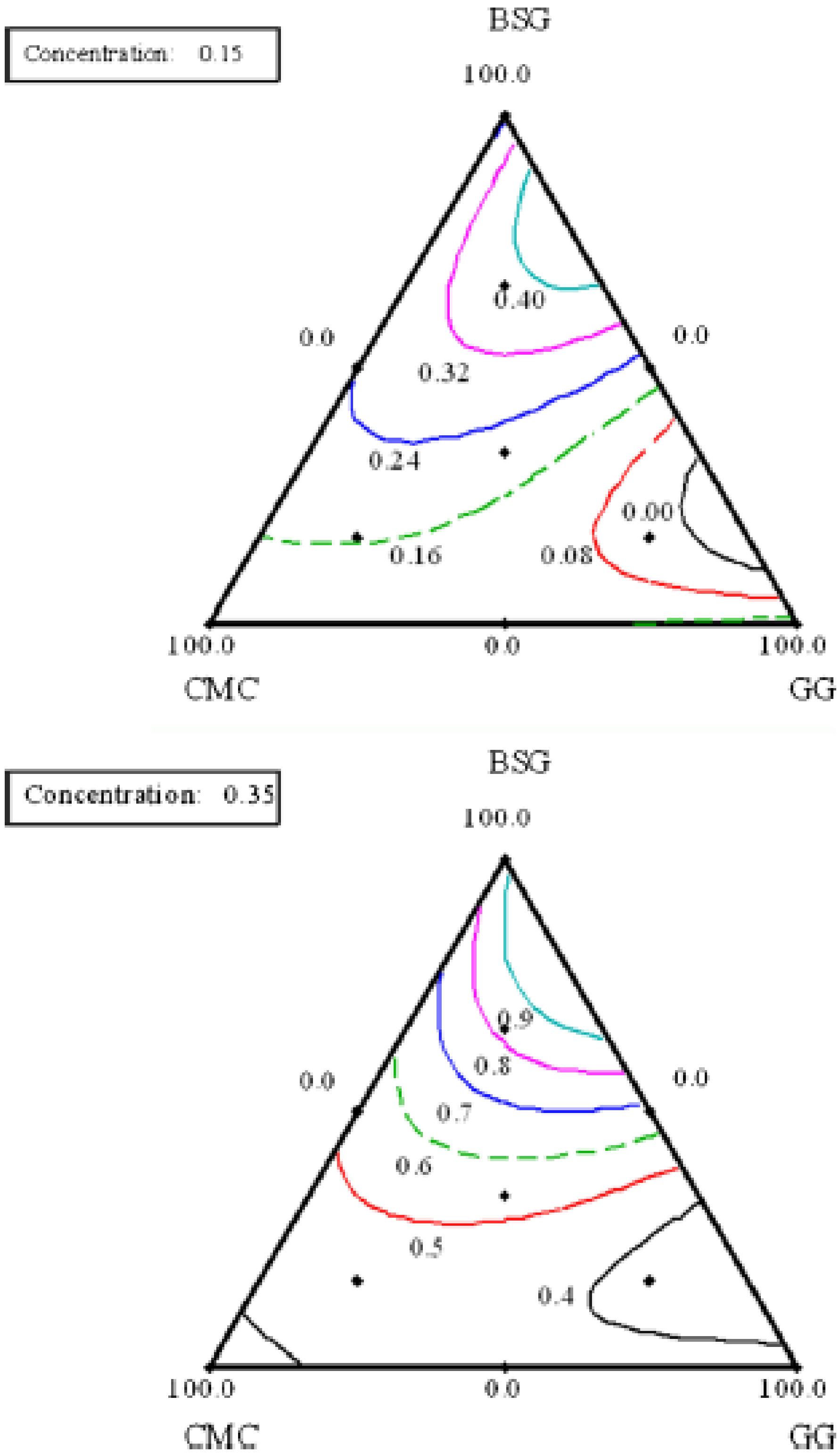


Fig. 17. Contour plots for the effect of different combinations of basil seed gum (BSG), guar gum (GG), and carboxymethyl cellulose (CMC) on apparent viscosity at two concentrations of 0.15 and 0.35 %

(BahramParvar *et al.*, 2015)

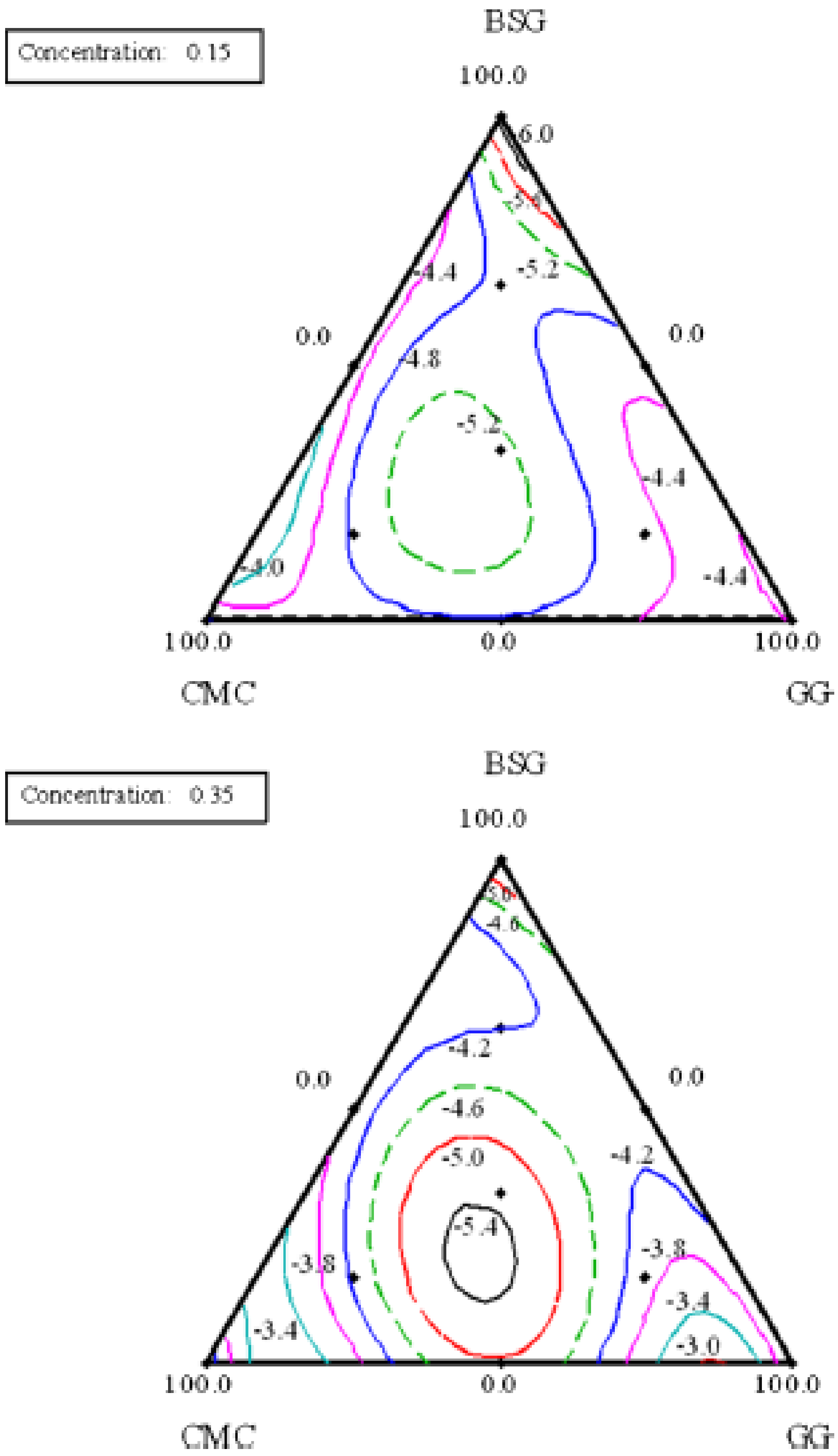


Fig. 18. Contour plots for the effect of different combinations of basil seed gum (BSG), guar gum (GG), and carboxymethyl cellulose (CMC) on draw temperature at two concentrations of 0.15 and 0.35 %

(BahramParvar *et al.*, 2015)

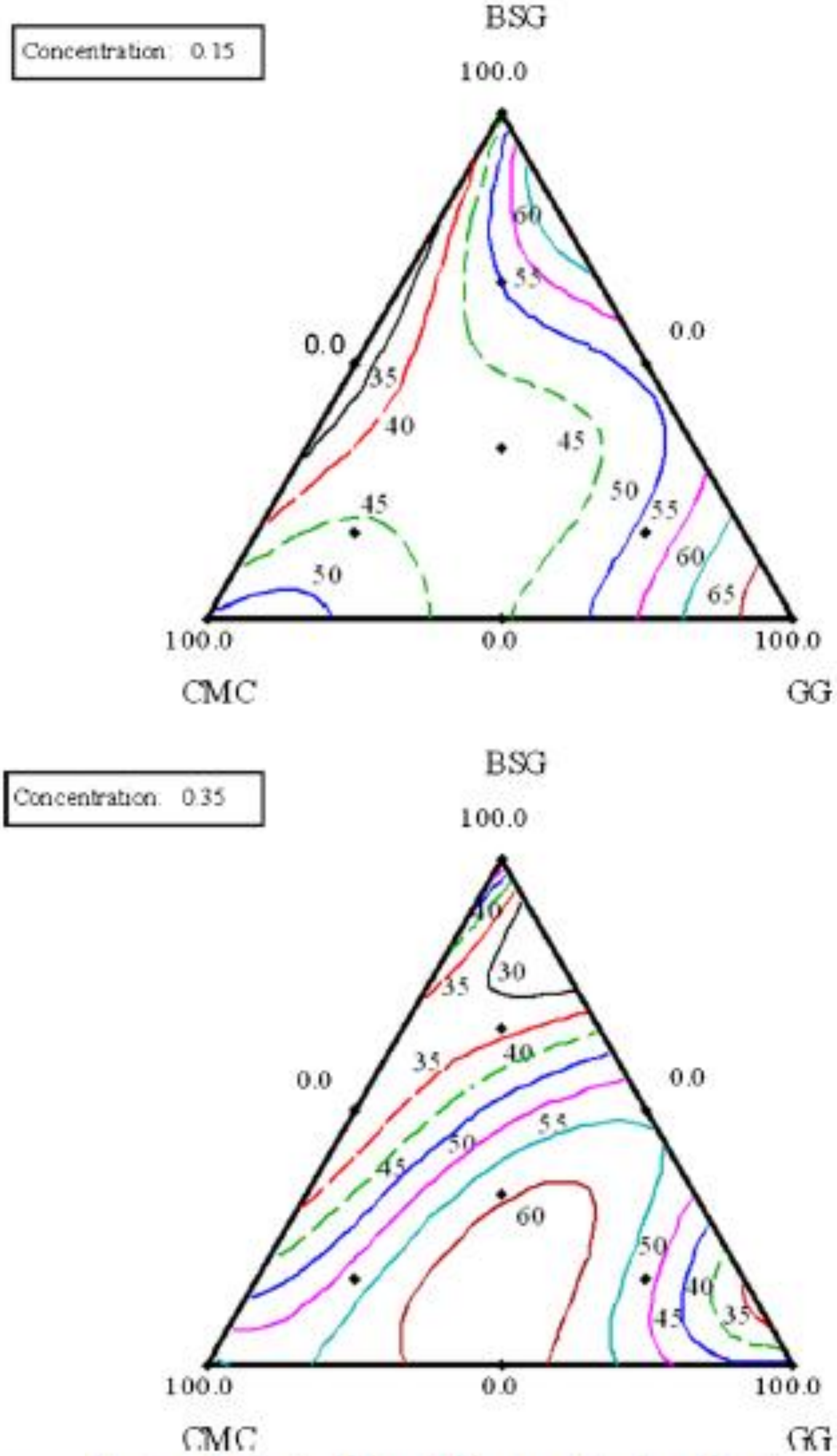


Fig. 19. Contour plots for the effect of different combinations of basil seed gum (BSG), guar gum (GG), and carboxymethyl cellulose (CMC) on overrun at two concentrations of 0.15 and 0.35 %

(BahramParvar *et al*., 2015)

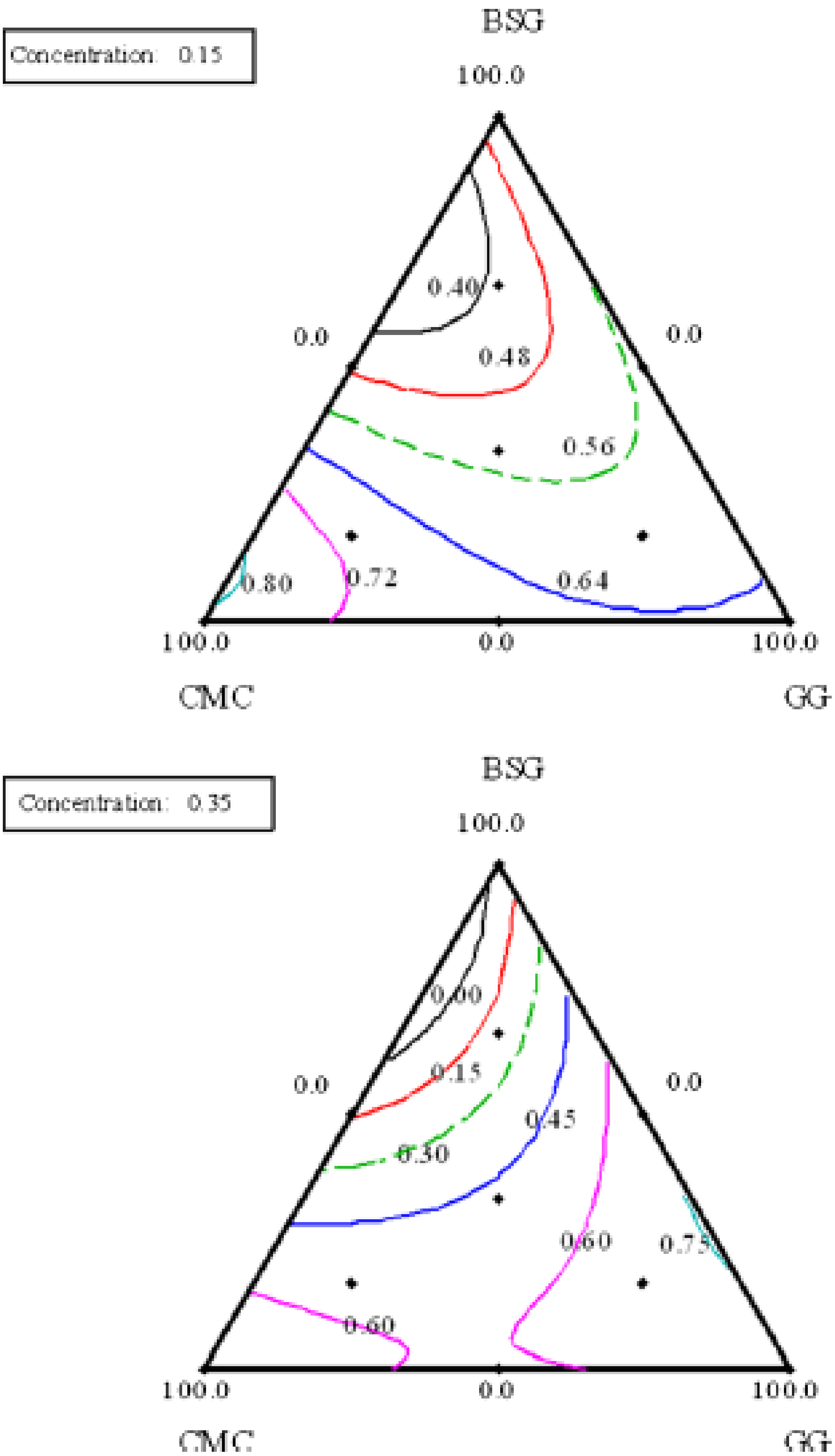


Fig. 20. Contour plots for the effect of different combinations of basil seed gum (BSG), guar gum (GG), and carboxymethyl cellulose (CMC) on melting rate at two concentrations of 0.15 and 0.35 %

(BahramParvar *et al.*, 2015)

Table 1
Formula breakdown (%) for ice cream mixes containing different protein levels from either nonfat dried milk, milk protein concentrate, whey protein isolate or procream.[a]

Ingredient	4% Protein				6% Protein				8% Protein				10% Protein			
	NFDM	MPC	WPI	PRO	NFDM	MPC	WPI	PRO	NFDM	MPC	WPI	PRO	NFDM	MPC	WPI	PRO
Water	59.28	59.7	59.55	59.55	58.66	58.75	58.55	58.53	58.44	57.80	57.56	57.47	57.62	56.83	56.56	56.49
AMF	11.92	11.93	11.98	9.79	11.87	11.89	11.98	8.69	11.84	11.86	11.96	7.58	11.77	11.82	11.95	6.48
Sucrose	16.70	16.70	16.69	16.65	11.47	15.60	15.54	15.5	7.25	14.50	14.40	14.40	0.86	13.4	13.25	13.20
DM	0	0.78	1.08	0.84	0	0.56	1.02	0.67	0	0.35	0.95	0.48	0	0.13	0.89	0.31
Lactose	0	5.78	5.8	5.8	0	5.71	5.74	5.74	0	5.64	5.69	5.68	0	5.57	5.64	5.63
NFDM	11.75	0	0	0	17.65	0	0	0	22.12	0	0	0	29.40	0	0	0
MPC	0	4.76	0	0	0	7.14	0	0	0	9.50	0	0	0	11.90	0	0
WPI	0	0	4.55	0	0	0	6.82	0	0	0	9.09	0	0	0	11.36	0
PRO	0	0	0	7.02	0	0	0	10.52	0	0	0	14.04	0	0	0	17.54
MDG	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.23	0.12	0.12	0.12	0.12	0.12
PS80	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Stabilizer	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20

[a] Abbreviations are: NFDM, nonfat dried milk; MPC, milk protein concentrate; WPI, whey protein isolate; PRO, procream; AMF, anhydrous milk fat; DM, dairy minerals; MDG, mono- and diglycerides; PS80, polysorbate 80.

(Daw and Hartel, 2015)

Table 2
Formula breakdown (%) for ice cream mixes containing different protein levels from blends of nonfat dried milk with either whey protein isolate or procream.[a]

Ingredient	NFDM 4%	NFDM-WPI 6%	NFDM-WPI 8%	NFDM-WPI 10%	NFDM-PRO 6%	NFDM-PRO 8%	NFDM-PRO 10%
Water	59.28	57.72	56.21	54.68	58.18	57.06	55.95
AMF	11.92	11.91	11.9	11.89	10.81	9.71	8.59
Sucrose	16.7	16	15.24	14.51	15.4	14.11	12.81
DM	0	0	0	0	0	0	0
Lactose	0	0	0	0	0	0	0
NFDM	11.75	11.75	11.75	11.75	11.75	11.75	11.75
WPI	0	2.27	4.55	6.82			
PRO	0				3.51	7.02	10.55
MDG	0.12	0.12	0.12	0.12	0.12	0.12	0.12
PS80	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Stabilizer	0.20	0.20	0.20	0.20	0.20	0.20	0.20

[a] Abbreviations are: NFDM, nonfat dried milk; MPC, milk protein concentrate; WPI, whey protein isolate; PRO, procream; AMF, anhydrous milk fat; DM, dairy minerals; MDG, mono- and diglycerides; PS80, polysorbate 80.

(Daw and Hartel, 2015)

Table 3

Ice crystal sizes of ice creams made with single protein sources at protein content of 4, 6, 8 and 10%.[a]

Protein source[b]	4%	6%	8%	10%
NFDM	$24.6^{CD} \pm 0.3$	$27.3^{BCD} \pm 1.5$	$29.8^{BCD} \pm 1.7$	$32.0^{ABC} \pm 2.4$
MPC	$25.3^{CD} \pm 2.4$	$29.4^{BCD} \pm 2.7$	$27.6^{BCD} \pm 0.4$	$35.7^{AB} \pm 1.8$
WPI	$22.0^{D} \pm 1.9$	$27.7^{BCD} \pm 0.9$	$26.2^{CD} \pm 3.3$	$22.0^{D} \pm 0.9$
Procream	$24.3^{CD} \pm 3.8$	$28.3^{BCD} \pm 1.0$	$28.7^{BCD} \pm 2.9$	$40.8^{A} \pm 2.1$

[a] Values are means ± standard deviation (the error between multiple measurements); values with same superscript letter are not significantly different from each other at $\alpha < 0.05$.

[b] Abbreviations are: NFDM, nonfat dried milk; MPC, milk protein concentrate; WPI, whey protein isolate.

(Daw and Hartel, 2015)

Table 4
Air cell sizes of ice creams made with single protein sources at protein content of 4, 6, 8 and 10%.[a]

Protein source[b]	4%	6%	8%	10%
NFDM	$18.2^{B} \pm 2.1$	$27.3^{AB} \pm 3.2$	$19.8^{AB} \pm 1.4$	$24.7^{AB} \pm 3.7$
MPC	$21.2^{AB} \pm 1.7$	$24.2^{AB} \pm 2.5$	$22.1^{AB} \pm 0.5$	$30.7^{A} \pm 2.3$
WPI	$24.8^{AB} \pm 2.3$	$23.4^{AB} \pm 1.4$	$25.5^{AB} \pm 0.8$	$23.8^{AB} \pm 2.1$
Procream	$24.0^{AB} \pm 5.2$	$30.0^{AB} \pm 6.3$	$26.6^{AB} \pm 4.2$	$28.2^{AB} \pm 1.2$

[a] Values are means ± standard deviation (the error between multiple measurements); values with same superscript letter are not significantly different from each other at $\alpha < 0.05$.
[b] Abbreviations are: NFDM, nonfat dried milk; MPC, milk protein concentrate; WPI, whey protein isolate.

(Daw and Hartel, 2015)

Table 5
Correlation coefficients between melt rate and mean ice crystal size, consistency coefficient, flow behavior index, and amount of partially coalesced fat of ice creams made with single protein sources.

Variable	Variable	Correlation coefficient	*P*-value
Melt rate	Mean ice crystal size (μm)	0.4752	0.008
	Consistency coefficient (Pa s^n)	0.4100	0.0302
	Flow behavior index (*n*)	−0.4787	0.01
	Amount of partially coalesced fat (%)	−0.6894	<0.0001

(Daw and Hartel, 2015)

Table 6

Changes in average particle diameter ($D_{4,3}$), span values for freshly prepared emulsions and flocculation degree (FD %) after ageing at 4 °C for one day for emulsions with different polysaccharide concentrations.

Emulsion	Gum concentration (%)	Day 0 $D_{4,3}$ (μm)	Span	Day 1		FD %
				$D_{4,3}$ (μm)	$D_{4,3\ SDS}$ (μm)	
SMP/CMC	0	0.99 ± 0.05[a]	1.81 ± 0.02[a]	0.98 ± 0.05[a]	0.87 ± 0.04[a]	12.88 ± 0.15[a]
	0.05	0.84 ± 0.02[b]	1.81 ± 0.03[a]	0.86 ± 0.02[b]	0.76 ± 0.02[b]	11.59 ± 0.24[b]
	0.10	0.77 ± 0.03[c]	1.74 ± 0.06[ab]	0.79 ± 0.03[c]	0.70 ± 0.03[b]	9.74 ± 0.04[c]
	0.20	0.77 ± 0.06[c]	1.68 ± 0.06[b]	0.76 ± 0.05[c]	0.70 ± 0.05[b]	9.87 ± 0.24[c]
	0.25	0.68 ± 0.03[d]	1.66 ± 0.05[b]	0.68 ± 0.03[d]	0.64 ± 0.02[c]	7.50 ± 0.25[e]
	0.30	0.65 ± 0.02[d]	1.69 ± 0.03[b]	0.67 ± 0.02[d]	0.62 ± 0.02[c]	5.33 ± 0.02[d]
	0.40	0.65 ± 0.03[d]	1.68 ± 0.07[b]	0.64 ± 0.03[d]	0.61 ± 0.03[c]	6.08 ± 0.20[f]
SMP/GG	0	0.99 ± 0.05[a]	1.81 ± 0.02[ab]	0.98 ± 0.05[a]	0.87 ± 0.04[a]	12.88 ± 0.15[a]
	0.05	0.76 ± 0.03[b]	1.81 ± 0.02[ab]	0.76 ± 0.03[b]	0.68 ± 0.03[b]	12.54 ± 0.30[b]
	0.10	0.64 ± 0.03[c]	1.84 ± 0.08[a]	0.65 ± 0.03[c]	0.59 ± 0.03[c]	8.34 ± 0.20[c]
	0.20	0.63 ± 0.02[c]	1.75 ± 0.04[ab]	0.65 ± 0.02[c]	0.58 ± 0.01[c]	7.19 ± 0.18[d]
	0.25	0.61 ± 0.03[c]	1.74 ± 0.03[b]	0.60 ± 0.03[c]	0.57 ± 0.02[c]	7.34 ± 0.06[d]
	0.30	0.64 ± 0.03[c]	1.63 ± 0.05[c]	0.64 ± 0.03[c]	0.61 ± 0.03[c]	4.73 ± 0.17[e]
	0.40	0.72 ± 0.02[b]	1.62 ± 0.07[c]	0.70 ± 0.03[b]	0.68 ± 0.02[b]	4.97 ± 0.15[e]

The numbers are mean ± SD of three replicate, with three readings made per sample.
Different superscript letters within a column indicate values are significantly different at the level of $p \leq 0.05$.

(Cheng *et al.*, 2015)

Table 7 Mixture design with 3 components (basil seed gum: BSG, carboxymethyl cellulose: CMC, guar gum: GG) and 1 process variables (gum concentration) as well as experimental responses

Formulation code	*BSG*	*CMC*	*GG*	*Gum concentration (%)*	*Apparent viscosity (Pa.s)*	*Draw temperature (°C)*	*Overrun (%)*	*Melting rate (g/min)*
1	100	0	0	0.15	0.170	−6.2	42.995	0.569
2	0	100	0	0.15	0.123	−4.85	50.765	0.802
3	0	0	100	0.15	0.160	−4.45	65.220	0.642
4	50	50	0	0.15	0.190	−4.15	30.732	0.541
5	50	0	50	0.15	0.123	−4.55	52.468	0.577
6	0	50	50	0.15	0.140	−4.75	44.628	0.626
7	33.33	33.33	33.33	0.15	0.113	−5.3	42.580	0.643
8	66.67	16.67	16.67	0.15	0.570	−4.85	49.885	0.321
9	16.67	66.67	16.67	0.15	0.117	−4.85	45.875	0.622
10	16.67	16.67	66.67	0.15	0.147	−4.5	51.725	0.615
11	100	0	0	0.35	0.857	−5.6	55.715	0.059
12	0	100	0	0.35	0.413	−4.6	56.815	0.658
13	0	0	100	0.35	0.480	−4.35	46.930	0.660
14	50	50	0	0.35	0.577	−3.9	30.600	0.102
15	50	0	50	0.35	0.773	−4.45	54.638	0.700
16	0	50	50	0.35	0.407	−4.95	61.460	0.632
17	33.33	33.33	33.33	0.35	0.553	−5.3	59.082	0.470
18	66.67	16.67	16.67	0.35	0.710	−4.2	33.192	0.216
19	16.67	66.67	16.67	0.35	0.407	−4.25	52.387	0.552
20	16.67	16.67	66.67	0.35	0.347	−3.95	51.800	0.658

(BahramParvar *et al.*, 2015)

Table 8 Predicted model for physicochemical data of ice cream formulations containing different ratios and levels of three stabilizers

Attribute	*Predicted model*	R^2	R^2 *(adj)*
Apparent viscosity	$Y = 0.535BSG + 0.236CMC + 0.336GG - 2.646(BSG \times GG) + 0.319(BSG \times X_1) + 0.148(CMC \times X_1) + 0.148(GG \times X_1)$	90.92 %	85.62 %
Draw temperature	$Y = -5.90BSG - 4.72CMC - 4.40GG + 5.13(BSG \times CMC) + 2.57(BSG \times GG) - 1.17(CMC \times GG) - 82.22(BSG \times CMC^2 \times GG) - 26.44(BSG \times CMC) - 31.84(CMC \times GG) + 0.30(A \times X_1) + 0.12(CMC \times X_1) - 0.32(BSG \times CMC \times X_1) - 0.47(BSG \times GG) - 0.72(CMC \times GG \times X_1) - 1.63(BSG \times GG \times X_1) - 8.30(BSG \times GG \times X_1) - 20.82(BSG \times GG \times X_1)$	99.98 %	99.84 %
Overrun	$Y = 49.6BSG + 53.8CMC + 56.4GG - 84.3(BSG \times CMC) + 216.4(BSG \times GG) + 6.4(BSG \times X_1) + 3.0(CMC \times X_1) - 9.1(GG \times X_1) - 19.0(BSG \times CMC \times X_1) + 45.9(CMC \times GG \times X_1) + 92.2(BSG \times G \times X_1) + 330.9(BSG \times CMC \times GG \times GG \times X_1) + 556.4(BSG \times GG \times X_1)$	99.93 %	99.36 %
Melting rate	$Y = 0.303BSG + 0.719CMC + 0.657GG - 0.829(BSG \times CMC) + 0.630(BSG \times GG) + 1.648(BSG \times CMC) - 0.262(BSG \times X_1) - 0.070(CMC \times X_1) + 0.756(BSG \times GG \times X_1)$	95.30 %	91.07 %

BSG, CMC, GG, and X1 mean basil seed gum, carboxymethyl cellulose, and gum concentration, respectively

(BahramParvar *et al.*, 2015)

Table 9 Analysis of variance for the different models fitted to responses of Table 1

	Apparent viscosity			*Draw temperature*			*Overrun*			*Melting rate*		
Variation source	df	Seq SS	P	df	Seq SS	P	df	Seq SS	P	df	Seq SS	P
Regression	7	1.01795	0.000	17	6.18895	0.001	17	1732.00	0.006	9	0.731954	0.000
Component only		-	-									
Linear	2	0.21157	0.007	2	1.14181	0.000	2	364.39	0.022	2	0.351614	0.000
Quadratic	-	-	-	3	2.47485	0.001	2	539.89	0.002	3	0.107768	0.002
Special cubic	-	-	-	-	-	-	1	68.76	0.131	-	-	-
Full cubic	1	0.07203	0.013	-	-	-	-	-	-	1	0.027445	0.020
Special quartic	-	-	-	1	0.80736	0.000	1	38.99	0.095	-	-	
Full quartic	-	-	-	2	0.95040	0.001	1	12.80	0.042	-	-	
Component× concentration												
Linear	3	0.72172	0.000	3	0.52481	0.007	3	149.57	0.006	2	0.167074	0.000
Quadratic	1	0.01263	0.246	3	0.01250	0.021	3	287.24	0.007	1	0.078080	0.001
Special cubic	-	-	-	1	0.00960	0.029	-	-	-	-	-	-
Full cubic	-	-	-	-	-	-	1	94.10	0.013	-	-	-
Special quartic	-	-	-	-	-	-	1	2.42	0.027	-	-	-
Full quartic	-	-	-	2	0.26763	0.004	2	173.85	0.007	-	-	-
Residual error	12	0.10170		2	0.00105		2	1.16		10	0.036086	
Total	19	1.11965		19	6.19000		19	1733.16		19	0.768040	

(BahramParvar *et al.*, 2015)

Table 10 The desirable ranges for each response for optimization of stabilizers formulation

Parameters	*Goal*	*Lower*	*Target*	*Upper*	*Weight*	*Importance*
Apparent viscosity	Maximum	0.113	0.8567	0.8567	1	1
Draw temperature	Minimum	−6.20	−6.20	−3.90	1	1
Overrun	Maximum	30.600	65.220	65.220	1	1
Melting rate	Minimum	0.0587	0.0587	0.8017	1	1

(BahramParvar *et al.*, 2015)