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Effect of egg yolk substitution by sweet whey protein concentrate (WPC), on physical properties of Gelato ice cream

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Abstract: The aim of this research was to evaluate the changes in the Gelato ice cream properties at different levels of sweet whey protein concentrate (WPC) substitutions of egg yolk. Samples were made with two levels of egg yolk (4.5 and 9%). For each level one control sample with no WPC addition and four levels of WPC substitutions (20, 50, 80 and 100%) were made. Three replications of each treatment were performed. Samples were evaluated for mix viscosity, overrun and texture. Determinations of these parameters were made after four weeks of storage. Results showed that samples containing 9% egg yolk were more viscous than those containing 4.5% egg yolk. Moreover, increasing WPC substitution led to increased overrun (%), number of air cells formation and texture characteristics of the Gelato samples. Overall, a significant ($P<0.05$) effect of fat content was observed and reported in all physical properties measured.

Keywords: Gelato, WPC, egg yolk, physical properties

Introduction

In the last 100 years, milk production has grown rapidly due to science innovation and fast technology movement (Walstra *et al*., 2006). Therefore, various different countries according to their technology and needs have contributed to the development of various types of 'Ice Cream'. For instance, Gelato developed in Italy, remains the biggest competition to ice cream. Although ice cream and Gelato appear similar, there are differences. Italian Gelato has little or no overrun (Marshall *et al*., 2003), whereas ice cream overrun varies from 30% or less for super-premium ice cream to 95-100% for other types (USDEC, 2001). Italian Gelato has no stabilisers or emulsifiers that typically are used in ice creams to increase viscosity (Marshall *et al*., 2003). Whey protein concentrate (WPC), is obtained by the removal of non-protein components aimed at achieving a protein proportion of 34% to 80% (Tunick, 2008). Practical applications of WPC involving interaction between water and protein include yoghurt, hard pack ice cream, low-fat ice cream, non fat ice cream, soft ice cream, sour cream, and coffee whiteners (Li-Chan, 2004; DeWit, 1990). In addition, the positive relation established between protein content in WPC and the emulsion stability can be attributed to a potential increase in viscosity of the "continuous water phase" as well as the quantity of protein adsorbed at the surface of fat globules (Li *et al*., 1997; Farrag, 2008). The configuration and interaction of the molecules of WPC eventually settled the appearance, texture and stability of such gels and tend to form of a three-dimensional network of aggregated proteins (Eissa *et al*., 2004; Goff *et al.*, 1989).

Egg yolks have high nutritional values and multi-functional properties which make them a high profile ingredient (Herald *et al*., 2008). Hence, egg yolks serve multiple functions in food formulations and no other food or replacer can compare to its multifunctional attributes (Li-Chan and Kim, 2008). The various components have the ability to coagulate on heating, play the part of emulsifiers in oil and water formulations, and when whipped they can create rich foams (Stadelman and Schmieder, 2002). Ice cream manufacture makes use of egg yolk in different forms such as pasteurised fresh egg yolk, frozen sugared pasteurised egg yolk (which has had about 10% sucrose added to protect it from damage during freezing) or as dehydrated egg yolk, whereas the usage of egg yolks solids is around 0.5-3% (Clarke, 2004). As WPC80 is substantially cheaper than egg yolk and is an ingredient widely available throughout the world, it was the objective of this study to investigate

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the different levels of sweet whey protein concentrate (WPC80) substitutions of egg yolk on some physical properties of Gelato vanilla ice creams.

Materials and Methods

Materials

Spray dried egg yolk powder (32.9% protein, 5.5% maximum moisture) was obtained from PACE Farms Pty. Ltd. Egg Production (Warabrook, NSW, Australia) and stored in a dry place at 17±1°C. A commercial sweet whey protein concentrate (WPC80) was supplied by Top Nutrition Company, (Newcastle, NSW, Australia) and stored at 17±1°C. Sucrose, vanilla extract (natural), skim milk powder (0.1%fat), commercial whole full cream milk (3.4% fat) and thickened cream (35% fat) were purchased from local supermarket. Milk and cream were stored at 4±1°C. The varying amounts of dried egg yolk and WPC80 used in the Gelato formulations are presented in Table 1.

Methods

Gelato ice cream manufacturing

Nine batches of Gelato ice cream mix were made and each batch represented one treatment. Three replications were performed and a total of 108 Gelato ice creams manufactured. All treatments contained 7-8% milk fat, 10-14% milk solid non-fat (MSNF) and 20% sucrose. Stabilisers and emulsifiers were not added to any treatments. Mixes were made by mixing skim milk powder and whey protein concentrate with milk and heated, at 45°C for 3 min. Egg yolk powder was reconstituted according to the manufacturer's instructions, and stored at 4°C overnight. The reconstituted egg yolk and the sucrose were mixed together prior to adding to the milk to ensure proper mixing. Mixes were cooked over low heat, stirring constantly, until a temperature of 85°C was reached and maintained for one minute. The mixture removed from the heat and stirred with the cream, then passed through a fine strainer and placed over an ice bath to chill (to achieve 20ºC). Vanilla extract was added and the mixture was stirred for one minute. The mixture was processed using an ice cream maker (II Gelataio, GC5000 model, Treviso, Italy). All samples were packed in 400ml Polypropylene containers (Julzar PTY. TD., Queensland, Australia). Samples were hardened by placing in a freezer (NUAIRE -85±1°C Ultralow Freezer) at -85±1°C for 30 minutes, and then stored in a commercial freezer (Fisher & Paykel freezer, model# H701) at approximately -18±1°C until the testing day.

Mix viscosity

Viscosity of the unfrozen mixes was evaluated according to Muse and Hartel (2004), and Akesowan (2008) methods. Viscosity was measured using a low viscosity viscometer, Model DV-II+ (Brookfield, Stoughton, MA, USA). Samples were placed in a 200 ml beaker at 8±1°C and viscosity was measured using spindle # 2 to take torque measurements at 50 rpm. One measurement was taken per sample. The apparent viscosity (Centipoise [cP]) was recorded.

Overrun

One overrun measurement was taken per sample by comparing the weight of Gelato ice cream mix and Gelato ice cream in a fixed volume container. The method of Datta *et al*. (2007) and AACC (1988) was used to measure samples overrun using rapeseed with a diameter of approximately 1.7 mm. Overrun (in %) was calculated as follows.

$$Overrun = \frac{(Vol.of\ ice\ cream - Vol.of\ mix\ used)}{Vol.of\ mix\ used} X\ 100$$

Texture using Cone Penetrometer

The method of Sun and Gunasekaran (2009) and

Table 1. Amounts of dried egg yolk and WPC80 added per 100g of base formulation of Gelato

	4.5% Egg Yolk				
Samples	Control	20%	50%	80%	100%
Dried Egg Yolk (g)	4.50	3.60	2.25	0.90	-
WPC80 (g)	-	0.90	2.25	3.60	4.50
	9% Egg Yolk				
Samples	Control	20%	50%	80%	100%
Dried Egg Yolk (g)	9.00	7.20	4.50	1.80	-
WPC80 (g)	-	1.80	4.50	7.20	9.00

Stathopoulos *et al*. (2009) was used to measure Gelato ice cream texture. A penetrometer (K19500, Koehler Instruments, New York, USA) was used to measure the hardness of the ice cream at -18±1ºC. The sample was removed from freezer at -18±1ºC and tested at room temperature (17±1ºC) within 15 seconds, to minimise variability. A 45 g stainless steel probe (60° cone) was aligned so that it touched the surface of the ice cream and then allowed to penetrate the samples under the force of gravity for five seconds. Three measurements were taken per sample and the mean for each sample was calculated. Penetration readings (in tenths of a millimetre) were obtained.

Texture using Texture Analyser

Texture Analysis was conducted using a microprocessor controlled texture analysis system in conjunction with data collection and analysis software (TMS-Pro, S.I. Instruments, S.A, Australia). The method of Lim *et al*. (2008) and Szczesniak (2002) was used to evaluate texture characteristics. In this assessment, the sample was transferred from the freezer at -18±1ºC and tested at room temperature (17±1ºC) within 15 seconds, to minimise variability. One measurement was taken per single sample. The conditions for analysis were as follows: a 2 mm diameter probe penetrated the ice cream to a depth of 10 mm. The analysis used 250 N load cells; while the probe speeds during and after penetration 25 and 400 mm/min, respectively. The maximum force was recorded.

Statistical analysis

Analysis of variance (ANOVA) was used to find relationships between Gelato ice cream physical properties. Complete randomised block design was used to evaluate the effect of individual treatments. Treatment means were considered significantly different at ($P<0.05$).

Results

Mix viscosity

The mean initial apparent viscosity values are displayed in Table 2. According to the results found in this study, samples containing 4.5% egg yolk had significantly different viscosity than those containing 9% at all levels of WPC80 substitution. Within the group containing 4.5% egg yolk no significant ($P>0.05$) effects on viscosity were observed, whereas the presence of WPC80 in all 9% egg yolk samples had a significant ($P<0.05$) effect on viscosity. As expected, the 4.5% egg yolk samples had the lowest viscosity values recorded because of lower fat content than the 9% egg yolk samples. Li *et al*. (1997) and Prindiville *et al*. (1999) reported that a significant increase in viscosity with a higher fat content was noted in their studies. In general, as the viscosity increases, the resistance to melting and smoothness of texture increases, but the rate of whipping decreases (Marshall *et al*., 2003). This could be because of the proteins solubility in water which is resulting in higher viscosity. Interaction between water and proteins was discussed at length by DeWit (1990). He noticed that above 85°C, whey proteins were denatured and aggregated to give rise to increased viscosity. Practical applications of WPC involving interaction between water and protein include soft ice cream, hard ice cream and non-fat ice cream (Li-Chan, 2004; DeWit, 1990).

Overrun

In our study, overrun was a significantly ($P<0.05$) different among 9% egg yolk samples with increasing WPC80 levels, except with samples at 50% WPC added. On the other hand, there was no significant ($P>0.05$) effect among 4.5% egg yolk samples. Gelato ice creams overrun ranged from 17% to 36 % as shown in Figure 1. Ferrari (2005) reported overrun (%) in Gelato ice cream ranging from 35-45%. The results for comparisons at the same egg yolk level (9% egg yolk) of WPC substitution showed that overrun (%) significantly increased ($P<0.05$) the number of ice crystals as the WPC80 level increased from 80% to 100% (shown in Figure 2). According to Thomas (1981) an increase in air cell dispersion causes a reduction in thickness of the unfrozen phase, which would result in limiting the size of ice crystals by mechanical hindrance of the numerous air cells and fat structure. It is believed that the ice crystals contribute to the shearing action on the fat globules, due to their physical shape, and that the concentration of components also leads to enhanced destabilisation. Likewise, Gelato ice cream made with high egg yolk content had a substantially higher level of fat destabilisation than the other ice creams, and this destabilised fat network may be the reason for the inhibition of air-cell collapsing. Destabilised fat in ice cream takes the form of clumps of fat globules that coat and support the air cells and chains of fat globules that build a fat network in the ice cream (Marshall *et al*., 2003).

Texture using Cone Penetrometer

Ice cream samples containing 9% egg yolk substituted with WPC80 were significantly having greater hardness ($P<0.05$) than ice cream samples containing 4.5% egg yolk, except the control sample

Table 2. Apparent viscosity mean values of Gelato ice cream mixes before freezing storage*

WPC (%)	4.5% Egg yolk Viscosity (cP)	9% Egg yolk Viscosity (cP)
0% (control)	4.08 ± 2.20 [a]	6.66 ± 1.30 [a]
20%	2.91 ± 0.26 [a]	4.41 ± 0.51 [b]
50%	3.31 ± 0.33 [a]	4.12 ± 0.33 [b]
80%	4.10 ± 0.57 [a]	4.38 ± 0.38 [b]
100%	3.69 ± 0.29 [a]	6.02 ± 0.66 [a]

* Values represent the mean of 3 replicate trials.
Means with different superscripts in the same column differ significantly (P<0.05).

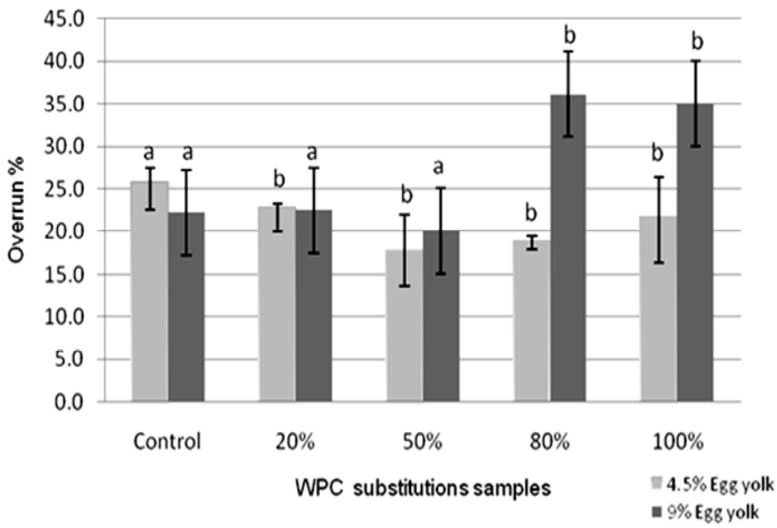

Figure 1. Effect of WPC80 substitutions on the overrun (%) of Gelato ice cream mixes. Error bars represent the standard errors of the means. Same colour columns with different superscripts differ significantly (P<0.05).

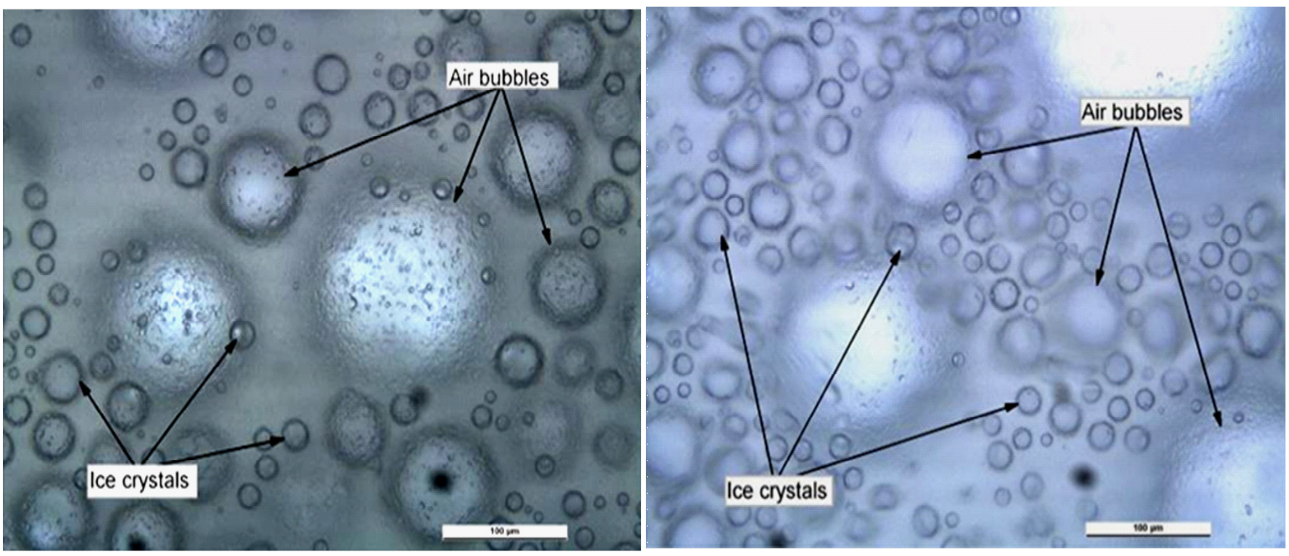

Figure 2. Effect of WPC80 substitutions (Top -80% WPC) and (Bottom- 100% WPC) on ice crystals formation, growth and number in Gelato ice cream using 9% egg yolk. (Bar scale=100µm).

(Figure 3). At the highest percentage of WPC80 substitutions samples overrun (%) increased in both 4.5% and 9% egg yolk and resulted in increased hardness (mm). This could be because of the denatured proteins exhibiting substantial hydrophobic interactions, resulting in increased amount of bound water (Eissa and Khan, 2006; Lim *et al.*, 2008). Therefore, hydrophobicity may increase hardness in ice cream. In addition, ice phase volume had a significant effect on Gelato ice creams. For instance, samples containing 80% and 100% WPC80 showed the highest hardness (mm) values, while they were having the highest overrun (%) comparing with other samples. This is in agreement with previous research which concluded that the hardness of ice cream increased as overrun (%) increased (Sofjan and Hartel, 2004; Tanaka *et al.*, 1972; Goff *et al.*, 1995). Furthermore, there was a significant interaction ($P<0.05$) between WPC80 and fat, which indicated that WPC80 increased hardness to a greater extent in the absence of fat.

Texture using Texture Analyser

There was a significant ($P<0.05$) difference in hardness (N) among 4.5% and 9% egg yolk samples. In particular, samples with 9% egg yolk

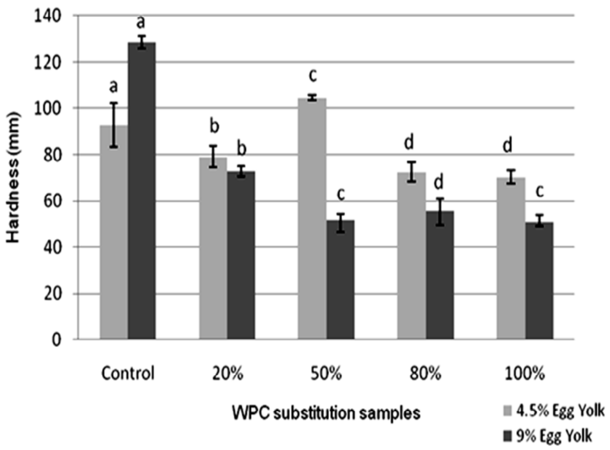

Figure 3. Effect of WPC80 substitutions on the hardness (mm) of Gelato ice cream mixes. Error bars represent the standard errors of the means. Same colour columns with different superscripts differ significantly (P<0.05).

were significantly ($P<0.05$) harder than 4.5% egg yolk samples. There were many factors affecting the final Gelato ice cream texture. Hardness was most affected by the fat network. In this work, a significant ($P<0.05$) increase in hardness (N) with a high fat content was obtained and is shown in Figure 4. This finding is in agreement with those obtained by numerous researchers (Tharp *et al.*, 1998; Ronald *et al.*, 1999a, 1999b; Prindiville *et al.*, 1999). Viscosity is another factor having an effect on Gelato ice cream texture. As found, increasing sample viscosity was resulting in firmer texture. The mass effect of the large amount of fat becomes evident and the viscosity increases. Damodaran (2007) noted that the protein gel is responsible for formation of a three-dimensional network of aggregated protein molecules. This network traps water by means of capillary forces and increases its firmness. In addition, air bubbles and ice crystals structures and numbers could have an effect on texture. There was no major change on air bubbles size and ice crystals among different levels of WPC80 substitutions using 4.5% and 9% egg yolk. The air bubble sizes ranged between 82.3-104.6 µm, while ice crystals ranged between 20.5-29.7µm. These values are within the ranges reported by other researchers who stated that the air bubbles diameter ranged between 30 and 150 µm with a mean diameter around 40 µm (Chang and Hartel, 2002; Caillet *et al.*, 2003), and the ice crystals mean size ranged between 20 and 75 µm with a mean value around 40 µm (Hagiwara and Hartel, 1996; Russel *et al.*, 1999).

Conclusion

The results obtained in this study using 4.5% and 9% egg yolk substitution with four levels of WPC80 showed a significant ($P<0.05$) effect on different physical properties of Gelato ice creams such as mix viscosity, overrun, and texture. Strong fat content effects were observed in all physical properties were measured. In general, viscosity of the mixes was lower for 4.5% egg yolk samples compared with 9%

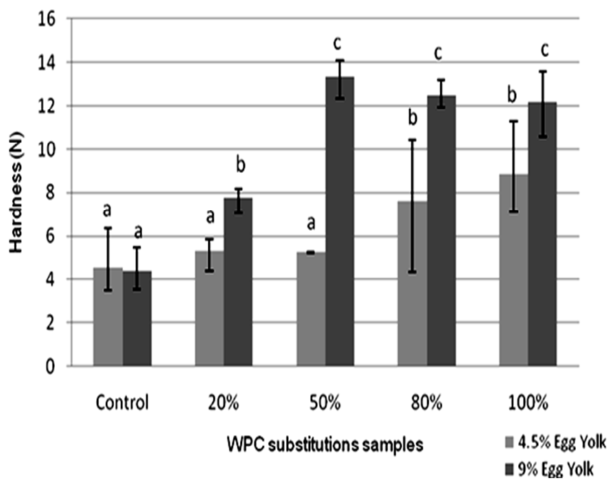

Figure 4. Effect of WPC80 substitutions on the hardness (N) of Gelato ice cream mixes. Error bars represent the standard errors of the means. Same colour columns with different superscripts differ significantly (P<0.05).

egg yolk. Also, data showed that increasing WPC80 level led to increased Gelato samples overrun (%) and increased the number of air cells formation. In addition, increasing WPC80 substitution in both 4.5% and 9% egg yolk samples improved the texture characteristics of the Gelato ice creams. The use of WPC80 substitution appears to be most advantageous for Gelato ice cream samples, as it would allow for the production of a cheaper alternative to Gelato without a compromise to the functional properties of the product.

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