Effect of Inulin Supplementation on Rheological Properties of Low-Fat Ice Cream

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Abstract: Inulin is a prebiotic ingredient that was approved by the Food and Drug Administration (FDA) for human consumption. A prebiotic is a food ingredient that benefits the host by selectively stimulating the growth and activity of the beneficial bacteria in the colon. This study investigated the effect of inulin supplementation (2.5% and 5%) on the rheological characteristics of low-fat ice cream with relation to their sensory attributes. The addition of 2.5% inulin to a low-fat ice cream mixture increased the ice cream's viscosity, adhesiveness, cohesiveness, elasticity, gumminess, chewiness, and fat instability. The hardness of the resulting low-fat ice cream increased when the amount of inulin was increased. The meltdown and overrun characteristics of the low-fat ice cream demonstrated a clear relationship with increased inulin levels. The sensory properties of the low-fat ice cream were significantly improved by the addition of inulin.

[Ismail E. A., A. A. Al-Saleh, and A. A. M. Metwalli. **Effect of Inulin Supplementation on Rheological Properties of Low-Fat Ice Cream.** *Life Sci J* 2013;10(3):1742-1746]. (ISSN: 1097-8135). http://www.lifesciencesite.com. 262

Keywords: inulin, ice cream, low-fat, rheological properties

1.Introduction

Producing a high-quality, low-fat frozen dessert is a challenge for the food industry. Recently, consumers have directed their interest towards low-fat, low-sugar frozen desserts, as they associate these foods with a reduced risk of obesity, coronary heart disease, and diabetes. Inulin can act as a fat replacer in different dairy products **(Meyer, et al., 2011).** Factors affecting ice cream texture and structure include the composition of total solids and milk fat and the size and state of ice-crystal/fat-particle dispersion **(Akalin, et al., 2008; El-Nagar, et al., 2002; Chantal,et al., 1996).**

Most European countries officially recognise chicory inulin and oligofructose as natural food ingredients **(Cummings**& Roberfroid,**, 1997).** Inulin is a carbohydrate composed of β-(2,1)-linked fructosyl residues, which mainly end with a glucose residue, and is present as a storage carbohydrate in many plants **(Van Loo, et al., 1995; Ritsema and Smeekens, 2003; and Meyer, et al., 2011).** In 2002, the United States deemed that inulin, fructooligosaccharide (FOS), and oligofructose were generally recognised as safe (GRAS) **(FDA, 2003)**. Several commercial grades of inulin are available that have a neutral, clean flavour and are used to improve the mouthfeel, stability, and acceptability of low-fat foods as a low-calorie texturising agent (**Niness 1999; Tungland & Meyer 2002).** The characteristics of inulin as a fat mimetic have been attributed to its ability to bind water molecules and form a particle gel network (**Franck 2002).** The addition of inulin has significant effects on the structure and texture of mixtures of ice cream and yoghurt.

The addition of inulin to a reduced-fat ice cream-yoghurt mixture increases the mixture's viscosity and hardness **(El-Nagar, et al., 2002). Schaller et al., (2001&1999)** reported an increase in the viscosity and a decrease in the freezing point of reduced-fat ice cream containing inulin. Inulin also increased the hardness but led to faster melting compared to regular ice cream **(Akalin, et al., 2008)**. Importantly, the addition of inulin to low-fat, semi-solid milk products changes the products' texture attributes, providing a creamy mouthfeel **(Meyer, et al., 2011).** The aim of this study was to compare the effects of the addition of inulin on the rheological characteristics and sensory attributes of low-fat ice cream.

2. Materials and Methods

2.1 Materials

The stabiliser-emulsifier (Cremodan) was purchased from Danisco Co. (Copenhagen, Denmark), and medium-heat, non-fat dry milk (NFDM) was purchased from Fonterra Co. (NZMP, New Zealand). Vanilla powder from a local market was used. Inulin was purchased from BDH Bio-Chemicals Co. (England). Pasteurised milk was purchased from a local market.

2.2. Ice cream production

Ice cream mixtures were prepared by mixing NFDM, sugar, cremodan, and inulin with fresh full-cream milk (3% fat) warmed to 55°C. The mixtures were stirred in a water bath at 80°C for 10 min to dissolve the dry ingredients and homogenised at approximately 14 MPa using a Technical homogeniser (Danich, Turnkey, Dairies, LTD, Rannie, Denmark). The homogenised mixtures were chilled and aged at 5°C overnight. Next, vanilla powder was added to the mixtures and stirred thoroughly; then, the mixtures were frozen in the batch ice cream freezer (Mix Gel Fre Mark, DS12, Giulino, Milanese, Italy). The frozen product was drawn into polystyrene hygienic cups (70 g) and immediately stored in the hardening room at -20°C for one day before further testing was conducted.

2.3. Viscosity

The apparent viscosity of the mixtures was evaluated after 24 h of aging using a Brookfield viscometer (Model DV-11, Brookfield Engineering Laboratories, Stoughton, Massachusetts, USA). Samples were tested in triplicate at 4°C with spindle No. 63 at a speed of 20 rpm.

2.4. Overrun

The overrun was calculated by weight using a formula described by **Marshall,et al., (2003).** The formula for overrun is as follows: Overrun % = [(weight of unit volume of mix) - (weight of unit volume of ice cream)]/(weight of unit volume of ice cream) × 100.

2.5. Meltdown rate

The meltdown rate was determined according to **Al-saleh, et al.,(2011)** by carefully cutting the plastic cups from the ice cream samples (pre-weighed as 70 g), placing the ice cream onto 1-mm stainless-steel mesh over a funnel and measuring the amount of ice cream that drained into the graduated cylinder at 20 ± 0.5°C. Meltdown was expressed as the volume melted over the time required to collect 20 mL of melt. The measurements were performed in triplicate.

2.6. Texture analysis

Texture analysis was conducted using a TA.XT2 Texture Analyser (Stable Micro Systems, Reading, UK) equipped with a 2.5-cm-diameter stainless-steel cylindrical probe. Ice cream samples stored at -20°C were tempered to -10°C for 24 h before analysis. The conditions for analysis were as follows: penetration distance = 15 mm, force = 5.0 g, probe speed during penetration = 3.3 mm s^{-1}, probe speed before and after penetration = 3.0 mm s^{1}. The ice cream, which remained in the plastic cup, was penetrated in two places on its largest smooth surfaces, and four measurements were recorded for each product. Hardness was measured as the peak compression force (g) during the penetration of the sample, and adhesiveness was measured as the negative peak force (g) during withdrawal.

2.7. Fat Instability

The fat instability was measured as described by **Keeney & Josephson (1958).** The turbidities of the diluted samples (1:500) were measured using a dual-beam ultraviolet-visible spectrophotometer (Biospec 1601, Shimadzu Scientific Instruments, Japan) with a quartz cuvette at 540 nm. The fat instability was calculated using the following formula:

Fat instability = turbidity of unfrozen mixture - turbidity of frozen sample / turbidity of unfrozen mixture × 100.

2.8. Sensory evaluation

Eleven panellists were selected to judge the sensory properties of the ice cream. Ice cream samples were evaluated for mouthfeel, flavour, body and texture, using five-point hedonic scales, with the highest number indicating an extreme liking and the lowest indicating an extreme dislike. Panellists were also asked to note any foreign flavour and other perceived attributes for appearance and colour. All ice cream samples (in 70 g cups) were coded with three-digit random numbers and presented to panellists on a tray in individual booths.

2.9. Statistical analysis

All data are expressed as the mean value of three replicates. Data were tested by one-way analysis of variance (ANOVA), and the mean values were compared by Duncan's multiple range method **(Duncan 1955)** ($p < 0.01$).

3. Results and Discussion

The chemical composition of the samples revealed that the targeted fat and total solids levels were achieved when the fat content was adjusted to 2.5% in the resultant low-fat ice cream, whereas the total solids ranged from 30.59% to 34.84% (Table 2). The increase in the total solids was attributed to the addition of inulin.

The results indicate that the addition of inulin altered the rheological properties of the ice cream samples. The addition of 2.5% inulin significantly increased the viscosity of the low-fat ice cream mixtures ($p < 0.01$) (Table 1). This result is in agreement of those reported by **(Akalin & Erisir 2008)**, who reported significant differences in viscosities among all mixtures and found that the viscosities of the mixtures increased with the addition of oligofructose or inulin. The increased viscosities of the inulin-supplemented ice cream mixtures appear to have been caused by the contribution of soluble fibres to the composition of the aqueous phase to increase the total solids **(Soukoulis, Lebesi, & Tzia 2009).** The increase in the viscosities of the low-fat samples containing inulin can be explained by the interactions of the dietary fibre and liquid components of the ice cream mixture **(El-Nagar, et al., 2002).** Furthermore, **Adapa, et al.,(2000)** noted that ice cream mixtures containing carbohydrate-based fat replacers exhibit a viscous behaviour because of their ability to imbibe water, which increases the viscosity of the system. However, **Akalin et al. (2008)** reported that the viscosity values did not vary between the samples of regular ice cream and reduced-fat or low-fat ice cream containing inulin.

The results in Table 1 also revealed that increasing the amount of inulin added to 5% significantly decreased the apparent viscosity of the low-fat ice cream mixture ($p < 0.01$), possibly due to the initial formation of inulin aggregates during the aging of the ice cream mixture at 5°C for overnight. These aggregates would contain inulin crystals with significant amounts of entrapped fluid, leading to an increase in the volume fraction of the dispersed phase **(Meyer, et al., 2011 and Bot, et al.,2004).** When 6% inulin was added to skimmed milk, the milk beverages appeared less viscous and less creamy than the whole-milk sample **(Meyer, et al., 2011).**The hardness of the low-fat ice cream increased gradually but significantly with the addition of 2.5% or 5% inulin ($p < 0.01$) (Table 1). The same results were reported by **Meyer, et al., 2011; Akalin, et al., 2008; Akalin & Erişir 2008.** The hardness of the low-fat ice cream containing inulin is likely dependent on the high degree of polymerisation and the long chain length. Inulin has the ability to form inulin microcrystals because of its long chain length when sheared in water or milk. These microcrystals interact to form a creamy texture and likely increase the hardness of the ice cream **(Akalin, et al., 2008; Niness 1999).**

The results in Table 1 indicate that the addition of 2.5% inulin significantly increased the adhesiveness of the low-fat ice cream ($p < 0.01$). This result is in agreement with **Akalin, et al. (2008)** and **Aime, et al., (2001)**. Increasing the amount of inulin added to 5% slightly reduced the adhesiveness of the low-fat ice cream, possibly due to the gelling properties of inulin, as mentioned above.

The addition of 2.5% or 5% inulin to the low-fat ice cream significantly increased the values of cohesiveness, chewiness, gumminess, and elasticity ($p < 0.01$, Table 1). In general, adding 2.5% inulin increased cohesiveness, gumminess, and elasticity more than adding 5% inulin to the low-fat ice cream. **Meyer, et al., (2011)** and **Scheller, et al., (2001)** found that inulin altered the texture and rheology of ice cream by increasing the ice cream's chewiness, flow consistency, and pseudo-plasticity. These researchers suggested that such changes in the product quality might be due to competition for water for hydration and/or interactions between inulin and milk proteins.

Table 1. Rheological properties of low-fat ice cream fortified with inulin (mean ± SD, n = 3).

Rheological properties	**Inulin %**		
	0	**2.5**	**5**
Viscosity (mPa s)	800.67 ± 1.53 ^{b}	928.0 ± 1.0 ^{a}	720.0 ± 1.0 ^{c}
Hardness (N)	50.16 ± 0.06 ^{c}	59.88 ± 0.15 ^{b}	61.42 ± 0.79 ^{a}
Adhesiveness (N/s)	19.85 ± 1.0 ^{b}	25.28 ± 0.52 ^{a}	18.86 ± 0.06 ^{b}
Cohesiveness	0.0605 ± 0.008 ^{c}	0.1350 ± 0.52 ^{a}	0.0869 ± 0.006 ^{b}
Chewiness	2.15 ± 0.37^{c}	7.99 ± 0.61^{a}	3.66 ± 0.28 ^{b}
Gumminess	3.03 ± 0.39 ^{c}	8.09 ± 0.39 ^{a}	5.34 ± 0.37 ^{b}
Elasticity	0.707 ± 0.07 ^{b}	0.989 ± 0.01 ^{a}	0.686 ± 0.08 ^{b}

^{a,b,c} Superscripts that are different in each row indicate significantly different outcomes at $p < 0.01$.

The results in Table 2 demonstrate that the addition of 2.5% or 5% inulin had an insignificant effect on the overrun of the low-fat ice cream ($p < 0.01$). Similar results were reported by **Akin, et al.,(2007),** who found that the addition of inulin had an insignificant effect on the overrun values of the ice cream samples. The ice cream mixtures containing inulin exhibit a viscous behaviour because of their ability to absorb water, which would increase the viscosity of the system. This increased viscosity might be the main reason for the decreased whipping ability of the ice cream samples with inulin added **(Adapa, et al., 2000).**

The incorporation of 2.5% and 5% inulin into the low-fat ice cream significantly decreased the meltdown rate, as shown in Table 2 ($p < 0.01$). The samples with inulin lost their shape and melted more quickly than those without inulin. **Akalin et al. (2008)** found that ice cream made with inulin melted significantly faster than the samples without inulin. Moreover, **El-Nagar et al., (2002)** found that adding increased amounts of inulin to yoghurt-ice cream mixtures reduced the melting rate of the frozen product.

Fat instability refers to the clustering, flocculation, and clumping process (partial coalescence) of the fat globules, which leads to the development of a continuous internal fat network or matrix structure in the product **(Al-saleh, et al., 2011; Goff,' & Jordan 1989).** Fat instabilisation during the freezing process of ice cream plays a role in determining the elasticity of the product **(Adapa et al., 2000).** The results in Table 2 demonstrate that the addition of inulin had an insignificant effect on the fat instability of the low-fat ice cream.

The fat instabilisation mechanism in ice cream involves the breakage of protein-lipid membranes, which surround the fat globules during freezing, as well as a part of the liquid fat release, which acts as a cementing agent between the damaged globules **(Al-saleh et al., 2011; Berger, 1990).** The differences between the instabilised fat content in the ice cream made from cow-milk constituents supplemented with inulin and low-fat ice cream made without inulin addition were insignificant ($p < 0.01$), possibly due to the lower fat content. Thus, the inulin content had no significant effect on the fat instability during the freezing process.

Table 2. Physicochemical properties of low-fat ice cream fortified with inulin (mean ± SD, n = 3).

Physicochemical properties	**Inulin %**		
	0	**2.5**	**5**
Total solids (%)	30.59 ± 0.44 [b]	32.26 ± 0.3 [b]	34.84 ± 0.93 [a]
Overrun (%)	68.51 ± 3.31 [a]	57.21 ± 7.54 [a]	61.74 ± 4.04 [a]
Meltability (minutes to collect 20 mL of melt)	100 ± 1.0 [a]	52 ± 1.0 [b]	45 ± 1.0 [c]
Fat instability (%)	5.74 ± 1.08 [a]	7.46 ± 1.91 [a]	6.72 ± 1.56 [a]

[a,b,c] Superscripts that are different in each row indicate significantly different outcomes at $p < 0.01$.

The results of the low-fat ice cream supplemented with 2.5% and 5% inulin (Table 3) revealed that the addition of inulin significantly improved the sensory properties of the low-fat ice cream, including the mouthfeel, texture, body, and flavour ($p < 0.01$). The improvement in the mouthfeel of the low-fat ice cream supplemented with 2.5% and 5% inulin may be related to the ice cream's increased meltability. These results are in agreement with those of **El-Nagar et al. (2002).** The improved texture and body of the low-fat ice cream supplemented with 2.5% and 5% inulin may be associated with the ice cream's increased hardness. The role of inulin as a fat replacer changes not only rheological properties, such as the hardness, but also other mouthfeel attributes, such as creaminess or smoothness.

Table 3. Sensory evaluation of low-fat ice cream fortified with inulin (mean ± SD, n = 11).

Characteristics (five-point scale)	**Inulin %**		
	0	**2.5**	**5**
Mouthfeel	2.91 ±0.831 [b]	3.82 ± 0.873 [a,b]	4.64 ± 0.674 [a]
Texture	2.82 ± 1.328 [b]	4.18 ± 0.404 [a]	4.36 ± 0.504 [a]
Body	3 ± 1.183 [b]	4 ± 0.774 [a,b]	4.5 ± 0.687 [a]
Flavour	3.18 ± 1.167 [a]	4 ± 0.774 [a]	4.18 ± 0.981 [a]
Total Score	2.82 ± 1.167 [b]	4.18 ± 0.603 [a]	4.64± 0.504 [a]

[a,b] Superscripts that are different in each row indicate significantly different outcomes at $p < 0.01$.

4. Conclusions

The supplementation of low-fat ice cream with inulin is an effective way to enhance the ice cream's nutritional and rheological aspects. The viscosity, hardness, cohesiveness, adhesiveness, chewiness, gumminess, elasticity, and meltability of the low-fat ice cream were significantly affected by the addition of inulin. In contrast, the addition of inulin had no significant effect on the overrun or fat instability of the low-fat ice cream. Furthermore, inulin can noticeably improve the mouthfeel attributes of the ice cream, which is critical for the successful development low-fat inulin-enriched products with good sensory attributes.

5. Acknowledgments

The authors would like to extend their sincere appreciation to the Deanship of Scientific Research at King Saud University for its funding of this research through the Research Group Project no. RGP – VPP – 232.

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8/12/2013