Frozen yogurt with added inulin and isomalt

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ABSTRACT

The objective of this study was to produce a frozen yogurt containing low fat and no added sugar. Samples containing 5% polydextrose, 0.065% aspartame and acesulfame-K mixture, and different levels of inulin and isomalt (5.0, 6.5, and 8.0%) were produced at pilot scale and analyzed for their physical and chemical properties including proximate composition, viscosity, acidity, overrun, melting rate, heat shock stability, as well as sensory characteristics, and viability of lactic acid bacteria. With the addition of inulin and isomalt, viscosity increased by 19 to 52% compared with that of sample B (reduced-fat control). The average calorie values of samples substituted with sweeteners were about 43% lower than that of original sample. Low-calorie frozen yogurt samples melted about 33 to 48% slower than the reduced-fat control sample at 45 min. Based on quantitative descriptive profile test results, statistically significant differences among products were observed for hardness, iciness, foamy melting, whey separation, and sweetness characteristics. The results of principal component analysis showed that the sensory properties of the sample containing 6.5% inulin and 6.5% isomalt were similar to those of control. Lactic acid bacteria counts of frozen yogurt were found to be between 8.12 and 8.49 log values, 3 mo after the production. The overall results showed that it is possible to produce an attractive frozen yogurt product with the incorporation of inulin and isomalt with no added sugar and reduced fat.

Key words: frozen yogurt, inulin, isomalt

INTRODUCTION

Frozen yogurt as also known as yogurt ice cream, characterized by the acidic taste of yogurt and the cooling effect of ice cream (Tamime and Robinson, 1999), is a dairy product produced with *Streptococcus*

thermophilus or *Lactobacillus delbrueckii* spp. *bulgaricus* (Hui, 1992; Marshall et al., 2003). Survival of yogurt cultures in frozen yogurt has great importance for the therapeutic image of the product, as yogurt has been a healthful product with high biological value (Tamime and Robinson 1999) and probable benefits, which are improvement of the immune system by destruction of bacterial cells, lactose digestion, regularity of intestinal flora, detoxification of harmful products, reduction of carcinogenic end products, and suppressing the multiplication of food-sourced pathogens (Hui, 1993). In addition, frozen yogurt is expected to present acceptable quality of flavor, body, texture, cooling effect, viscosity, whipping ability, and freezing properties of dairy frozen desserts (Chandan, 1997).

Several researchers focused on producing functional frozen yogurt or yogurt ice cream containing stabilizers (Martinou-Voulasiki and Zerfiridis, 1990), inulin (El-Nagar et al., 2002), fat-replacers (Kaur et al., 2007; Aykan et al., 2008), or different hydrocolloids (Soukoulis and Tzia, 2008), and several others investigated the characteristics of these products (Inoue et al., 1998; Zhenjian and Haili, 2003; Özdemir et al., 2005; Singh et al., 2006; Guner et al., 2007). However, limited information is available on the properties of functional frozen yogurt having fat and sugar replacements.

To produce a low-calorie frozen yogurt, inulin and sugar alcohols deserve particular attention. Inulin, a soluble dietary fiber, can be used to improve the quality of the product with nutritional and technological advantages (Franck, 1998; Rowan, 1998). Addition of inulin in low-fat frozen yogurt formulation (El-Nagar et al., 2002) or using inulin as a corn syrup replacer in reduced-fat ice cream (Schaller-Povolny and Smith, 1999, 2001, 2002) are good examples of its application in frozen desserts. On the other hand, sugar alcohols, such as isomalt, are used as sugar replacers in frozen desserts (Marshall and Goff, 2003) for their low glycemic index (Macrae et al., 1993) and low caloric value (McNutt and Sentko, 1996).

The objective of this study was to produce a low-calorie frozen yogurt containing reduced fat and no added sugar, which were replaced with inulin, isomalt, polydextrose, and intensive sweeteners, and having acceptable rheological and sensory attributes.

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Table 1. Frozen yogurt formulations¹

Sample	Description	Inulin (%)	Isomalt (%)
A	Control (with sugar and whole fat)	—	—
B	Control (with sugar and reduced fat)	—	—
C	No sugar and reduced fat	8.0	5.0
D	No sugar and reduced fat	6.5	6.5
E	No sugar and reduced fat	5.0	8.0

¹Each formulation was replicated twice. The total solids amount was 35.13% (6% fat) in sample A and 32.13% (3% fat) in the rest of the samples. Sugar (18%) in samples A and B was replaced 100% by inulin + isomalt + polydextrose (wt/wt) in samples C, D, and E, which also contained 5% polydextrose and 0.065% aspartame/acesulfame-K mixture (at a proportion of 70:30).

MATERIALS AND METHODS

Ingredients

Food additives were polydextrose (Litesse-Ultra, Danisco Sweeteners, Copenhagen, Denmark), inulin (Raftiline GR, Dora Company, Istanbul, Turkey), and isomalt (Palatinit ST-PF, Kurmed Company Ltd., Istanbul, Turkey). Starter cultures (MYE-96), yogurt and thermophilic culture development medium (Thermo W1) were obtained from the Maysa Company, Istanbul, Turkey. All of the production trials were carried out at pilot scale in a commercial ice cream manufacturing plant in Turkey.

Experimental Design

Before starting to produce different formulations of frozen yogurt samples (5 different formulations as described in Table 1), the optimum pH value of the product (control sample formulation, sample A in Table 1) was evaluated by conducting a consumer preference and acceptance test (Meilgaard et al., 2007). Forty kilograms of samples having 2 different pH values (pH 4.8 and 5.2) were produced and evaluated by 88 panelists using a simple comparison sensory test. In the test, one sample pair was provided for each panelist by balancing the presentation of samples and then the panelists were asked for their preference, degree of liking, and purchase intent for the preferred sample. The degree of liking was evaluated on a category scale composed of 7 scores: 1 (extremely dislike), 2 (dislike), 3 (slightly dislike), 4 (neither like nor dislike), 5 (lightly like), 6 (like), and 7 (extremely like). In addition, the panelists were asked to evaluate their purchase intent on a category scale composed of 5 points: 1 (definitely will not buy), 2 (probably will not buy), 3 (not sure), 4 (will probably buy), and 5 (will definitely buy).

Based on the preference of the panelists, the pH value of the samples was determined, and 5 new formulations were prepared using 40-kg batches (Table 1). These

samples were further analyzed for their composition, viscosity, melting rate, sensory characteristics, and lactic acid bacteria (**LAB**) count.

Frozen Yogurt Production

Ingredients were weighed to obtain a 40-kg mixture for each batch of production. The formula of frozen yogurt samples used in the study was designed according to the original recipes of a commercial ice cream manufacturing plant in Turkey (Algida, Unilever Inc., Tekirdağ). Nonfat milk solids (10.5%), sweetening agents (sugar or inulin + isomalt + polydextrose + aspartame + acesulfame-K, Raftiline GR, Dora Company; Palatinit St-PF, Kurmed Company Ltd.; Litesse-Ultra, Danisco Sweeteners), and stabilizer mixture (0.1% locust bean gum + 0.1% guar gum + 0.1% carboxymethylcellulose + 0.03% carrageenan + 0.3% emulsifier; Algida, Unilever Inc.) were incorporated with cream and water in a mixing tank. Then, the mixture was heated at 85°C for 10 min and homogenized under a pressure of 190 bar. The mixture was cooled down to 44°C and transferred into a sterile container (approximately 37-kg mix). Following the inoculation of 5% starter culture, the mixture was incubated at 40°C until a pH value of 5.2 was reached. The samples with a pH of 4.8 used for the consumer preference and acceptance test were also produced in the same manner. The cultured mixture was placed in a resting tank and cooled down to 5°C while stirring. Vanilla flavor (0.1%; oil-soluble, nature-identical flavor, Aromsa Food Flavor and Additives Co., Inc., Istanbul, Turkey) was added at this stage, and cultured mixture was pumped into the ice cream freezer (Hoyer freezer MF50, APV Technohoy, Axel Kiers Vej 28–30, Aarhus-Højbjerg, Denmark) where the temperature of the samples reached –6°C. The samples were then packed into 1-, 2-, and 5-L plastic cups and placed in a freezer at –23°C. The samples were then transferred from Algida, Unilever Inc., to the laboratories of Istanbul Technical University (Turkey) and stored at –18°C until analysis.

Starter Culture Propagation

Main yogurt cultures used to prepare the intermediate cultures were obtained in freeze-dried form (MYE-96, Maysa Company). The processing culture used for the production of frozen yogurt samples was prepared from this intermediate culture under sterile conditions (Istanbul Trade Organization, 1985). In the preparation of intermediate culture, thermophilic culture development medium (Thermo W1) was used instead of milk. Sixty grams of medium was dissolved in 940 g of water and heated up to 90°C while stirring. After keeping at 90°C for 10 min, the medium was cooled down to 45°C. Main culture (0.02 g of main culture for 1 kg of milk that has been treated at 90°C for 10 to 15 min) was added to the mixture at 45°C, incubated for 4 h at 43°C and stored at 4°C. Intermediate culture preparation was repeated for every week of production.

Processing cultures were prepared separately for each batch, the day before production. Two hundred sixty-four grams of nonfat milk solids was added to 1,936 g of water to obtain 12% total solids and mixed for 2 min. Then, it was prepared similarly to the intermediate culture, except for adding 3% intermediate culture (66 g) instead of the main culture. The pH was tracked using a hand pH meter (MP120 pH meter, Mettler-Toledo GmbH, Schwerzenbach, Switzerland) and the mix was cooled as the pH reached 4.6 and stored at 4°C the day before production. Processing culture (5%) was added to the frozen yogurt mix (weighed as approximately 37 kg after the pasteurization and homogenization steps).

Analysis of Composition and Calculation of Overrun

Sample preparation was performed according to AOAC, 969.20 (AOAC, 2002). Total solids and protein analyses were based on AOAC 941.08 and 930.33 (AOAC, 2002), respectively. Ash content and acidity were analyzed using AOAC methods 945.46 and 947.05, respectively (AOAC, 2002). Fat content was analyzed by Turkish Standard (TS) method 4265 (TSE, 1992). Carbohydrate content was determined by the calculation method and the calorie values were calculated according to the energy conversion factors in the Turkish Food Codex (Notice No. 2002/58; Turkish Ministry of Agriculture, 2002). Based on the Codex, the conversion factor for carbohydrates (excluding sugar alcohols) is 4 kcal/g; for sugar alcohols, 2.4 kcal/g; for proteins, 4 kcal/g; for fats, 9 kcal/g (Turkish Ministry of Agriculture, 2002); for inulin, 1.5 cal/g (Boeckner et al., 2001); and for polydextrose, 1 kcal/g (Craig, 2000). Overrun values of the samples were calculated according to the method by Goh et al. (2008).

Analyses of Viscosity and Melting Rate

Before freezing, viscosities of the frozen yogurt mixtures were measured for each batch using a Brookfield Viscometer (model DV-II, spindle no. 3 at 30 rpm at 5°C, 12 rpm at 6°C, and 6 rpm at 5.5°C) with 3 replications, according to Martinou-Voulasiki and Zerfiridis (1990) and El-Nagar et al. (2002).

For the melting rate test, a 2.5-mm iron wire mesh screen (Analysensieb, Retsch, D-5657 Haan, Germany) was used. The test was carried out according to the method of El-Nagar et al. (2002) with small modifications. Forty grams of cubic cut sample was placed on the screen, which was mounted on a beaker. The weight of the collected sample in the beaker was recorded at min 15, 30, and 45 of melting. The ratio of these values to the initial weight of frozen yogurt was calculated.

Quantitative Descriptive Profile Test

The sensory characteristics of the samples, including flavor, texture, and melting quality were evaluated by 9 trained panelists from the Department of Food Engineering of Istanbul Technical University. The samples that were stored at -18°C were taken out of the freezer and kept outside for approximately 5 min to reach the serving temperature of -15°C for the sensory analysis, as suggested by Hui (1993). The quantitative descriptive profile test (QDPT) was performed according to Meilgaard et al. (2007) and the quantitative descriptive analysis (QDA) method was applied according to Guinard et al. (1997) and Poste et al. (1991). Panelists were trained for 8 h at 4 sessions.

For the first training session, a terminology list for the texture and flavor attributes of frozen yogurt was prepared, combining the characteristics of ice cream and yogurt (Harper et al., 1991; Hui, 1992, 1993; Specter and Setser, 1994; Guinard et al., 1997; Davidson et al., 2000; Prindiville et al., 2000). The references that best described the product were selected from the literature (Harper et al., 1991; Guinard et al., 1997; Prindiville et al., 1999, 2000; Meilgaard et al., 2007); however, the panelists were free to give their own terms.

At the second training session, the list of terms was revised and the panelists were trained for using an unstructured line scale. The intensity of each reference was judged on an unstructured scale consisting of a horizontal 15-cm line (anchored by the words "none" and "very" at the 2 ends) by consensus of the panelists. The reference samples were supplied during each session.

The third training session was carried out in 3 stages; the first stage involved the individual evaluation of one

attribute of texture (creaminess) and one flavor characteristic (sweetness) using the reference samples; the second stage included the individual evaluation of all attributes for 2 samples with pH values of 4.8 and 5.2; and, at the third stage, a set of criteria for melting quality was developed by the panelists because no suitable references exist for this attribute.

Quantitative descriptive profile test sessions were performed in separate booths, and no special lighting (fluorescent lights) was used. To prevent the fatigue of the panelists, 5 samples were presented at each session and repeated 2 times. One ice cream spoonful of sample, which is approximately 30 g, was placed in each 150-mL plastic cup, covered, and stored in the freezer (-18°C) before analysis. Water and crackers with no sugar were served to the panelists to condition their mouths between testing of each sample. Frozen yogurt attributes, definitions, and references that were used in sensory analysis are given in Table 2.

Analysis of Lactic Acid Bacteria Count

Lactic acid bacteria count was performed in 2 parallels using the pour-plate method involving Elliker broth (Erkmen, 2000; Downes and Ito, 2001). Colonies were counted on the second day of incubation at 30°C . For the analysis, 25 g of frozen yogurt for each sample was weighed into the stomacher and placed in the freezer (0°C), and the dilutions in the range of 10^{-1} to 10^{-7} were prepared. Two hundred and fifty milliliters of 0.1% peptone water was added to the samples, which were then placed on a hot plate (45°C for 15 s) and homogenized for 2 min. (Erkmen, 2000; Downes and Ito, 2001).

Statistics

The results of the consumer preference and acceptance test that was performed to select the optimum pH value were evaluated according to the significance ($P < 0.05$) of preference values in the statistical tables of Meilgaard et al. (2007). The differences in scores of flavor, texture, and appearance, as well as consumer purchase intent of samples, were evaluated by *t*-test with Minitab 14.10 statistical software (Minitab Inc., State College, PA; $P < 0.05$). The differences in viscosity, LAB count, and overrun among formulations were investigated with completely randomized design with SPSS 9.0 statistical software (SPSS Inc., Chicago, IL) and the means were compared using the least significant difference test ($P < 0.05$). Principal component analysis (PCA) of QDPT was performed by Minitab 14.10 software (Minitab Inc.) using a correlation matrix. For the 5 formulations (A, B, C, D, and E) mean values of

the scores of flavor, texture and melting quality were determined and PCA was applied to this matrix.

RESULTS AND DISCUSSION

In the study, the preliminary consumer preference and acceptance test was performed to determine the pH value (pH 4.8 or 5.2) according to the preference of the consumers. The results showed that 69% of the panelists preferred the sample having a pH value of 5.2 in comparison to the sample with pH 4.8 (data not shown). As the preference of the panelists was statistically significant ($P < 0.05$), the pH of samples was adjusted to 5.2 in the following stages of the study. It is known that the pH value of frozen yogurt samples can be in a range of 4.3 to 5.3 and even in some cases between 4.0 and 5.7, based on the consumer's preference (Martinou-Voulasiki and Zerfiridis, 1990). Similar to our findings, the study of Inoue et al. (1998) showed that the highest total sensory scores were given to the sample having a pH of 5.5. The purchase intent of the preferred sample was between 4 (probably buy) or 5 (definitely buy) on a category scale (data not shown).

The compositions of all formulations were determined (data not shown). According to the results, the average total solid and fat contents of the control and reduced-fat samples were found to be 30.1 and 33.1%, and 3.2 and 6.1%, respectively. The average protein, ash, and carbohydrate contents of the control sample were 3.3, 0.9, and 22.8%, respectively. These results are in accordance with the values reported in the literature, where fat, protein, ash, and total solids contents were in the range of 1.8 to 5.9%, 3.5 to 3.8%, 0.7 to 1.0%, and 28.8 to 34.2%, respectively (Tamime and Robinson, 1999; Tamime, 2006).

Acidity of the samples was in between 0.69 and 0.72% in terms of lactic acid (data not shown). Similar values were reported by Guner et al. (2007) who reported that lactic acid levels higher than 0.7% caused progressive loss of sensory quality in the frozen yogurt samples. On the other hand, the pH of each formulation was adjusted to 5.2, and was controlled for each formulation during production.

Overrun is one of the most important characteristics of frozen desserts (Marshall et al., 2003), and it affects the texture as well as the price of the product. The targeted overrun in frozen yogurt samples was 80%, and it was observed to be between 70 and 78%, without any significant differences among the samples ($P < 0.05$).

The reduced-fat control sample (B) had a 15% lower energy value in comparison to the whole-fat control sample (A; Table 3). Also, the calorie values of samples C, D, and E were decreased by about 33% in comparison to sample B. On the other hand, the average calorie

Table 2. Frozen yogurt attributes of texture, flavor, and melting quality in addition to their definitions and references used for scaling

Attribute	Definition	Reference and intensity ^{1,2}
Texture		
Hardness	The force applied to the spoon for inserting into the frozen yogurt at an angle of 90°	Pinar kashkaval cheese (13) Pinar triangular melted cheese (9) Sana soft margarine (1)
Crumbliness	Tendency of frozen yogurt to break down when spooned	Dr. Oetker powdered ice cream (reconstituted with milk) (13)
Melting rate	The rate of transition from solid to liquid phase in mouth	Algida Maras type ice cream ³ (8)
Iciness	Size and abundance of ice crystals that do not melt immediately	Algida Maras type ice cream (0) Dr. Oetker powdered ice cream (reconstituted with milk) (5) Hüptirik yogurt tube (frozen) (13)
Sandiness	Presence of crystals that melt slowly and remain on tongue	Sek yogurt (0) Sek yogurt with added 1 coffee spoonful of desiccated coconut (Malatya Pazari) (15)
Fluffiness	Air content perceived when frozen yogurt is taken into mouth	Sek yogurt (0) Algida Maras type ice cream (9)
Chewiness	Chewy characteristic of frozen yogurt	Dr. Oetker whipped cream (14) Sek yogurt (0)
Smoothness	Absence of grainy structure and smooth texture of frozen yogurt during chewing	Kremini milky toffee (14) Hüptirik yogurt tube (frozen) (2) Dr. Oetker powdered ice cream (prepared with milk:water at a ratio of 1:1) (10)
Creaminess	Creamy mouth feel perceived while the frozen yogurt is melting in the mouth	Algida Maras type ice cream (15) Sek skim milk (1) Sek whole milk (7)
Fatty	Oily feeling such as coating the palate of the mouth	Sek cream (14) Sek yogurt (4) Mixture of yogurt:cream (Sek) at a ratio of 1:1 (9) Sek cream (14)
Flavor		
Sweetness	Sweet/sugar taste	Sucrose solutions in water 5.0% (5) 10.0% (10) 16.0% (15)
Acidity	Sour taste	Citric acid solutions in water 0.05% (2) 0.08% (5) 0.20% (15)
Astringency	Puckery flavor	Dimes grape juice (5) Tamek rose hip jam (7)
Yogurt flavor	Yogurt flavor	1:1 mixture of yogurt:water (Sek) (7.5) Sek yogurt (15)
Vanilla flavor	Vanilla flavor	Sek yogurt (0) Sek yogurt with sugared vanilla powder (Migros) (10)
Negative aftertaste	Unpleasant/negative aftertaste	
Melting quality		
Melting resistance	Resistance of a spoon of frozen yogurt to melting after left for standing about 10 to 15 min at room temperature	
Foamy melting	Presence of big and stable air bubbles remaining in the melted frozen yogurt	
Curdled melting	Melting into clear small particles rather than a smooth and uniform white liquid. A solid with curd particles will be observed.	
Whey separation	Separation of the serum and solid phase during melting	
Watery melting	Poor and watery consistency of melted frozen yogurt	

¹Numbers shown in parenthesis for the references indicate the intensity of the reference on an unstructured scale consisting of a horizontal 15-cm line anchored with the words “none” and “very” at the ends.

²References: Algida Maras type ice cream, Kremini (milky chewy candy/toffee), Dr. Oetker ice cream powder, Dr. Oetker whipped cream powder, Hüptirik yogurt tube (frozen), Sek yogurt, skim milk, whole milk, cream, Dimes grape juice, Tamek rose hip jam, Migros powdered sugar with vanilla, citric acid and sucrose solutions. The references were obtained from a local supermarket in Istanbul, Turkey.

³Algida Maras type ice cream is a commercial product that is characterized by its smooth structure.

Table 3. Texture, flavor, and melting quality scores of frozen yogurt samples¹

Attribute	Sample				
	A	B	C	D	E
Texture					
Hardness	7.8 ± 3.4 ^b	8.4 ± 3.0 ^b	9.5 ± 3.3 ^{ab}	7.9 ± 4.8 ^b	10.4 ± 3.0 ^a
Crumbliness	9.0 ± 2.6 ^a	9.2 ± 3.1 ^a	9.3 ± 3.4 ^a	8.4 ± 4.1 ^a	9.3 ± 3.5 ^a
Melting rate	9.4 ± 2.3 ^a	9.8 ± 2.3 ^a	9.8 ± 1.9 ^a	10.0 ± 2.2 ^a	9.8 ± 2.4 ^a
Iciness	4.0 ± 2.5 ^b	4.7 ± 2.7 ^{ab}	4.3 ± 2.7 ^{ab}	3.9 ± 2.5 ^b	5.5 ± 2.8 ^a
Sandiness	1.1 ± 1.2 ^a	1.6 ± 1.7 ^a	1.3 ± 1.4 ^a	1.3 ± 1.5 ^a	1.6 ± 1.7 ^a
Fluffiness	10.0 ± 2.2 ^a	9.9 ± 2.6 ^a	10.0 ± 1.9 ^a	10.4 ± 1.7 ^a	9.7 ± 2.6 ^a
Chewiness	2.7 ± 1.9 ^a	2.7 ± 1.9 ^a	2.9 ± 2.1 ^a	2.6 ± 2.2 ^a	3.2 ± 2.1 ^a
Smoothness	12.3 ± 2.0 ^a	11.3 ± 2.8 ^a	12.1 ± 2.3 ^a	12.5 ± 2.0 ^a	11.5 ± 2.7 ^a
Creaminess	8.3 ± 3.2 ^a	7.6 ± 3.3 ^a	8.2 ± 2.9 ^a	7.7 ± 3.4 ^a	8.0 ± 3.3 ^a
Oiliness	7.8 ± 2.3 ^a	7.2 ± 2.4 ^a	7.8 ± 2.4 ^a	7.6 ± 2.4 ^a	7.9 ± 2.3 ^a
Flavor					
Sweetness	7.4 ± 1.6 ^b	7.3 ± 1.9 ^b	7.9 ± 1.8 ^{ab}	7.5 ± 1.7 ^b	8.5 ± 2.0 ^a
Acidity	4.2 ± 1.6 ^a	4.1 ± 1.7 ^a	4.2 ± 1.9 ^a	3.9 ± 1.9 ^a	4.1 ± 2.0 ^a
Astringency	2.7 ± 1.7 ^a	2.5 ± 1.8 ^a	2.6 ± 1.5 ^a	2.5 ± 1.7 ^a	2.8 ± 1.5 ^a
Yogurt flavor	5.4 ± 2.3 ^a	5.3 ± 2.2 ^a	5.4 ± 2.1 ^a	4.8 ± 2.2 ^a	5.4 ± 2.3 ^a
Vanilla flavor	5.7 ± 2.3 ^a	5.5 ± 2.4 ^a	5.9 ± 2.3 ^a	5.8 ± 2.5 ^a	5.9 ± 2.6 ^a
Negative aftertaste	0.9 ± 1.2 ^a	1.0 ± 1.5 ^a	0.8 ± 1.3 ^a	0.8 ± 1.5 ^a	1.3 ± 1.8 ^a
Melting quality					
Melting resistance	7.7 ± 2.6 ^a	7.8 ± 2.9 ^a	7.3 ± 2.8 ^a	6.8 ± 3.1 ^a	7.2 ± 3.1 ^a
Foamy melting	0.3 ± 0.8 ^b	1.0 ± 1.3 ^a	0.4 ± 0.8 ^{ab}	0.4 ± 0.6 ^b	0.4 ± 0.9 ^{ab}
Curdled melting	7.5 ± 3.2 ^a	7.2 ± 3.2 ^a	8.8 ± 2.8 ^a	7.2 ± 4.1 ^a	8.6 ± 3.4 ^a
Whey separation	6.2 ± 4.1 ^{ab}	6.3 ± 4.1 ^{ab}	7.6 ± 4.0 ^{ab}	5.8 ± 4.2 ^b	8.1 ± 4.2 ^a
Watery melting	6.9 ± 2.8 ^a	7.3 ± 2.6 ^a	7.4 ± 3.1 ^a	7.3 ± 3.3 ^a	7.3 ± 2.8 ^a

^{a,b}Values having different letters in rows are significantly different ($P < 0.05$).

¹Values represent the means and standard deviations of 4 replications with 9 panelists ($n = 36$). Sample A = control (with sugar and whole fat), sample B = control (with sugar and reduced fat). Samples C–E had no sugar and reduced fat, and contained 5% polydextrose and 0.065% aspartame/acesulfame-K mixture (at a proportion of 70:30). Sample C also contained 8.0% inulin and 5.0% isomalt; sample D contained 6.5% inulin and 6.5% isomalt; and sample E contained 5.0% inulin and 8.0% isomalt.

values of samples substituted with sweeteners (C, D, and E) were about 43% lower than that of the control sample A (containing sugar). Therefore, these samples could be defined as low calorie according to the Turkish Food Codex, where low-calorie foods are expected to have 25% lower calorie values in comparison with the original formulation (control; Turkish Ministry of Agriculture, 2002).

The viscosity values of all formulations are shown in Figure 1. Viscosities of 5 formulations showed statistically significant differences ($A > C > D > E > B$) from each other ($P < 0.05$). The viscosity of the reduced-fat control sample (B) was significantly lower (38–46%) than that of the whole-fat control sample (A). Because the sucrose amount (18%) is identical in both samples, the viscosity decrease may be associated with the decreased fat and total solid contents. On the other hand, the viscosities of low-calorie products (C, D, and E) were observed to be higher (29.8, 19.3, and 15.4%, on average, respectively) than that of the reduced-fat control sample (B). As the total solids and polydextrose levels are constant in the samples having no sugar and reduced fat, the variation in viscosities among these samples ($C > D > E$) are expected to be related to the addition of inulin and isomalt ingredients. The ad-

dition of inulin and isomalt increased the viscosity of samples C, D, and E at a level of 52, 27, and 19%, respectively, in comparison to the reduced-fat control at 6 rpm (5.5°C; Figure 1). However, the viscosities of those samples were lower by about 18.3 to 32.8% than that of the whole-fat control sample (Figure 1). Schaller-Povolny and Smith (2001) observed that the substitution of corn syrup with inulin increased the viscosity and the consistency of the fat-reduced ice cream samples. In another study, investigating the effects of inulin and whey protein concentrate on the physicochemical properties of mango flavored frozen yogurt, it was observed that incorporation of inulin increased the viscosity, whereas supplementation with whey protein concentrate alone decreased it (Kaur et al., 2007). Increased viscosity in the reduced-fat samples containing inulin can be explained by the interactions of the dietary fiber and liquid components of the frozen yogurt mix. Inulin, being highly hygroscopic, would bind water and form a gel-like network that, in addition to the other components, would modify the rheology of the mix (El-Nagar et al., 2002).

The results of the melting rate measurements are shown in Figure 2. The most rapid melting was observed in the reduced-fat sample B (71% at min 45) having de-

Figure 1. Viscosity of yogurt ice cream samples ($n = 6$). Sample A = control (with sugar and whole fat), sample B = control (with sugar and reduced fat). Samples C–E had no sugar and reduced fat, and contained 5% polydextrose and 0.065% aspartame/acesulfame-K mixture (at a proportion of 70:30). Sample C also contained 8.0% inulin and 5.0% isomalt; sample D contained 6.5% inulin and 6.5% isomalt; and sample E contained 5.0% inulin and 8.0% isomalt.

creased levels of fat and total solid amounts compared with the control sample (A). Low-calorie frozen yogurt samples (C, D, and E) melted more slowly (33–48% at min 45) than did the reduced-fat control (B); on the other hand, particularly samples D and E melted more rapidly (50 and 44%, respectively) than did the whole-fat control sample (A), which had a melting rate of 32% at min 45. (Figure 2). Sample C, having the

Figure 2. Melting rates of yogurt ice cream samples measured at min 15, 30, and 45. Values represent the means of 4 replications ($n = 4$). Sample A = control (with sugar and whole fat), sample B = control (with sugar and reduced fat). Samples C–E had no sugar and reduced fat, and contained 5% polydextrose and 0.065% aspartame/acesulfame-K mixture (at a proportion of 70:30). Sample C also contained 8.0% inulin and 5.0% isomalt; sample D contained 6.5% inulin and 6.5% isomalt; and sample E contained 5.0% inulin and 8.0% isomalt.

highest inulin and lowest isomalt levels, was evaluated to be the closest product to the control sample (A), because of its low melting rate and similar melting trends. In the melting test, the first drip points, in terms of minutes, were in the order of A (13.5) > C (11.5) > D (10.8) > B (9.8) > E (8.5). Based on the first drip point value, sample C was again observed to be similar to the control sample (A). Melting rate and the appearance of the melted mix are considered significant characteristics of ice cream (Hui, 1993). Melting rate is especially important when the ice cream is consumed in an ice cream cone. Rapid melting of the product is an indicator of low quality, and such products would also cause problems, as they will easily be affected by heat shock. Products having too much air or fat tend to melt slowly. Air bubbles act as an isolation material and fat stabilizes the foam structure (Marshall et al., 2003).

The sensory scores measured by the QDPT test are presented in Table 3. Statistically significant differences among products were only found for the characteristics including hardness, iciness, sweetness, foamy melting, and whey separation ($P < 0.05$). Except for the foamy melting attribute, no significant difference in any of the sensory characteristics between control samples A and B were found ($P < 0.05$). Sample C and E had the highest levels of the hardness textural attribute, which are followed by the order B > D > A. The hardness characteristic was found to be statistically different in sample E in comparison with the samples A and B ($P < 0.05$). The lowest level of iciness was observed for sample D among the low-calorie formulations, which was not statistically different from the control sample (A). However, the difference in the iciness attribute was statistically significant between samples D and E ($P < 0.05$; Table 3).

Isomalt addition at a level of 8.0% (sample E) resulted in significantly higher sweetness scores ($P < 0.05$). However, no significant difference was observed in sweetness of samples C (5% isomalt) and D (6.5% isomalt) compared with the control samples (Table 3). Several studies have pointed out the advantages of using isomalt in different food materials, such as the improvement of the sensory attributes and contribution to the nutritive value (McNutt and Sentko, 1996; Gostner et al., 2006; Radowski, 2006).

According to the scores of melting quality, foamy melting, and whey separation, properties were significantly different between samples ($P < 0.05$; Table 3). Sample B (reduced-fat control) had the highest foamy melting characteristic, which was found to be statistically different from samples A and D ($P < 0.05$), although no significant difference between the rest of the samples was present. In addition, whey separation was highest

in sample E and lowest in sample D (Table 3) and the difference between these samples was statistically significant ($P < 0.05$), whereas no differences between samples A, B, and C were observed. Contrary to the proposal of El-Nagar et al. (2002), indicating a clear relationship between increased inulin levels and improved melting properties in frozen yogurt, no significant effect of inulin addition on melting attributes was observed ($P < 0.05$) in this study.

These results showed that inulin addition in a range of 6.5 to 8.0% slightly affected the sensory attributes of frozen yogurt samples. Akin (2005) reported that the addition of inulin improved viscosity, first dripping, and complete melting times, but had no effect on the sensory properties of probiotic fermented ice-cream. In another study, a good quality frozen yogurt was prepared by blending inulin at a level of 3% in yogurt mix. However, the results of this study showed that the sensory properties of frozen yogurt were improved with increased fat and nonfat solids content (Kaur et al., 2007). On the other hand, according to Aykan et al. (2008), sensory evaluation of ice creams showed that the low-fat ice cream had a better taste and texture than did the control. In that study, it was claimed that, besides its health benefits, inulin also improved the taste and the texture of the low-fat ice cream (Aykan et al., 2008). Similarly, other studies reported that samples containing inulin as a fat replacer had higher scores for creamy, fatty, and smooth texture attributes in ice cream and frozen ice (Cho and Prosky, 1999; Boeckner et al., 2001; Koole and Meyer, 2001). The consumer acceptability of several low-fat foods containing inulin, such as ice cream, cookies, muffins, cakes, and beef sausages was investigated by Devereux et al. (2003). The results showed that these low-fat foods were rated as acceptable by an untrained test panel but they obtained consistently lower scores than their full-fat counterparts (controls). Regression analysis of that study showed that, unlike the controls, texture was more important than flavor in determining overall acceptability of the low-fat foods (Devereux et al., 2003).

The results of PCA are shown in Figure 3. The PCA was carried out on 2 principal components that were chosen by the common rules (Meullenet et al., 2007). The first principal component (PC1; X-axis) explained 45.3% of the total variation in the data set. This component points out the contrast of fluffiness with sweetness and yogurt sensory characteristics, such as yogurt flavor, acidity, and astringency. The second principal component (PC2; Y-axis) explained 24.9% of the total variation and corresponded to the contrast of sandiness with smoothness, creaminess, and vanilla flavor. According to the PCA diagram, the low-calorie formulations approaching the control sample (A) were

observed to be sample D (6.5% inulin + 6.5% isomalt) and, to some extent, sample C (8% inulin + 5% isomalt). Sample B was close to the control (A) with respect to PC1 but showed differences in attributes in the second principal component. On the other hand, samples C, D, and E were similar to the control (A) with respect to PC2 but showed significant differences in PC1 (Figure 3). The PCA was very useful in investigating the correlations among the attributes and in evaluating the samples all together in general. According to the values obtained by the PCA, some of the descriptors could be correlated (Lawless and Heymann, 1998). For example, creaminess, fatty texture, and smoothness attributes were found to be at the same region. Similarly, yogurt sensory characteristics like acidity, astringency, and yogurt flavor were close to each other and some texture attributes such as hardness, crumbliness, and iciness were found to be at close points on the PCA map (Figure 3).

After 3 mo of storage, the results of the LAB count showed white-colored, single-type colonies in frozen yogurt. The catalase test results were negative for the colonies. Lactic acid bacteria numbers of frozen yogurt samples were found to be in the range of 8.12 to 8.49 log. The whole-fat control (A) had significantly more LAB than did samples B (reduced-fat control), C, and D ($P < 0.05$). A decrease of fat and total solids content caused a significant decrease (0.34 log) in the LAB number ($A > B$). Similarly, Kim et al. (1993) reported higher LAB numbers in frozen yogurt samples prepared with full-fat milk powder than those of samples produced with skim milk powder. The results of the current study showed lower LAB numbers in samples containing 6.5 to 8% inulin (C and D), contrary to the findings of Božanić et al. (2002), which showed no effect of inulin on LAB counts of ice cream samples. Despite the fact that slight decreases occur during storage, it is generally expected that traditional yogurt cultures (*Strep. thermophilus* and *L. delbrueckii* ssp. *bulgaricus*; Bielecka et al., 1988; Hui, 1993; Lopez et al., 1998; Var et al., 2000), mixtures of probiotic and traditional yogurt cultures (Davidson et al., 2000; Ordonez et al., 2000), and probiotic cultures (Otero et al., 1996) survive in the frozen yogurt. Survival of LAB after 3 mo of storage of samples is in full alignment with these studies.

CONCLUSIONS

In the view of the results of the current study, it is apparent that addition of inulin and isomalt allows the production of a frozen yogurt with acceptable flavor and texture attributes, except for the melting quality (the occurrence of very few ice crystals was perceived by the panelists). Such troubles may be overcome by

Figure 3. Principal component analysis (PCA) of sensory attributes of yogurt ice cream samples. Sample A = control (with sugar and whole fat), sample B = control (with sugar and reduced fat). Samples C–E had no sugar and reduced fat, and contained 5% polydextrose and 0.065% aspartame/acesulfame-K mixture (at a proportion of 70:30). Sample C also contained 8.0% inulin and 5.0% isomalt; sample D contained 6.5% inulin and 6.5% isomalt; and sample E contained 5.0% inulin and 8.0% isomalt.

changing the types and levels of stabilizer/emulsifiers, which, in turn, will positively affect the viscosity. It is possible to produce an attractive frozen yogurt product with the incorporation of inulin and isomalt with no added sugar and reduced fat.

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