INTRODUCTION

The demand for health-promoting food products has been increasingly raised in recent years. Probiotic foods are the food products having sufficient population of viable probiotic microorganisms which promote beneficiary effects for the human body (Cruz et al., 2009). During the production of probiotic foods, the viability of probiotic microorganisms needs to be retained and the final product should contain at least

Production of synbiotic ice cream using Lactobacillus casei/Lactobacillus plantarum and fructooligosaccharides

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Abstract
Production of synbiotic ice creams formulated with fructooligosaccharides was performed in this study. Fermentation of ice cream mix was carried out using Lactobacillus casei and Lactobacillus plantarum. Fermented samples had lower pH and higher acidity than unfermented samples. The highest viability of probiotics during storage was associated with synbiotic ice creams, demonstrating a beneficial role of fructooligosaccharides for the growth of lactic acid bacteria (LAB). The highest degree of hydrolysis (DH) (9%–12%) and the highest 2,2-diphenyl-1-picrylhydrazyl radical scavenging activity (75%–78%) was associated with synbiotic ice creams. The results showed that melting postponed, and the apparent viscosity (μapp) was increased for the ice creams formulated with fructooligosaccharides. The maximum μapp (~2 Pa·s) and the highest gumminess (9,528.70 gf) and cohesiveness (0.32) were associated with the synbiotic ice cream having L. casei. Sensory analysis showed that the fermented ice creams had lower overall acceptability than the unfermented ice creams due to the high acidity as a consequence of LAB growth.

Novelty impact statement:
• A comparison between Lactobacillus plantarum and L. casei for the development of synbiotic ice creams showed that the ice cream fermented by L. casei had a higher apparent viscosity, gumminess, and cohesiveness.
• Addition of fructooligosaccharides to the ice cream mix inoculated with lactic acid bacteria reduced the adverse effect of LAB on the sensory properties.
• The incorporation of fructooligosaccharides and LAB resulted in the development of synbiotic ice creams with improved technos-functional properties and higher antioxidant activity compared to the control ice cream.
10^7 CFU/ml of probiotics (Di Criscio et al., 2010). Probiotics have several therapeutic and prophylactic effects such as antimicrobial activity, alleviation of symptoms of lactose intolerance, reduction of serum cholesterol level, antitumor activity, and immune stimulation (Lee, 2014). Different probiotic strains may have various health effects; thus, the characteristics of one strain are not necessarily similar to other strains. Therefore, selection of a proper strain is important for the manufacture of food probiotics (Daliri & Lee, 2015). To this end, several criteria should be met which include (but not limited to) the following: (a) Probiotics should have beneficial effects for the consumer health; (b) probiotics need to be selected from the GRAS list; (c) probiotics need to be highly reproducible; (d) probiotics should be able to ferment prebiotics; (e) probiotics in food products need to be genetically stable throughout their shelf-life; (f) the presence of probiotics and consequent fermentation should not cause any undesirable organoleptic changes in food products; (g) probiotics are preferred to be part of the natural flora of the human gastrointestinal tract; and (h) probiotics should suffer the conditions within the gastrointestinal tract.

The viability of probiotic microorganisms can be modified via changing different factors such as the probiotic strains used, the presence of hydrogen peroxide and dissolved oxygen, pH, the concentration of metabolites such as lactic and acetic acids, storage temperature, the nature of supplemented ingredients, and the food matrices (Shori, 2015). Dairy industry plays a key role to provide probiotic products for the consumers (Khalesi et al., 2017). Utilization of probiotic bacteria derived from dairy products is a promising strategy to balance the intestinal microflora, which may result in a healthy body. Among dairy products, ice cream is a suitable media for probiotics to survive for a longer period (Öztürk et al., 2018).

On the other hand, prebiotics are nondigestible compounds that selectively stimulate the growth or the activity of bacterial population in the colon which may also improve the growth and the survival of probiotics in the food products (EL-Sayed et al., 2015). Prebiotics, such as fructooligosaccharides, galactooligosaccharides, lactulose, lactitol and inulin, are often used as a source of carbon or nitrogen for the growth of probiotics and may also possess various therapeutic effects including constipation, improving the composition of the intestinal flora, increasing food calcium absorption resulting in osteoporosis prevention, preventing cancer cell growth, as well as improving and strengthening the immune system (Nobre et al., 2018). The use of prebiotics may also improve the nutritional quality of the end product via the inclusion of fibers in food products and being as a low-energy alternative ingredient for the fat molecules of the end products (Nobre et al., 2018). Among different prebiotics, fructooligosaccharides are broadly used in dietary, diabetic, and infant formula. A study showed that including of inulin and fructooligosaccharides in human diets increased the calcium absorption and enhanced the bone mineral content (Boscher et al., 2006). Recent studies demonstrated that fructooligosaccharides and galactooligosaccharides may stimulate the growth of some microorganisms, especially Lactobacillus and Bifidobacteria, in the intestine (Quigley, 2019).

Formulation of food products with a combination of probiotics and prebiotics may cause several therapeutic advantages (Villi, 2012). Consumption of these products, named synbiotics, is broadly recommended for the elderly and children and also to the specific groups requiring health-promoting foods. It has been reported that the use of synbiotic products in infant formula stimulated the growth of infants (Mazzola et al., 2015). Synbiotic dairy products, for example, synbiotic ice creams, are promising sources of prebiotics which may likely deliver the probiotics to human body, accordingly possess several health-promoting effects (EL-Sayed et al., 2015).

Therefore, the objective of this study was to develop synbiotic ice creams formulated with fructooligosaccharides as a prebiotic and lactic acid bacteria (Lactobacillus plantarum and Lactobacillus casei) as probiotics. The physico-chemical, microbiological, and sensory characteristics, along with the antioxidant activity of different ice creams, were compared.

2 | MATERIALS AND METHODS

2.1 | Materials

Low-fat sterile milk (1.5% fat) (Pegah Shiraz Company, Shiraz, Iran), milk powder (Pegah Shiraz Company, Iran), sucrose (Marvdasht Sugar Company, Fars, Iran), vanilla powder (Attarak Co., Iran), salep (from Shiraz, Atar, Iran), cream with 30% fat (Pegah Shiraz Company, Iran) and oligofructose, and a fraction of oligosaccharides produced by the enzymatic hydrolysis of inulin (Abtinchem, Isfahan, Iran) were purchased for the formulation of ice creams. Glycerol was from Pouya Chemical Company (Iran), Man, Rogosa, and Sharpe (MRS) agar, methanol, 2,2-diphenyl-1-picrylhydrazyl, o-phthalaldehyde, boric acid, chloridric acid, and methyl red were from Merck (Darmstadt, Germany).

2.2 | Culture propagation

The strains L. plantarum LP299v and L. casei ATCC 393 were provided from Pards Roshd Mehregan Bioproducts (Shiraz, Iran) for the fermentation of the ice creams. These two strains were previously reported as routinely used probiotics in industry (Karapetsas et al., 2010; Klarin et al., 2019). The strains were stored in MRS broth with 50% glycerol at ~80°C until use. To prepare the inoculum, an aliquot (100 µl) from each culture was individually transferred into 10 ml MRS broth and placed in an incubator at 37°C for 24 hr. After that, 10 ml culture was diluted to 100 ml and re-incubated at 37°C for 48 hr. It was then centrifuged at 5,000 rpm at 25°C for 10 min in order to isolate the probiotics from the MRS (Ayyash et al., 2018).

2.3 | Ice cream production

Ice creams were produced at pilot plant in the Department of Food Science and Technology (Shiraz University). For the production of ice creams, low-fat sterilized milk (1.5% fat) and cream (30% fat) were used. Other ingredients were weighed and added according to the
formulation (Table 1). After mixing and dissolving the formulated compounds for 1 hr at room temperature, the resultant mixture was pre-heated at 40°C for 5 min. The mixture was then pasteurized at 85°C for 10 min. The ice cream mixture was transferred to a glass container and cooled until the temperature of 37°C. The cultures L. casei and L. plantarum were then inoculated in ice creams labeled as probiotics. These ice cream mixes were then placed in an incubator at 37°C until the pH reached to pH 5.80. The mixture was transferred into a batch laboratory ice cream maker (Noel, Russia) with a 5 L capacity and the production continued (at −6°C) until the volume doubled. This was monitored using the volume degree labeled in the ice cream maker chamber. All ice cream samples were packed in the plastic containers and stored in a freezer at −18°C until analysis (Figure 1).

2.4 | Characterization of ice creams

Chemical, physical, microbial, biological, and sensory properties of ice creams were evaluated on specified intervals associated with each experiment.

2.4.1 | Chemical analysis

The pH measurement and the acid titration of ice cream samples were carried out (Akalin & Erisir, 2008). The pH of the melted ice creams was measured using a digital pH meter (STARTER3000, Ohaus Co., USA). Acid titration was carried out via titrating the melted ice creams (10.0 g) using 0.1 N NaOH and using phenolphthalein as the indicator. Protein content was measured according to the Kjeldahl method with a conversion factor of 6.38 (Maubois & Lorient, 2016).

2.4.2 | Physical analysis

Apparent viscosity (μ_{app}) of the ice cream samples was evaluated at 4°C using a Brookfield viscometer as described by Akalin and Erisir (2008).

Texture analysis was carried out using a Brookfield texture analyzer. For this, the ice cream samples were transferred to a freezer at −10°C for approx. 24 hr prior to analysis. The operation parameters were as follows: penetration rate, 15 mm; applied force, 5 g; probe penetration rate, 3.3 mm/s; and probe speed before and after penetration, 3.0 mm/s. The parameters including firmness, cohesiveness, and gumminess were determined \( n = 3 \) (Akalin et al., 2018).

Melting behavior, expressed as melting rate (%), was evaluated as outlined by Di Criscio et al. (2010). Briefly, 25 g of the ice cream samples was weighed on a wire mesh screen. The time of the first drop and the weight of the melted ice cream (every 5 min) were recorded for each sample. Then, a curve for the kinetics of melting was plotted according to the percentage of the melted ice creams (w/w%) versus the time. The melting rate (g/min) of each ice cream was obtained accordingly.

Color analysis of ice cream samples was carried out as described by Khatib et al. (2020) using the \( L^*, a^*, \) and \( b^* \) parameters, where \( L^* = \) lightness, \( a^* = \) red-green color, and \( b^* = \) yellow-blue color. These parameters were obtained using a digital camera (Canon Powershot A540 Tokyo, Japan) having six megapixels resolution, under controlled conditions in a special designed chamber. The overall color differences (\( \Delta E \)) between the ice cream sample after treatment and the control ice cream was calculated according to Equation (1):

\[
\Delta E = \sqrt{(L_i - L_c)^2 + (a_i - a_c)^2 + (b_i - b_c)^2} 
\]

where \( L_i, L_c \) (black-white indicator), \( a_i, a_c \) (red-green indicator), and \( b_i, b_c \) (yellow-blue indicator) were the color indicators of the ice cream treated samples and \( L_{i, c}, a_{i, c}, \) and \( b_{i, c} \) were the color indicators of the control ice cream.

2.4.3 | Microbial analysis

To count the number of probiotics, ice cream samples were cultured on MRS agar plates after dilution in saline and incubated at 37°C (Di Criscio et al., 2010). The bacterial count was reported in CFU/mL. The test was carried out on the inoculum, fermented ice cream mixtures (before adding into ice cream maker), and ice cream samples at d0, d1, d10, d30, and d60.

| Composition | A | B | C | D | E | F |
|-------------|---|---|---|---|---|---|
| Culture activation | - | - | L. casei | L. plantarum | L. casei | L. plantarum |
| milk powder (g) | 50 | 50 | 50 | 50 | 50 | 50 |
| milk (ml) | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 | 1,000 |
| probiotic (g) | 0 | 0 | 1 | 1 | 1 | 1 |
| Cream(g) | 150 | 150 | 150 | 150 | 150 | 150 |
| Sugar (g) | 150 | 50 | 150 | 150 | 50 | 50 |
| Vanilla (g) | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 | 1.5 |
| Salep (g) | 5 | 5 | 5 | 5 | 5 | 5 |
| Fructooligosaccharide (g) | 0 | 100 | 0 | 0 | 100 | 100 |
2.4.4 | The degree of hydrolysis (DH%) and antioxidant activity measurement

To determine DH, a proteolytic activity assay using o-phthalaldehyde (OPA) reagent was determined as described by Ayyash et al. (2018).

Briefly, 3 ml of 0.75% trichloroacetic acid (TCA) was added to 6 ml of the melted ice cream and stirred for 10 min at room temperature. It was then centrifuged at 8,000 g and 10°C for 30 min. Finally, the mixture was filtered using a Whatman 42 filter paper. After that, 150 µl of the filtered suspension was added to 3 ml of OPA reagent.
and hold at 25°C for 2 min. The absorbance was measured using a UV-spectrophotometer (UV-1650PC, Shimadzu, Kyoto, Japan) at \( \lambda = 340 \) nm. The DH was reported as the percentage of peptide content over the initial protein content.

The antioxidant activity was determined using 2,2-diphenyl-1-picrylhydrazyl radical (DPPH\(^*\)) scavenging assay (Asl et al., 2018). Briefly, 600 \( \mu \)l of the DPPH reagent (0.1 mM DPPH dissolved in 95% methanol) was added to 400 \( \mu \)l of ice cream samples in glass test tubes. The samples were shaken and incubated in a dark room at room temperature for 30 min. Methanol was used as a blank. The absorbance of the incubated samples was measured at \( \lambda = 517 \) nm. The DPPH\(^*\) scavenging activity was calculated using the Equation (2):

\[
\text{DPPH}^* \text{ scavenging activity (\%)} = \left(1 - \frac{\text{sample absorbance at } \lambda_{517}}{\text{control absorbance at } \lambda_{517}}\right) \times 100
\]

\[
(2)\]

2.4.5 | Sensory evaluation

The ice cream samples were stored at −18°C for 20 days, and then the sensory evaluation was carried out by a group of 10 untrained panellists. For this, the ice cream samples were coded randomly and the attributes including odor, taste, texture, and overall acceptability were rated on a 5-point hedonic scale by the panelists (Gahruie et al., 2019).

2.5 | Statistical analysis

All tests were performed with three measurements. The results were evaluated using one-way analysis of variance (ANOVA) at a significance level of .05. Duncan’s multiple range tests were used for comparison between the mean values. All statistical tests were performed using SAS software (ver. 9.1.3, SAS Institute Inc., Cary, NC, USA).

3 | RESULTS AND DISCUSSION

3.1 | Acidity and pH of the ice creams

The results of pH and acidity are summarized in Table 2. The pH of the fermented samples (i.e., probiotic and synbiotic ice creams) was lower than the unfermented samples (i.e., control and prebiotic samples). The pH of the fermented ice creams was in a range of pH 5.75–5.86, while for the unfermented ice creams it was in a range of pH 6.49–6.62. The acidity of the fermented ice creams was in a range of 0.16–0.19. High acidity and low pH of probiotic and synbiotic ice creams were due to the conversion of lactose to lactic acid as a result of the fermentation of LAB. The results herein were in accordance with Kataria et al. (2018) who produced a probiotic ice cream containing Bifidobacterium longum and showed it had a lower pH than the unfermented ice cream. Balthazar et al. (2018) and Akalin and Erisir (2008) also reported similar results.

| Sample | pH        | Acidity     |
|--------|-----------|-------------|
| A      | 6.56 ± 0.06\(^a\) | 0.17 ± 0.02\(^a\) |
| B      | 6.54 ± 0.05\(^a\) | 0.17 ± 0.01\(^a\) |
| C      | 5.81 ± 0.02\(^b\) | 0.26 ± 0.02\(^b\) |
| D      | 5.80 ± 0.05\(^b\) | 0.26 ± 0.02\(^b\) |
| E      | 5.82 ± 0.04\(^b\) | 0.27 ± 0.02\(^b\) |
| F      | 5.81 ± 0.03\(^b\) | 0.25 ± 0.02\(^b\) |

Note: Different letters represent significant differences between data in each column (\( p < .05 \)).

Herein, the presence of fructooligosaccharides did not change the pH and the acidity of the ice creams.

The ice cream components, especially proteins and minerals (mainly phosphates and citrates), along with the dissolved carbon dioxide in milk, are crucial for the natural pH and the acidity of ice creams (Goff & Hartel, 2013). Ice cream with a high acidity is not desirable for the consumers since it may induce unpleasant taste and flavor. Moreover, high acidity during the ice cream production may cause the denaturation of caseins (Goff & Hartel, 2013).

3.2 | Viscosity of ice creams

Figure 2 displays the viscosity changes in control, prebiotic, probiotic, and synbiotic ice creams as a function of shear rate. The \( \mu_{app} \) was reduced in all ice cream samples with increasing the shear rate. Among the ice cream samples, the prebiotic and synbiotic ice creams produced using L. casei had the highest viscosity which was likely associated with a synergistic effect of L. casei growth and the presence of fructooligosaccharides during fermentation. It seems that a combination of L. casei and fructooligosaccharides (sample E) had a higher synergist effect to increase the \( \mu_{app} \) in comparison with a combination of L. plantarum and fructooligosaccharides (sample F). The presence of probiotics also enhanced the viscosity of probiotic ice creams (samples C and D) in comparison to the control ice cream (sample A). This suggested the possibility of the formation of microbial metabolites having a viscosity enhancing effect, for example, exopolysaccharides (EPS), in the ice cream mix during the fermentation. Recently, both L. casei and L. plantarum have been reported as EPS producing bacteria (Ren et al., 2020; Yılmaz & Simsek, 2020).

Similarly, Balthazar et al. (2018) investigated the effect of inulin and L. casei on the viscosity of probiotic and synbiotic ice creams. They showed that the \( \mu_{app} \) of synbiotic ice cream was higher than probiotic and control ice creams, while the control sample had the lowest \( \mu_{app} \).
that the fermentation of rives was promising to obtain a high viscous fermented ice cream. Media are important for the final viscosity (Amador et al., 2017). It seems mixture and the capability of microbial strains to grow in dairy-based mixture (Bazmi et al., 2008). Additionally, the formulation of ice cream the storage temperature has been shown to increase the viscosity of the temperature is another key factor for the viscosity of ice creams. Decreasing of milk proteins and stabilizers, crystallization of fat droplets, and separation, as most of the species of LAB (including L. casei and L. plantarum) have a high capability to produce EPS. No significant difference in the gumminess and also in the firmness among the fermented samples was observed, which was likely due to the similar pathway metabolism of L. casei and L. plantarum in dairy products.

### 3.3 Firmness, cohesiveness, and gumminess of ice creams

Table 3 shows the results of firmness, cohesiveness, and gumminess of control, prebiotic, probiotic, and synbiotic ice creams. The prebiotic sample had the highest firmness, while the control sample had the lowest firmness. Generally, polysaccharides increase the firmness of the samples through absorbing water molecules and providing chemical bonds within the molecular structures. Balthazar et al. (2018) investigated the effect of inulin and L. casei on the hardness of probiotic and synbiotic ice creams and observed a synergistic effect between the presence of inulin and the growth of L. casei. They showed that the hardness of control, probiotic, and synbiotic samples were 46.79, 42.58, and 88.01 N, respectively.

No significant difference was observed between the cohesiveness of samples. The control ice cream had the lowest gumminess among all samples. High gumminess observed for the probiotics was probably due to the production of EPS during the fermentation process, as most of the species of LAB (including L. casei and L. plantarum) have a high capability to produce EPS. No significant difference in the gumminess and also in the firmness among the fermented samples was observed, which was likely due to the similar pathway metabolism of L. casei and L. plantarum in dairy products.

### 3.4 Melting behavior

The melting behavior of ice cream samples was investigated. The results of melting (%) of ice creams as a function of time are depicted in Figure 3. Moreover, Table 3 shows the results of the first dripping.
time and the melting rate of ice creams. Overall, all treated ice creams melted ~95% after 40 min keeping at room temperature, while the control sample melted 100% at this point. The results of this study showed that the fermentation of ice cream postponed melting of samples and reduced the melting rate. The most significant factor to reduce the melting rate and also to postpone the first dripping time was, however, the presence of fructooligosaccharides in the ice creams. The lowest melting rate (3.44 g/min) and the lengthiest first dripping time (11.65 min) were recorded for the sample B (i.e., nonfermented ice cream having fructooligosaccharide). These results showed that the symbiotic and prebiotic ice creams had higher delayed melting compared to the control and probiotic ice creams. No significant difference was observed between the samples C and D (p > .05) demonstrating a similar melting behavior of LAB tested strains.

Góral et al. (2018) produced probiotic ice creams using L. rhamnosus and L. lactis and showed that the first dripping time of samples was in a range 1.9–4.2 min. Also, Balthazar et al. (2018) investigated the melting behavior of probiotic and synbiotic ice creams produced using a combination of inulin and L. casei. They showed that the melting rate of samples for control, probiotic, and synbiotic ice creams were 2.04, 1.94, and 2.00 g/min, respectively. El-Nagar et al. (2002) investigated the effect of adding inulin to yoghurt ice cream desserts and showed a reducing effect of inulin on the ice cream melting rate.

The results herein demonstrated an effective role of the supplementation of fructooligosaccharides to postpone melting of ice creams. This may be attributed to the strong affinity of fructooligosaccharides to bind to the water molecules. Furthermore, it was shown that the fermentation process was a delay factor for melting of the ice creams, probably due to the formation of EPS by the microbial strains.

### 3.5 | Color analysis

The results of color analysis of ice cream samples are represented in Table 3. The ice cream ingredients and the process involved in production of ice creams are crucial for the color of the ice creams. Variation in color parameters between ice cream samples was observed. The results showed that the L* value of the samples was in a narrow range between 72 and 85. The highest L* value belonged to the L. plantarum fermented probiotic ice cream and the prebiotic sample. The highest a* and b* values were associated with the L. casei synbiotic ice cream. Previously, Akalin and Erisir (2008) reported that increasing the fat content in ice cream increased the b* value due to the presence of carotenoids in milk. However, the fat content of the ice creams in this study was similar in all samples. Therefore, the differences between the b* value may be attributed to the fermentation and the presence of fructooligosaccharide. The results of color analysis herein were in accordance with the previous studies, for example, Akbari et al. (2016), Akalin et al. (2008), Góral et al. (2018), Balthazar et al. (2018), and Tiwari et al. (2015).

Variation in color parameters between the fermented ice creams was also clear which demonstrated the differences of the growth behavior and the enzymatic activities of the L. casei and L. plantarum in dairy based media.

According to Table 3, the maximum ΔE (which represents the difference between overall color of ice cream samples and the control ice cream) was associated with samples D and B, while the minimum ΔE was associated with sample E. In general, ΔE > 5 shows a significant difference between the treated and untreated samples. In this study, all samples had ΔE > 5 showing that the treatments involved in manufacturing of ice creams B, C, D, E, and F significantly changed the color parameters of the ice creams in comparison with the control ice cream. It was shown that the fermentation of ice cream with L. plantarum and also the presence of fructooligosaccharides in the ice creams without fermentation changed the color of ice cream with a higher extent compared to other ice cream samples.

### 3.6 | Survival of probiotics

Figure 4 represents the results of LAB counts in the probiotic and synbiotic ice creams. The bacterial counts in the starting culture and ice
The prokaryotic activity assay was carried out using OPA method. The initial protein content in all samples was determined to be 3.40%–3.76%. Previously, Parussolo et al. (2017) developed a synbiotic ice cream using yacon flour and L. acidophilus; (D) L. plantarum fermented ice cream; (E) L. casei fermented ice cream formulated with fructooligosaccharides; (F) L. plantarum fermented ice cream formulated with fructooligosaccharides. Different capital letters represent significant difference (p < .05) between each cluster columns, while different small letters represent significant difference (p < .05) between same samples in different conditions.

3.7 | Proteolytic activity assay and antioxidant activity

The proteolytic activity assay was carried out using OPA method. The initial protein content in all samples was determined to be 3.40%–3.76%. Previously, Parussolo et al. (2017) developed a synbiotic ice cream using yacon flour and L. acidophilus and showed that the protein content of the samples was in the range of 3.70%-3.96%. Kataria et al. (2018) produced a probiotic ice cream containing B. longum and showed that the protein content of the samples was in the range of 3.05%–3.21%.

Table 4 represents the DH of control, prebiotic, probiotic, and synbiotic ice creams. The synbiotic ice creams had the highest DH, while the lowest DH belonged to the control sample. Generation of bioactive peptides in the samples C-F as a consequence of proteolytic activity obtained by LAB resulted in a higher DH in fermented samples compared to the control sample. This was in agreement with a recent study by Ayyash et al. (2018). Probiotics are capable to break down the proteins and to produce low molecular weight peptides.

Antioxidant activity is also an important biofunctionality of protein and peptides (Khalesi et al., 2016; Rahimi et al., 2016). Table 4 represents the antioxidant activities of the control, prebiotic, probiotic, and synbiotic ice cream samples. The synbiotic ice creams had the highest DPPH* scavenging activity (77.62% and 75.70% for sample E and F, respectively), while the control ice cream had the lowest DPPH* scavenging activity (49.59%). Higher antioxidant activity observed for the fermented ice creams may be attributed to the production of bioactive peptides and probably the release of phenolic compounds by LAB during the fermentation. Balthazar et al. (2018) reported that the antioxidant activity of the control, probiotic, and synbiotic ice creams having inulin and L. casei was 22%, 72%, and 81%, respectively. The results herein were in accordance with the reports by Apostolidis et al. (2007) and Ayyash et al. (2018). They showed that the fermentation process increased the antioxidant activity due to the generation of bioactive peptides. Ayyash et al. (2018) showed that the bioactive peptides released during the fermentation possess a number of health-promoting properties, for example, the control of the blood pressure and also the antioxidant and anticancer activity (Ayyash et al., 2018).

3.8 | Sensory evaluation

Figure 5 represents the results of sensory evaluation of the ice cream samples. The results showed that the acceptance of the odor...
was lower for the probiotic and synbiotic ice creams compared to the unfermented samples, probably due to the growth of probiotic bacteria and generation of unpleasant odor components during the fermentation. In terms of the ice cream taste, the prebiotic samples were less favorable than the control sample, which could be attributed to the decrease in the sweet taste (due to replacement of sugar with fructooligosaccharides) and increase in the bitter taste (due to the generation of peptides in the fermented samples). This may be a reason for the low overall acceptability of the probiotic ice creams. It seems that the fructooligosaccharides reduced the adverse effects of probiotics on the sensory properties, as the probiotic ice creams obtained a higher score than the prebiotic samples in terms of the taste, odor, and overall acceptability. This means that fructooligosaccharides masked the bitter taste detected in the samples with only probiotics. According to the results, synbiotic and prebiotic ice cream samples had improved texture properties due to the presence of fructooligosaccharides. In general, the probiotic, synbiotic, and prebiotic samples had lower overall acceptability than the control sample. However, these changes could have some effects on the process of fermentation, the textural behavior, and other properties of the final product.

4 | CONCLUSION

Synbiotic ice cream is a functional food having probiotics and prebiotics. The physico-chemical, textural, microbiological, and sensory characteristics of the probiotic, prebiotic, and synbiotic ice creams generated with two strains of LAB (i.e., *L. casei* and *L. plantarum*) and fructooligosaccharides were investigated in this study. The results showed that fructooligosaccharides improved the rheological properties of the ice creams and enhanced the viability of the probiotics. Higher antioxidant activity was observed in the fermented ice creams, likely due to the generation of bioactive peptide using the probiotic bacteria. Nevertheless, the sensory evaluation showed that the overall acceptability of the synbiotic ice creams was lower than other ice cream samples. This may be attributed to (a) reduction in sweetness as a result of using fructooligosaccharides instead of sugar in the formulation and (b) generation of peptides having a bitter taste as a result of proteolytic activity of LAB and the acidic flavor appeared as a result of fermentation. In order to improve the sensory properties of the synbiotic ice cream, it seems that the supplementation of flavor/taste masking agents in the formulation of synbiotic ice creams can be a promising strategy.

As fructooligosaccharides exhibits sweetness levels between 30% and 50% of sugar in commercially prepared syrups, the missing sweetness could be added by the corresponding sucrose content especially for the tasting—to get better comparable results. However, these changes could have some effects on the process of fermentation, the textural behavior, and other properties of the final product.
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CONFLICT OF INTEREST

The authors have declared no conflicts of interest for this article.

AUTHOR CONTRIBUTION

Negar Sabet: Formal analysis; Investigation; Methodology; Writing-original draft. Mohammad Hadi Eskandari: Funding acquisition; Project administration; Supervision. Seyed Mohammad Hashem Hosseini: Investigation; Writing-review & editing. Mehrdad Niakousari: Methodology; Writing-review & editing. Hadi Hashemi Gahruie: Formal analysis; Software. Mohammadreza Khalesi: Conceptualization; Funding acquisition; Project administration; Supervision; Writing-review & editing.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon request.

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