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Application of jaban watermelon exocarp powder in low-calorie ice cream formulation and evaluation of its physicochemical, rheological, and sensory properties

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Abstract

Jaban watermelon seeds are one of the most favorable nuts in Iran. The production of these popular nuts leaves a large amount of environmental pollutants. The aim of this study was to evaluate the rheological, physicochemical, and sensorial properties of ice cream by replacement of milk cream with watermelon exocarp powder (WEP) at 0%, 20%, 40%, 60%, 80%, and 100% levels. The results showed that although all samples showed the pseudo-plastic behavior rheologically, the replacement of cream with WEP significantly affected the physicochemical properties. Adding the WEP increased the textural properties and melting resistance of the samples, whereas overrun, draw temperature, and the flow behavior index decreased, significantly ($p < 0.5$). Hedonic evaluation showed not only that adding the WEP at 20% level does not have a significant effect on sensory properties, but also received the highest scores. Finally, regarding the high amount of fiber and minerals in WEP can lead to produce lower calorie ice cream with higher nutritional value.

Novelty impact statement

1. A new look on using Jaban watermelon environmental pollutants to produce economically and nutritionally valuable by-products.
2. Investigation of macro- and micro compounds in watermelon exocarp powder.
3. Producing of low calorie and high nutritional value ice cream by replacing cream with WEP.

1 | INTRODUCTION

Ice cream is a product that is commonly consumed all over the world due to its cooling and enjoyment effect and has a high nutritional and caloric value because it is based on milk, fat, sugar, and emulsifiers (Karaman et al., 2014). Scientific results have shown that there is a close relationship between high-fat intake and diseases such as obesity and cardiovascular disease (Akil & Ahmad, 2011). Therefore, due to the negative effects of fat, trend for consuming low-fat products in the diet, such as low-fat ice cream has increased (Azari-Anpar et al., 2017). Since ice cream is a relatively fat product and is of particular popularity among the general public, there is a great demand for low-fat or non-fat varieties (Al-Sayed & Ahmed, 2013). Fat removal or reduction, depending on its key role in the acceptability of features such as texture, shape, appearance, smell, flavor, and mouth feel may lead to several problems in the structure and texture of the produced ice cream such as coarseness and roughness, iciness, crushing, and reduces the size and bad flavor (Azari-Anpar, Khomeiri, et al., 2017). The most important role of fat in ice cream is to stabilize air bubbles (Aime et al., 2001). Therefore, it is important to find the optimal formulation to remove fat or fat substitute (Azari-Anpar et al., 2017). Fat substitutes are classified into three categories: carbohydrate, fat and protein, low-calorie fats, emulsifiers, and combined products (Peng & Yao, 2017).

Food waste or by-products most commonly refer to edible food products, which are intended for the purposes of human consumption but have instead been discarded, lost, degraded, or consumed by pests, and do not include the inedible or undesirable portions of foodstuffs (Helkar et al., 2016). Recently, the use of fruit and vegetable waste to reduce environmental pollution has become an important source of polyphenols, natural antioxidants, and dietary fiber (Hemaida, 1994; Larrosa et al., 2002). In this regard, we can mention cases such as xoconostle fruit cultivars as sources of antioxidants, pomegranate peels and seeds as sources of nutraceutical components, and pomace of apple as sources of pectin, cellulose, hemicellulose, lignin, and gums (Helkar et al., 2016).

Jaban watermelon is a product that is grown for its use as nuts. At harvest time, after removing the seeds, the rest of the watermelon contains rind and fruit flesh left in the field and pollutes the environment, these wastes are source of fiber, pectin, vitamins, minerals, and phenolic compounds (Dane & Liu, 2007). However, the watermelon rind accounts for approximately one third of the total fruit mass and it is usually discarded, despite being edible. The rind contains mineral salts, fat, protein, carbohydrates, vitamins, phytochemicals, and citrulline. Since carbohydrates are the main compounds of the watermelon exocarp (Petkowicz et al., 2017), it has been pointed out that it could be used as fat substitutes.

The beneficial use of watermelon exocarp will reduce the environmental impact of waste and improve the nutritional value of some food and snacks (Ho et al., 2016). Finally, the main purpose of this study was to investigate the possibility of using watermelon exocarp powder (WEP) as a part of fat replacement in frozen ice cream formulation to produce low-fat, low-calorie, and health-related ice cream as well as the effect of this replacement on sensory, physicochemical, and rheological properties.

2 | MATERIALS AND METHODS

2.1 | Materials

In this study, pasteurized skimmed milk (0.5% fat), pasteurized cream (30% fat), and sucrose were purchased from a local market, pulsegarded (emulsifier) was purchased from Sedigh, and jaban watermelon was purchased from Neyshabur, Iran. All the chemical reagents used were of analytical grade.

2.2 | Preparation of watermelon exocarp powder

To make WEP, watermelons were first washed with water to remove surface contamination. After cutting and removing the outer and red parts of the fruit, the watermelon white rinds were carefully cut and divided into thin sheets (4.5 × 4.5 × 4.5 cm), then dried at 50°C for 24 hr. The dried sheets were sieved using a NO.4 (mesh number 25 mm) and were kept in glass containers with lids, in the 4°C refrigerator for subsequent tests (Ho et al., 2016).

2.3 | Ice-cream production

The control ice cream formulation consisted of 10% cream, 15% sugar, 11% MSNF (milk solids not-fat), 0.5% stabilizer, and 0.1% vanilla. Depending on the applied treatments different amounts of WEP were substituted with cream at different levels including 0%, 20%, 40%, 60%, 80%, and 100%. For the production of ice cream samples, after blending of ice cream ingredients the prepared mixture was stirred thoroughly for 3 min and pasteurized at 80°C for 25 s and immediately cooled to refrigerator temperature. To ensure complete hydration, the ice cream mixture was stored at 5 ± 1°C overnight and then vanilla was added. The aged ice cream mixture was packed in 50 ml plastic cups and placed in a freezer at −18°C for subsequent experiments (Azari-Anpar, Soltani Tehrani, et al., 2017).

2.4 | Methods

2.4.1 | Analysis of WEP

Chemical composition analysis of WEP

Chemical constituents of WEP including protein, fat, carbohydrate, soluble and insoluble fibers, ash, and moisture content were measured. Protein content was measured according to the Kjeldahl method (Chang & Zhang, 2017). Carbohydrate, soluble and insoluble fibers contents were measured according to Garcia-Amezquita et al. (2018) (Garcia-Amezquita et al., 2018). The ash content was determined using the AOAC Official Method 942.05 (2000) (Association of Official Analytical Cemists [AOAC], 2000). The crude fat was determined in duplicate by extracting 5 g of samples in a Soxhlet apparatus using petroleum ether with a boiling point range of 40–60°C (Schönfeldt & Pretorius, 2011). The moisture content of WEP was determined according to the AOAC Official Method 931.15 (2000) (AOAC, 2000). All experiments were performed in three replications.

Analysis of mineral elements of WEP

The composition of minerals including iron (Fe), aluminium (Al), zinc (Zn), copper (Cu), boron (B), potassium (K), manganese (Mn), barium (Ba), strontium (Sr), sodium (Na), calcium (Ca), magnesium (Mg), cadmium (Cd), cobalt (Co), lithium (Li), chromium (Cr), lead (Pb), bismuth (Bi), and nickel (Ni) of WEP was determined by inductively coupled plasma spectrophotometer ICP-OES model Integra XL (made in Australia) according to (Hoque & Iqbal, 2015). Sample preparation and test conditions were performed according to ISO16943:2017 (2017).

Particle size analysis of WEP

Since particle size and size distribution have a great influence on the mechanical strength, density, and optical and thermal properties of the finished product, determination of these sizes is necessary. DLS (Light Diffraction Method), for measuring particle size in liquid environment was used to measure the particle size and specific surface area of the powder, its dispersion in methanol was determined and confirmed using UK-based particle size analyzer by Malvern's ZS Nano Zetasizer Analyzer (Ziaee et al., 2015).

2.4.2 | Ice-cream analyses

pH measurement

pH value of ice cream mixes was determined according the National Standard of Iran No. 2450 using Metrohm model (pH 5) pH meter.

Special weight

Specific gravity of ice cream mixes was determined by a picometric method at 25°C. The pycnometer was first emptied and cleaned and then the pycnometer was weighed by distilled water at 25°C and then it was filled with ice cream mixture at 25°C and the specific gravity (SG) was calculated using the following equation (Mahdian et al., 2011).

$$\text{Specific Gravity} = \frac{G_3 - G_1}{G_2 - G_1}$$

In this regard, G_1 is the mass of empty pycnometer, G_2 is the mass of pycnometer and distilled water, and G_3 is the mass of pycnometer and ice cream mixture (Mahdian et al., 2011).

Exit temperature of ice cream maker

Immediately after the ice cream was prepared in the ice cream maker and before the samples were placed in the containers, the exit temperature of the ice cream was measured by placing a digital thermometer inside the ice cream maker (Bradley et al., 1992).

Melting resistance

Ice cream samples were weighted and 30 ± 1g placed on a sieve with pore diameter of 2 mm and plates incubated at 25 ± 1°C and the weight of the melted ice cream was measured as a percentage of the prototype after 40 min (Mahdian et al., 2011).

Overrun determination

The coefficient of increase of ice cream volume was calculated by weighing a certain volume of ice cream before and after the freezing step and calculating the percentage of their difference based on the following relationship (Bradley et al., 1992).

$$\text{Overrun \%} = \left(\frac{\text{weight of the ice cream mix} - \text{weight of the ice cream}}{\text{weight of the ice cream mix}}\right) \times 100$$

Rheological tests

The apparent viscosity of ice cream mixes samples was measured using a Bohlin rotational viscometer, Bohlin Instruments, UK (equipped with thermal circulator) Julabo, Model F12-MC, Julabo Labortechnik, Germany (at 5°C). Samples were tested in triplicate using spindle No. 5 at speed 100 rpm at 5°C. To determine the rheological behavior of samples, shear rate and shear stress values (at rotation speeds of 14–400 rpm) were calculated using obtained data from the viscometer according to Mitchka's equations (Akalın et al., 2008). The power law model, Herschel–Bulkley model, and Casson model were used to calculate the consistency index (k), the flow behavior index (n), yield stress (τ_0), and correlation coefficient (R_2) of samples. Finally, the experimental data were fitted according to these three models (Azari-Anpar et al., 2021).

Power law model:

$$\tau = k(\gamma)^n$$

Herschel–Bulkley model:

$$\tau = \tau_0 + k(\gamma)^n$$

Casson model:

$$\tau^{0.5} = \tau_0^{0.5} + k(\gamma)^{0.5}$$

where τ is the shear stress (Pa), k is the consistency coefficient (Pa s^n), γ is the shear rate (s^{-1}), n is the flow behavior index, and τ_0 is the yield stress (Pa). Apparent viscosity (Pa·s) was recorded at a shear rate of 50 s^{-1}.

Texture analysis

Texture analyzer (Texture Analyzer Brookfield CT3-10kg, US) was used to evaluate the texture of 50 gram specimens. For this purpose, a probe with a diameter of 6 mm was used to penetrate the specimens to a depth of 15 mm at a speed of 2 mm/s. The maximum compressive force during the infiltration was considered to be gram (Akalın et al., 2008).

Sensory evaluation

The test was conducted at research center for fruit and vegetable processing in Ferdowsi University of Mashhad. Fifteen panelists consisting of 7 men and 8 women aged 21–26 years were selected and trained. The samples, which had undergone a day of hardening, were then randomly coded and submitted to the referees. In this study, 9-point hedonic test was used for sensory evaluation. The traits studied included body and texture, taste, color, appearance, and general acceptance.

Statistical analyses

In order to evaluate the obtained physical and chemical properties, results were analyzed based on a completely randomized design using SPSS software (version 16). Average data were compared using the Fisher test at the 95% level, and graphs were plotted using Microsoft Excel (version 2016). All tests and experiments were performed in three replicates.

3 | RESULTS AND DISCUSSION

3.1 | Chemical composition of WEP

The results of chemical composition and mineral analysis of WEP are presented in Table 1. The results showed that WEP contains considerable amount of high molecular weight compounds and essential minerals that can have beneficial functional effects on food systems. The moisture content of WEP was 9.7%. The moisture content of rind was recorded between 6.2% (Bawa & Bains, 1977) and 10.61% (Al-Sayed & Ahmed, 2013). The ash, protein, and fat contents in WPC were 10.5%, 6.67%, and 1.13%, respectively. These amounts were recorded as 13.09%, 11.17%, and 2.44% for ash, protein, and fat, respectively (Al-Sayed & Ahmed, 2013). The total carbohydrate and crude fiber contents in WEP were 50.37% and 15.52%, which was similar to the amount reported by Al-Sayed and Ahmed (Al-Sayed & Ahmed, 2013). The highest mineral content was Fe, followed by Al, Zn, Cu, B, K, Mn, Ba, Sr, Na, Ca, Mg, Cd, Co, Li, Cr, Pb, Bi, and Ni, respectively. The type and level of compositions of vegetables, fruits, and grains depends on many factors, including the plant part, geographical source, soil conditions, harvest time, storage conditions, and post-harvest processing (Marles, 2017).

In general, minerals are essential for regulating the body's natural metabolism in small amounts (Hoque & Iqbal, 2015). Insoluble dietary fiber (IDF) is the largest fraction of WEP, however, a high amount of soluble dietary fiber (SDF) was also found (between 6.64 g/100 g and 15.52 g/100 g DM). The high content of both fractions indicates that consumption of WEP may result in positive physiological effects. This could occur because soluble fiber is associated with decreased blood cholesterol and intestinal absorption of glucose, and insoluble fiber contributes to proper functioning of the intestinal tract (Grigelmo-Miguel et al., 1999). Fiber can increase the water retention capacity as well as food viscosity (Figuerola et al., 2005).

3.2 | Particle size analysis of WEP

Investigating the variables related to particle measurement in various respects is important in influencing the quality and stability of the formulation, homogeneity, texture, and rheological properties of the mixture as well as taste and other physicochemical properties in the food industry (Carrillo et al., 2012). By particle size apparatus, the mean Z-average for WEP was 520/013 nm and the particle dynamic analyzer value (PDI) was 0.3476. As for the specific surface area, the smaller the surface area, the higher the specific surface area. Studies have shown that particle sizes as small as 25 μm can be detected by the palate. In addition, investigating the effect of particle size and concentration on perceived creaminess of soft model systems containing solid particles showed reduced creaminess with larger particle size and higher concentration (Engelen et al., 2005). An increase in particle size is associated with an increase in apparent viscosity, especially for compounds that have a high water absorption capacity (Imai et al., 1995). The proportion of people who perceived grittiness grew with increasing particle size and increasing particle concentration (Engelen et al., 2005). An increase in viscosity with increasing concentrations of polysaccharides was also observed when using inulin and maltodextrin as fat replacement strategies in ice cream formulations (Rolon et al., 2017). The mentioned points could be reasons why ice cream formulas containing 80% and 100% fat replaced WEP received significantly lower scores than other formulas when evaluating sensory effects.

3.3 | Effect of adding WEP on some properties of ice cream

The results of pH values for the different treatments are shown in Table 2. It is clear that the pH values were not affected by fat replacement and the percentage of substitution of WEP had no significant effect on the mean changes of this property ($p < .05$). According

TABLE 1 Chemical and mineral contents of WEP

Components	Content (per 100 g of dry matter)	Components	Content (per 100 g of dry matter)
Mn	50.37% ± 1.3	Carbohydrate	7.9 ppm
Ba	9.7% ± 0.27	Moisture	1.2 ppm
Sr	1.13% ± 0.32	Fat	1.2 ppm
Na	6.67% ± 0.45	Protein	0.95%
Ca	10.5% ± 0.28	Ash	0.62%
Mg	6.64% ± 1.02	Soluble fiber	0.13%
Cd	15.52% ± 0.41	Insoluble fiber	0.1 ppm
Co	166.34 ppm	Fe	0.1 ppm
Li	138.02 ppm	Al	0.1 ppm
Cr	108.92 ppm	Zn	0.1 ppm
Pb	24.26 ppm	Cu	0.1 ppm
Bi	10.23 ppm	B	0.1 ppm
Ni	7.12%	K	0.1 ppm

TABLE 2 The effect of different levels of WEP on physicochemical properties of ice cream

WEP concentration (%)	Specific gravity	Draw temperature (°C)	pH	Overrun (%)	Melting resistance (%)
0	1.06 ± 0.001^{b}	3.74 ± 0.09^{d}	6.53 ± 0.04^{a}	34.86 ± 0.97^{c}	68.24 ± 0.08^{e}
20	1.05 ± 0.002^{a}	4.09 ± 0.29^{c}	6.48 ± 0.1^{ab}	55.16 ± 2.80^{a}	77.24 ± 0.061^{d}
40	1.08 ± 0.001^{c}	4.20 ± 0.37^{c}	6.52 ± 0.02^{a}	45.26 ± 1.08^{b}	80.95 ± 1.02^{c}
60	1.09 ± 0.003^{c}	4.70 ± 0.25^{b}	6.48 ± 0.03^{ab}	31.05 ± 0.57^{d}	82.74 ± 0.39^{b}
80	1.10 ± 0.001^{d}	4.87 ± 0.25^{b}	6.50 ± 0.02^{ab}	29.63 ± 0.49^{d}	83.03 ± 0.68^{b}
100	1.11 ± 0.002^{e}	5.16 ± 0.78^{a}	6.36 ± 0.05^{a}	28.11 ± 0.24^{d}	90.53 ± 0.19^{a}

Note: In each column, means with same superscripts had no significant difference with each other ($p > .05$).

to the standard, the optimal pH for ice cream is about 6.2–6.4, which is in good agreement with the results in this study. According to Marshall and Arbuckle (1996), in a mixture containing 11% fat-free milk solids, the pH is about 6.3 (Vivek, 2001) and the fat-free milk fat percentage affects this property (Arbuckle & Arbuckle, 2002). The value was 11%, and no significant difference was found between the pH of the samples.

The exit temperature of the ice cream maker reflects the amount of heat taken from the ice cream mixture during freezing. The results of Table 2 show that by increasing the cream substitution with WEP, the freezing temperature decreases. Ice cream prepared with 100% WEP had the lowest freezing temperature (−5.16). The temperature of the sample containing 80% protein when leaving the ice cream maker was higher than other samples. The study found that by reducing the fat percentage of the samples and replacing the fat with WEP, the ice cream temperature decreased when removed from the ice cream maker. This may be due to one of the reasons it is called fat reduction because the fat itself acts as an insulator and prevents the lowering of the ice cream temperature (Carrillo et al., 2012; Goff & Hartel, 2013). Also, fat affects indirectly the freezing point (Marshall & Arbuckle, 1996; Soukoulis et al., 2008; Trgo et al., 1999). By reducing the fat percentage of the formulation and increasing the fat substitution with the WEP, there will be more water for dissolution of the soluble material due to the decrease in phase concentration. For Liquid, the freezing point will increase. Therefore, the observed temperature difference due to fat replacement can be attributed to the above reasons.

The results of Table 2 show significant difference ($p > .05$) between the specific gravity of ice-cream treatments. Increasing WEP replacement increased the specific gravity of ice cream so that the ice cream sample with 100% WEP had the highest specific gravity and the lowest specific gravity was related to ice cream with 20% WEP which was significantly different from the control sample ($p < .05$). The results showed that the replacement of cream or fat with 20% WEP provides a lighter specimen than the control.

Overrun (OR) is affected by various factors such as the type of mix components, the amount of fat, the amount of: fat, MSNF, sweeteners, and the presence of stabilizers. Reducing overrun is directly related to feeling cold in the mouth. If the volume coefficient is too high, the ice cream has a foam state (Sun-Waterhouse et al., 2013). Table 2 shows the overrun of ice cream treatments using WEP. By substituting milk cream by different levels of WEP in the ice cream formulation, the overrun percentage was significantly reduced as compared to control sample except for the treatment containing 20% WEP, which had the highest OR content (55.16%) while the substitution with 60, 80, and 10% had non-significant effect on the OR. By adding WEP, viscosity of ice cream mix significantly affected, it seems that the changes of OR associated with the mechanisms that altered the viscosity (Liou, 2006). By adding powder up to 40%, OR and viscosity increase, and leads to increase in the efficiency of OR. Increasing the viscosity at higher levels of WEP reduces the OR, which seems to increase the viscosity, preventing the proper distribution of air in the ice cream tissue during the freezing process, which is considered to have a negative effect on OR. Also, the fat cells surrounding the air bubbles inside the ice cream mix play an important role in the stability and the stability of these bubbles. Therefore, by reducing the fat content of ice cream, can be retained and sustained (Goff, 2008).

As shown in Table 2, the melting resistance % increased with increasing percentage of WEP. Significant increase in melting resistance was observed at all levels of WEP ($p < .05$). The ice cream containing 100% WEP had the highest melting resistance and the control sample had the lowest melting resistance. Ice cream loses its texture and appearance and has an inappropriate appearance, which is known as a quality defect for ice cream (Muse & Hartel, 2004). Increasing ice cream mix viscosity resulted in lower melting rate and also improved product smoothness (Herald et al., 2008). Melting rate of frozen dairy desserts was affected by OR values where samples with higher values of OR showed more resistance to melting (Moeenfard & Tehrani, 2008; Sakurai, 1996). The melting point of the ice cream is such that as the viscosity increases, the melting resistance increases. It was found that by increasing the WEP in the ice cream samples the viscosity of the ice cream mixture increased, resulting in a higher melting resistance, of the high fiber content of watermelon fibers, which increased the free water band viscosity in the non-asymmetric phase. The ice cream became thicker and, as a result, the resistance to melting ice cream increased (Damodaran & Parkin, 2017). They stated that citrus fiber as a single stabilizer could not improve the viscosity, OR, and sensory properties of ice cream samples, but had a positive effect on the melting resistance (Dervisoglu & Yazici, 2006).

3.4 | Rheological changes of ice cream mixes

According to primary test results, all samples were non-Newtonian, time-independent fluids in conformity with previous reports (Goff & Davidson, 1994; Kaya & Tekin, 2001). The results for changes in shear stress and shear viscosity at different aging times are shown in Figures 1 and 2. The apparent viscosity of all specimens decreased with increasing shear degree, which was almost identical for all specimens except for the sample containing 100% WEP, which shows a steeper slope viscosity diagram (Figure 1). As the shear velocity increases, the apparent viscosity value for all samples decreases. High viscosity at low shear degree can be attributed to the irregular arrangement of the molecules and the presence of large molecules in the ice cream mixture, as well as a decrease in viscosity at high shear degree can be due to congruence. Intermolecularity was considered at the beginning of the degree of cleavage because of the complexity of the sample, the rheology being influenced by many factors such as their composition and concentration, lipids, polysaccharides, and proteins (dehydration, maturation, protein aggregation, and crystallization), fat, fat accumulation, etc. (Arbuckle, 2013; Goff, 2002, 2008). In this study, viscosity was increased by decreasing the percentage of cream and replacing it with WEP, which can be attributed to the high fiber content of exocarp, that increases the water uptake and consequently the viscosity (Al-Sayed & Ahmed, 2013). Therefore, the main reason for the increase in viscosity is due to the presence of protein, soluble polysaccharides (mainly pectin), and cellulose and hemicellulose (in ice cream blend containing WEP); thus the presence of these compounds of high molecular weight through grafting with water and forming a gel network increase viscosity. Soukoulis et al. (2008) also found that adding dietary fiber to ice cream increases the viscosity and affects the rheological properties of the ice cream mixes. They reported an increase in viscosity due to an increase in the concentration of soluble serum resulting from fiber retention. The consistency index (K), flow behavior index (n), and R^2 are given in Table 3. Flow behavior index values indicated that all samples showed non-Newtonian pseudoplastic behavior (because $n < 1$). The results of the rheological test in this study showed that the apparent viscosity and consistency coefficient of the ice cream mix increased with increasing amount of WEP. As can be seen from Table 3, the highest consistency indices were seen in ice cream mixes with 100% WEP ($p < .05$). It can be said that the main reason for the higher viscosity and consistency coefficient is due to the presence of high carbohydrate fiber and carbohydrate in WEP in ice cream mix, because the presence of these compounds that have high molecular weight in WEP can increase through water bonding and gel network formation. Viscosity has been identified as a factor influencing the rate of increase in volume, creamy rate, mass and heat transfer rate, and milk flow conditions and dairy products (Bahramparvar et al., 2008). According to the results (Table 3) and values less than one flow behavior index (n) for all samples, it was clear that all samples had pseudoplastic behavior (loosening by cutting). The lower the flow behavior index, the higher the sodaplastic behavior of the mixture, and samples with a lower flow behavior index and higher viscosity have more pleasant oral properties (Dail & Steffe, 1990). Goff and Davidson (1994) reported that the ice cream flow behavior index was about 0.7, (Goff & Davidson, 1994) and Soukoulis et al. (2009) stated that the behavior index of mixed ice cream flow with fiber was between 0.45 and 0.81, which was completely consistent with the results of this study (Soukoulis et al., 2009). The study of rheological behavior independent of the time of ice cream samples showed (Table 3 and Figure 2) the high efficiency power model ($R^2 \geq .99$) in describing the rheological behavior of ice cream mixed samples. Therefore, this model was used to investigate the effect of formulation compounds on rheological properties (flow behavior index and consistency coefficient) of ice cream mix samples.

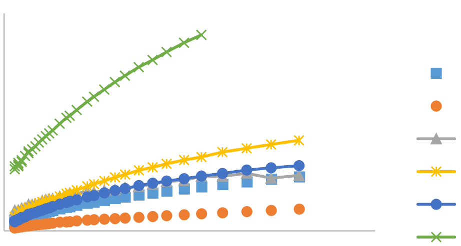

FIGURE 1 Rheogram of shear stress against the degree of shear of the ice cream mixture containing different percentages of watermelon exocarp powder (temperature of 20°C)

3.4.1 | The texture properties of ice cream with WEP

Texture, stiffness, and adhesion of the specimens were evaluated as tissue markers. Ice cream stiffness is an important qualitative feature of ice cream because it directly affects its spoonability and is influenced by various factors including: initial freezing point, sugar content, solids content, volume coefficient, amount and type of stabilizers, and is also used as a measure of the growth of ice crystals (Muse & Hartel, 2004). The size of ice crystals has a great effect on the texture of the ice cream, as increasing the size of the ice crystals creates a thicker texture in the ice cream, and the amount of water available to the ice crystals is more. The crystals will be larger, in addition the stiffness may be affected by the components of the ice cream mixture, including fat, protein, sugar, hydrocolloids, and process conditions such as homogenization, aging, and freezing of the final product (H Goff & Hartel, 2013; Varela et al., 2014). The variables obtained from texture permeation test for different types of ice cream mixes over time were investigated. The results are as shown in Table 4. Tissue stiffness of all samples was higher than that of the control, with the sample containing 100% WEP having the highest stiffness (2,675 g), all treatments had significant differences in stiffness ($p < .05$). Increasing the percentage of substitution of watermelon powder in ice cream increased the stiffness. The lowest and highest adhesions were observed for control and samples containing 100% WEP with values of 5.2 and 8.2 (mj), respectively.

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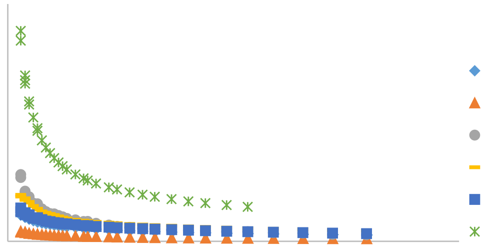

FIGURE 2 Rheogram of apparent viscosity against the degree of shear of ice cream mixed with different levels of watermelon exocarp powder

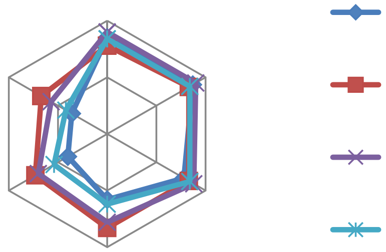

FIGURE 3 Sensory evaluation of ice cream samples supplemented with different WEP percentages

TABLE 3 The effect of different levels of WEP on the consistency coefficient and flow behavior index values of ice cream

WEP concentration (%)	Power-law model		
	N	K (Pa. s^n)	R^2
0	0.65 ± 0.006[d]	2.53 ± 0.06[f]	.9985
20	0.59 ± 0.009[c]	4.81 ± 0.05[e]	.996
40	0.45 ± 0.01[b]	9.74 ± 1.06[d]	.9967
60	0.42 ± 0.01[a]	13.93 ± 1.27[c]	.9966
80	0.40 ± 0.007[a]	22.76 ± 0.20[b]	.9945
100	0.40 ± 0.004[a]	27.21 ± 0.10[a]	.9939

Note: In each column, means with same superscripts had no significant difference with each other ($p > .05$).

TABLE 4 The effect of different levels of WEP on the textural properties of ice cream

WEP concentration (%)	Adhesiveness (mj)	Hardness (g)
0	5.2 ± 0.36[a]	801 ± 49[a]
20	5.1 ± 0.58[a]	921 ± 41[a]
40	5.6 ± 0.9[ab]	1,251 ± 15[b]
60	6.2 ± 0.65[c]	1,891 ± 74[c]
80	6.8 ± 0.4[cd]	2,121 ± 8.5[d]
100	8.2 ± 0.42[e]	2,675 ± 10.4[e]

Note: In each column, means with same superscripts had no significant difference with each other ($p > .05$).

Also, the sample with 20% WEP had the least firmness and adhesion. Therefore, ice cream samples with 100% WEP had the highest stiffness and adhesion. The addition of watermelon powder caused a significant increase in firmness, which could be attributed to the influence of the rheological properties and the nature of the serum phase, thus the higher viscosity and consistency of the WEP resulted in a stronger firmness and thus, the specimen is more resistant to penetration by the probe of the weaving machine. The results of the present study were in accordance with the findings of Karaman et al. (2014). They concluded that with increasing levels of persimmon puree in ice cream, the stiffness increased (Liou, 2006), moreover, Güven and Karaca (2002) in a study suggested that adding strawberries to frozen fruit yogurt increases stiffness (Güven & Karaca, 2002).

3.4.2 | Sensory evaluation

The sensory profiles of the ice cream samples were evaluated in terms of color, appearance, texture, flavor, and overall acceptability as shown in Figure 3. It can be seen that WEP in the formulation influenced the sensory characteristics of the ice creams ($p <.05$). No differences in color, appearance, flavor, texture, and overall acceptability were found between the control sample and the sample containing 20% WEP ($p > .05$). Sensory evaluators also gave the lowest scores to samples containing 80 and 100% WEP. Adapa et al. (2000) suggested using a good balance of fat, protein, and carbohydrate in the production of ice cream with desirable structure. Examination of the results of tissue evaluation in Figure 3 also showed that with increasing the use of WEP in ice cream formulation, the amount of tissue scores decreased. The fiber in WEP acts as centers and nuclei for the growth of ice crystals, expanding the volume of the ice phase in ice cream tissue. Also, the percentage of increase in volume decreases significantly with increasing the percentage of WEP, which reduced the scores of patients' tissue (Micheli et al., 1999). One of the reasons for these changes was the increase in hardness due to the increase in the percentage of WEP fiber. Dervisoglu and Yazici (2006) also obtained lower scores for ice cream with added citrus fiber compared to a control sample without fiber. The results show that by increasing the replacement of WEP with fat in ice cream at levels above 20%, the satisfaction of evaluators with the taste of ice cream decreased.

4 | CONCLUSION

Ice cream is a product that is commonly consumed by people around the world due to its cooling and enjoyment effects, in recent years reducing the amount of fat consumed in food products due to its association with certain diseases such as diabetes, cholesterol, heart disease, and the vascular and gastrointestinal system has received much attention. In this study, cream milk was replaced with jaban watermelon exocarp powder at different levels in ice cream. The results of evaluating rheological, physicochemical, and sensory properties indicated that replacing cream with WEP at 20% level not only leads to producing low-calorie ice cream, but also can increase the nutritional value of ice cream because of its fiber and micro-nutrients.

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CONFLICT OF INTEREST

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

AUTHOR CONTRIBUTIONS

fakhri shahidi: Conceptualization; Funding acquisition; Project administration. **Shiva Ghaedrahmati:** Conceptualization; Data curation; Formal analysis; Investigation; Methodology. **Sahar Roshanak:** Formal analysis; Methodology. **marzie nassiri mahallati:** Investigation.

DATA AVAILABILITY STATEMENT

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

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