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Physicochemical Properties, Antioxidant Capacity, and Consumer Acceptability of Ice Cream Incorporated with Avocado (*Persea Americana* Mill.) Pulp

Jutamas Moolwong[1], Worasaung Klinthong[2], Thanida Chuacharoen[1,*]

[1]Faculty of Science and Technology, Suan Sunandha Rajabhat University, 1 U Thong Nok Road, Dusit, Bangkok 10300, Thailand
[2]Greenday Global Co., Ltd., 829 Moo 2 Bangpoo Industrial Estate (North), Mueang Samutprakarn, Samutprakarn 10280, Thailand

Avocado pulp is low in sugar contents but quite high in dietary fiber, nutrients, and phytochemicals with potential health benefits. In this study, the avocado pulp was incorporated into ice cream. The effects of replacing milk fat with avocado on the physical and chemical properties of ice cream and consumer acceptability were evaluated. Milk fat-based ingredients of the ice cream were partially replaced with avocado pulp at ratios of 10, 20, and 30% (*w/w*). All ice creams were subjected to physical and chemical analyses and were evaluated in sensory acceptability tests. Replacing milk fat with avocado pulp significantly reduced moisture content, protein, and fat content, while it increased the carbohydrate (3.70 to 7.91 g/100 g) and crude fiber content (0.39 to 1.38 g/100 g). A higher content of avocado pulp caused a reduction in overrun and retarded the melting rate due to the effect of high fiber content. Increased viscosity and hardness were observed. The ice cream with the highest avocado pulp content had approximately 3-fold higher total phenolic content determined by the Folin-Ciocalteau method and 2-fold higher antioxidant capacity evaluated as DPPH$^{\bullet}$ and ABTS$^{\bullet+}$ scavenging activity, and ferric reducing antioxidant power compared to that of the control. Sensory evaluation showed the 20% (*w/w*) avocado pulp was the suitable ratio for incorporating in the ice cream, which showed a good level of overall acceptability. Thus, our results suggest the potential use of avocado pulp to replace milk fat in frozen dairy products.

Key words: avocado pulp, fiber-rich ice cream, antioxidant capacity, textural property

INTRODUCTION

Consuming desserts incorporated with high amounts of fiber and phytochemical agents obtained from fruits and vegetables plays an essential role in maintenance of healthy eating. Avocado (*Persea Americana* Mill.) is a subtropical fruit native to Mexico, and it has recently become a popular fruit to grow in northern Thailand. The avocado is a nutrient- and phytochemical-dense food consisting of 17.34 g of crude fat, 6.94 g of carbohydrates, 5.55 g of dietary fiber, and 2.08 g of proteins per 100 g of fresh pulp, and it is a useful source of energy [Dreher & Davenport, 2013; Marlett & Cheung, 1997; Yahia & Woolf, 2011]. According to Dreher & Davenport [2013], avocado oil fatty acids consist of 71% monounsaturated fatty acids, 13% polyunsaturated fatty acids, and 16% saturated fatty acids, and are thus considered high in monounsaturated fatty acids. Potassium, sodium, magnesium, ascorbic acid, vitamin K, folate, vitamin B_6, niacin, pantothenic acid, riboflavin, choline, carotenoids, tocopherols, and phytosterols contained in avocado pulp appear to support a wide range of potential health effects [Dreher & Davenport, 2013; Krumreich *et al.*, 2018; Ramos-Aguilar *et al.*, 2021]. Due to its healthy fat

***Corresponding Author:**
e-mail: thanida.ch@ssru.ac.th (Thanida Chuacharoen)

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content, consuming avocado helps to reduce total cholesterol, low-density lipoprotein cholesterol, and triglycerides, resulting in increased HDL cholesterol levels, which helps to promote a healthy blood lipid profile [Mahmassani *et al.*, 2018]. In addition, avocado is a source of phenolic compounds including phenolic acids, flavonoids, lignans, and stilbenes, the content of which correlates with its antioxidant potential [Lyu *et al*., 2023]. The avocado phenolics have also anti-inflammatory, as well as anticancer and antimicrobial activities, which are beneficial for health [Ford *et al*., 2023]. Avocado components such as fatty acids, carbohydrates (including dietary fiber) also confer potential cardiovascular health benefits. It is claimed by the United States Department of Agriculture (USDA) [2011] that the composition profile of avocado has qualified its heart health-improving potential similar to that of almonds, pistachios, and walnuts with less than half the calories.

In many countries, avocados are consumed as a vegetable in savory dishes, such as guacamole, and they are often used as a fresh cream in sweet dishes, such as shakes, smoothies, and ice creams [Cortés Rodríguez *et al.*, 2019]. Thus, because the avocado has potential functional components, such as healthy fatty acid, dietary fiber, and bioactive phytochemicals, its pulp is hypothesized to be able to substitute fat ingredients and enrich dietary fiber in various functional foods, including beverages along with dairy and bakery products for commercial use.

Milk-based ice cream is a frozen dairy dessert [Yeon *et al.*, 2017], which has gained in popularity with all age groups in Thailand. Its main ingredients are milk, whipped cream, and sugar, which can cause adverse health effects, such as diabetes, obesity, and high blood pressure. Thus, partially replacing milk-fat ingredients in ice cream with avocado pulp should reduce the risk of chronic diseases as well as enhance the nutritional values and health benefits of ice cream.

Given the aforementioned potential health benefits of using the avocado pulp as an alternative to dairy fats in desserts, we aimed to identify the ratio of avocado pulp substitution of dairy ingredients (*i.e.*, milk, whipped cream, and skimmed milk) in ice cream that affects the ice cream's physical properties and sensory acceptability to create a healthy functional ice cream with the benefits of high dietary fiber and antioxidant capacity.

MATERIALS AND METHODS

Preparation of the avocado ice cream

Avocado (*Persea Americana* Mill.) fruits were supplied by Greenday Global Co., Ltd., Samutprakarn, Thailand. Ingredients of ice cream production were purchased from a local market in Bangkok, Thailand. Avocado pulp was prepared according to Ospina *et al.* [2019] and Chuacharoen *et al.* [2021] by washing the avocados thoroughly with clean water, followed by vertically cutting avocados into four pieces, removing their seeds, and peeling them. Avocado pieces were blended into a paste using a kitchen blender, and 0.2% (*w/w*) of citric acid was added to reduce enzymatic activity. Four formulations of ice cream incorporated with the avocado pulp were prepared by the formulation of milk--based ice cream. Briefly, the liquid ingredients were pre-heated at 65°C and then the dried ones were mixed. Avocado pulp replaced 10% (A10), 20% (A20), and 30% (A30) (*w/w*) of the fat ingredients of the standard formulation, *i.e.*, fresh milk, whipped cream, and skimmed milk (Table 1). A sample without avocado (A0) was prepared as a control. The mixture was homogenized using a homogenizer (T25 Ultra-Turrax, IKA, Staufen im Breisgau, Germany) at 5,000 rpm for 2 min, pasteurized at 80°C for 25 s, and then immediately cooled down to 4°C before it was hardened at this temperature for 24 h. After hardening, the ice cream mix was produced and then frozen in an ice cream maker for 15 min. The avocado ice cream samples were stored at −18°C for further analyses.

Physicochemical analyses

To assess the quality of the ice cream, the physicochemical parameters including proximate composition, color, viscosity, melting rate, and overrun were determined.

Proximate analysis was performed based on the methodologies proposed by the Association of Official Analytical Chemists [Latimer, 2019]. Moisture content was determined by gravimetric method. In brief, the sample was dried in a convection oven at 110°C for 2 h (method 968.11). Ash content was quantified by burning the sample at 550°C in a muffle furnace (ELF11/14B, Carbolite, Derbyshire, UK) (method 945.38). Crude protein content was estimated in a digester (KI 11/26, Gerhardt, Koenigswinter, Germany) by the Kjeldahl method (method 971.09). Crude fiber content was determined by sequential acid and base

Table 1. Percentage (*w/w*) of ingredients in formulations of ice cream (A0) and ice cream with avocado pulp as a substitute of 10% (A10), 20% (A20), and 30% (A30) (*w/w*) of the fat ingredients.

Ingredient	A0 (control)	A10	A20	A30
Fresh milk	58.80	52.25	45.70	39.16
Whipped cream	23.00	20.44	17.88	15.32
Sugar	10.00	10.00	10.00	10.00
Skimmed milk	8.00	7.11	6.22	5.33
Guar gum	0.20	0.20	0.20	0.20
Avocado pulp	0.00	10.00	20.00	30.00

digestion (method 962.09). The total lipid content was extracted by the Soxhlet method for 80 min using *n*-hexane as the extraction solvent at 120°C (method 920.39) and carbohydrate content was established by difference and expressed as a nitrogen-free extract.

Color was measured using a MiniScan XE Plus colorimeter (Hunterlab, Reston, VA, USA). The *L**, *a**, and *b** values were determined. *L** characterized the lightness of the ice cream samples ranging from 0 (darkest) to 100 (lightest); *a** characterized the scale of green to red with negative values defined as hues of green and positive ones for hues of red; and *b** characterized the scale of blue to yellow with negative values for hues of blue and positive ones for hues of yellow.

Viscosity was measured using a Brookfield viscometer (DV-II, Brookfield, Middleboro, MA, USA) with spindle no. 2 at 100 rpm. A sample of 600 mL was analyzed at 14±1°C and was kept in cold water at 14±1°C to prevent temperature fluctuations during analysis. The results were expressed as cP.

Hardness was measured using a texture analyzer (XT-plus, Lloyd Ltd., Carlisle, UK) equipped with a 1 cm-diameter stainless steel cylindrical probe by the modified method of Bolliger *et al.* [2000]. The ice cream samples were stored at −22±1°C for 24 h before analysis. The conditions used for analysis were a penetration distance of 5 cm, a load cell of 1 kN, and a probe speed during penetration of 2.0 mm/s. The hardness (N) was measured as the peak compression force during the penetration of the sample.

Melting rates were measured by the modified method of Sofjan & Hartel [2004] in a controlled temperature chamber at 25°C. The frozen ice creams were tempered in a freezer at −18°C. A sample of 30 g was then placed on a 2 mm stainless steel screen with a funnel and graduated cylinder beneath it to collect the melt. The dripped weight was recorded once every 5 min for up to 60 min and the plot of the percentage of the melted ice cream was developed *versus* time. The slope of the plot indicated the melting rate expressed as g/min.

The percentage of overrun was measured by comparing the weight of melted ice cream in a fixed volume container with the weight of frozen ice cream [Aljewicz *et al.*, 2020]. The percentage of overrun was calculated according to the following formula (1):

$$\%\ \text{Overrun} = \frac{W_{\text{melted IC}} - W_{\text{frozen IC}}}{W_{\text{frozen IC}}} \times 100 \quad (1)$$

where: $W_{\text{melted IC}}$ is weight of melted ice cream and $W_{\text{frozen IC}}$ is weight of frozen ice cream.

Antioxidant capacity determination

Extract preparation

Approximately 5 g of ice cream was extracted with 50 mL of methanol followed by vortexing and mechanical shaking for 4 h. The mixture was sonicated for 20 min and then filtered through Whatman No. 1 filter paper and centrifuged at 1,277×*g* for 30 min. The supernatant was separated and kept at −20°C for further analyses.

Total phenolic content determination

Total phenolic content (TPC) was determined with the Folin-Ciocalteau reagent, according to the method described by Singleton *et al.* [1999] and Chuacharoen *et al.* [2021] with a slight modification. Briefly, 20 µL of the extract, gallic acid standard, or blank sample taken in separate test tubes were mixed with 1.58 mL of distilled water, followed by the addition of 100 µL of Folin–Ciocalteau reagent, and the mixture was mixed thoroughly. Next, 300 µL of 7% aqueous sodium carbonate solution was added to the test tubes containing the mixtures within 8 min, and these were then immediately vortexed and allowed to stand in darkness for 30 min at room temperature. The absorbance was then recorded at 765 nm using a UV-Vis spectrophotometer (Spectronic™ GENESYS™2, Thermo Fisher Scientific, Waltham, MA, USA). TPC was calculated from a standard curve of gallic acid, and the results were expressed in mg gallic acid equivalent (GAE)/g of ice cream.

Antioxidant capacity determination

The antioxidant capacity of ice cream was measured by 1,1-diphenyl-2-picrylhydrazyl (DPPH) assay, 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) (ABTS) assay, and ferric reducing antioxidant power (FRAP) assay.

DPPH assay was performed according to the procedure described by Ghafar *et al.* [2010] with a slight modification. Briefly, 200 µL of the extract was reacted with 2.8 mL of 100 µM $DPPH^{\bullet}$ dissolved in methanol for 30 min in darkness. A control containing only $DPPH^{\bullet}$ solution and 80% (*v/v*) methanol solution was used as the blank. The absorbance was then measured at 515 nm using a UV-Vis spectrophotometer (Spectronic™ GENESYS™2, Thermo Fisher Scientific). A standard curve was obtained by using a Trolox standard solution at various concentrations in 80% methanol solution. The results were expressed as mg of Trolox equivalents (TE)/g of ice cream

ABTS assay was carried out as described by Chuacharoen & Sabliov [2016] with a slight modification. Briefly, $ABTS^{\bullet+}$ solution was prepared by dissolving 7 mM of ABTS with 2.45 mM potassium persulfate and keeping the mixture in darkness for 15 h at room temperature. The $ABTS^{\bullet+}$ solution was then diluted with 5 mM sodium phosphate buffer at a pH of 7.4 to reach an absorbance of 0.70±0.02 using a UV-Vis spectrophotometer (Spectronic™ GENESYS™2, Thermo Fisher Scientific) read at 734 nm. Fifty µL of each extract was mixed thoroughly with 150 µL of the $ABTS^{\bullet+}$ solution, and incubated for 10 min at 25°C. The $ABTS^{\bullet+}$ scavenging activity was calculated from the calibration curve of Trolox. Results were expressed as mg of Trolox equivalent (TE)/g of ice cream.

FRAP assay was carried out according to the method described by Bakar *et al.* [2022] with a slight modification. Briefly, 100 µL of the extract was dissolved with 300 µL of distilled water, and the 100 µL of the diluted sample was pipetted into the test tube. The stock solutions including 300 mM acetate buffer (3.1 g sodium acetate trihydrate and 16 mL acetic acid) adjusted to pH 3.6, 20 mM $FeCl_3$ hexahydrate solution, and 10 mM 2,4,6-tri(2--pyridyl)-1,3,5-triazine (TPTZ) in 40 mM HCl solution were freshly prepared. Then, 3 mL of FRAP reagent (10:1:1 (*v/v/v*) of sodium acetate buffer, TPTZ, and $FeCl_3$ solutions) heated up to 37°C was added to the sample test tube. The mixture was allowed to react for 30 min in darkness. Reading of the colored product (ferrous-tripyridyltriazine complex) was performed at 593 nm using a UV-Vis spectrophotometer (Spectronic™ GENESYS™2, Thermo Fisher Scientific). The FRAP was calculated from the calibration curve of Trolox. Results were expressed as mg of Trolox equivalent (TE)/g of ice cream.

Consumer acceptability test

Acceptability of avocado ice cream was evaluated by a semi-trained panel of 30 judges selected among graduate students, researchers, and academic staff of the Faculty of Science and Technology, Suan Sunandha Rajabhat University, Bangkok, Thailand. The semi-training consisted of presenting the aim of the study and introducing the sample properties to the panelists for 1 h. Subsequently, panel members were trained to identify the desired ice cream in terms of appearance, color, odor, taste, texture, resistance to melting, and overall acceptability. Ice cream samples stored at −20°C were removed from the freezer and tempered for 5 min at 20°C before sensory analysis. The samples of approximately 45 g were served in random code to panelists one by one to avoid melting of samples. During testing samples, the panelists were served drinking water to clean their palates. The sensorial properties were evaluated based on a 9-point hedonic scale for appearance, color, odor, taste, texture, resistance to melting, and overall acceptability using 1 – dislike and 9 – like, respectively [Di Criscio *et al.*, 2010; Karaman *et al.*, 2014; Kushwaha *et al.*, 2023; Tobin *et al.*, 2013].

Statistical analysis

The experiments were performed in triplicate, and the results were reported as mean ± standard deviation and analyzed using Statistical Package of the Social Science (SPSS) version 26 (IBM, Armonk, NY, USA) using one-way analysis of variance (ANOVA). Duncan's multiple range test was performed to determine the differences between mean values, and the differences were considered to be statistically significant at $p<0.05$.

RESULTS AND DISCUSSION

Proximate composition of avocado ice cream

The proximate compositions of the ice cream are shown in Table 2. Formulations having avocado pulp were significantly ($p<0.05$) higher in carbohydrates and crude fiber but significantly lower ($p<0.05$) in moisture, crude protein, total lipid, and ash contents compared with the control. Protein content was obviously reduced because the protein content of the controls was mainly obtained from fresh milk, whipped cream, and skimmed milk, which were partially replaced by avocado pulp.

Total lipid content of ice cream was reduced from 12.67 to 11.08 g/100 g (12%) and 9.1 g/100 g (28%) by partially replacing milk fat with 10% and 30% avocado pulp, respectively. Fat-reduced ice cream with avocado pulp should be a healthy choice. In addition, avocado contains oils that are rich in dietary beneficial monounsaturated fatty acids [Bes-Rastrollo *et al.*, 2008]. In a similar study, Harith *et al.* [2016] successfully used avocado puree as a fat replacer in muffins. They aimed to propose muffins with the benefit to promote healthy blood lipid profiles and regulate blood glucose levels. Additionally, the lipid fraction of avocado contains fat-soluble vitamins, including tocopherols [Green & Wang, 2020]. For this reason, this is a valuable phenomenon for substituting milk-fat ingredients of ice creams with avocado pulp.

Carbohydrate content in avocados includes about 80% dietary fiber, consisting of 70% insoluble and 30% soluble fiber [Marlett & Cheung, 1997]. Avocados contain 4.6 g of dietary fiber *per* 69 g approximately one-half of avocado fruit. Thus, consuming one-half an avocado can help to achieve about one-third of the adequate intake of 14 g dietary fiber *per* 1,000 kcal [USDA, 2011]. At this high level of carbohydrates, especially dietary fiber contained in an avocado, adding avocado pulp resulted in significantly ($p<0.05$) increased carbohydrate and fiber contents in the ice cream products, which was 2–3 times higher than that of the control (Table 2). It was hypothesized that adding cellulose fibers obtained from plants to ice cream could slow the melting rate. For example, citrus fiber was used to improve the melting quality of ice cream, but it failed to improve viscosity, overrun, and texture [Dervisoglu & Yazici, 2006]. Rice flour was a satisfactory fat replacer, but it caused a powdery mouthfeel in the ice cream [Cody *et al.*, 2007]. Soukoulis *et al.* [2009] studied the effects of four dietary fiber sources, which were oat, wheat, apple, and inulin, on the physicochemical properties of ice cream. They concluded that the enrichment of ice cream with dietary fibers was an effective way to enhance the nutritional and physiological

Table 2. Proximate composition (g/100 g) of ice cream (A0) and ice cream with avocado pulp as a substitute of 10% (A10), 20% (A20), and 30% (A30) (*w/w*) of the fat ingredients.

Component	A0 (control)	A10	A20	A30
Moisture	66.89±0.21^{a}	62.77±1.54^{b}	60.03±1.82^{bc}	59.59±1.12^{c}
Crude protein	15.50±0.21^{a}	12.49±1.09^{b}	10.15±0.96^{c}	9.29±0.38^{c}
Total lipids	12.67±0.11^{a}	11.08±0.98^{b}	10.14±0.83^{bc}	9.10±0.43^{c}
Carbohydrate	3.70±0.39^{c}	5.21±1.83^{b}	7.80±0.50^{a}	7.91±0.50^{a}
Ash	0.85±0.02^{a}	0.79±0.02^{b}	0.77±0.03^{b}	0.65±0.02^{c}
Crude fiber	0.39±0.07^{d}	0.84±0.22^{c}	1.11±0.55^{b}	1.38±0.60^{a}

Data are presented as mean ± standard deviation (n=3). $^{a-d}$ superscripts represent a significant difference within the same row ($p<0.05$) according to Duncan's multiple range test.

properties of the ice cream. Incorporating dietary fibers from plants not only affects the physical aspects of the food but also enhances the bioavailability of nutrients and phytochemicals [Unlu *et al.*, 2005]. Thus, ice cream incorporated with avocado may be healthier than the standard milk ice cream formulation because it has a lower fat content and higher fiber content.

The moisture content of ice cream was significantly (p<0.05) different between the samples having milk fat substituted with avocado pulp and control (Table 2). The control sample (A0) had the highest moisture content and moisture content decreased as the ratio of avocado pulp in the formulation was increased. This was due to decreasing the ratio of fresh liquid milk in the formulation. In general, a standard ice cream formulation should have a water content of about 55 to 65 g/100 g, and a mixture with high water content relates to a lower total solid content, and this proportion affects the physical properties of ice cream, particularly the texture and hardness [Choi & Shin, 2014].

Physical properties and color values of avocado ice cream

The physical parameters, including viscosity, melting rate, overrun, hardness, and color parameters, of control ice cream and ice cream with avocado pulp are shown in Table 3. The viscosity of ice cream differed significantly (p<0.05) among the formulations, and A30 had the highest value, followed by A20, A10, and A0, respectively. Overall viscosity increased as the ratio of avocado pulp added to the ice cream was increased. The viscosity of ice creams is particularly affected by adding stabilizer, sugar, or fiber [Syed, 2018]. In this study, guar gum was added at the same amount for all formulations, so crude fiber and sugar in avocado pulp incorporated into the ice cream played a significant role in its viscosity profile. The higher content of avocado pulp directly contributed to the increased sugar levels because of the natural sugars in avocados. Thus, higher contents of avocado pulp caused thicker and more viscous ice cream mixtures. Our results are consistent with the physical properties analysis of ice-cream frozen yogurts by Güven & Karaca [2002], who reported the amount of sugar and fruit increased viscosity values. Although avocado contains 1.2 g/100 g total sugar, it also contains 28 g/100 g dietary fiber [Dreher & Davenport, 2013]. Dietary fiber has the ability to bind with water, resulting in increased thickening of the ice cream mixture, as described by Soukoulis *et al.* [2009]. They explained that the increased viscosity of the fiber-enriched ice cream is caused by both the soluble and insoluble fibers. The contribution of the soluble fibers promotes soluble matter to the composition of the aqueous phase. Similarly, the contribution of insoluble fibers increases total solids affecting the three-dimensional conformation of the hydrated fibers. It is well known for its gel-forming ability and hydrogel structure reinforcement.

The melting rate of ice cream with avocado pulp differed significantly (p<0.05) between the formulations (Table 3). The control (A0) had the highest melting rate, followed by A10, A20, and A30. The melting rate decreased as the ratio of avocado pulp was increased, which may have been the dietary fiber in the avocado pulp that decreased the melting rate due to binding ability with water as mentioned earlier. A similar study on frozen dairy dessert by Soukoulis *et al.* [2009] reported that adding dietary fiber to a frozen dairy dessert could improve the melting quality of the ice cream, and insoluble fiber was able to increase the shear-thinning properties of the ice cream mixture as well.

Generally, a higher overrun level significantly contributes to a higher melting rate in the ice cream [Sofjan & Hartel, 2004]. In the present study, the overrun of ice cream was significantly (p<0.05) different among the formulations, which had the same trend as the melting rate. Increasing the ratio of avocado pulp to replace the milk fat in the ice cream mixture significantly reduced the overrun of the ice cream. The controls had a high overrun value resulting in a high melting rate due to the instability of air bubbles incorporated in the ice cream mixture. These air bubbles may have caused the temperature to increase while the ice cream was melting.

Overrun also affected the hardness profile of ice cream (Table 3). The hardness refers to the resistance of the ice cream to deform affected by an external force and it has an inverse relationship with the overrun [Muse & Hartel, 2004]. The highest hardness value was determined in the samples with the highest avocado pulp added, followed by A20 and A10, which were significantly (p<0.05) higher than those found in the controls. It can

Table 3. Physical properties of ice cream (A0) and ice cream with avocado pulp as a substitute of 10% (A10), 20% (A20), and 30% (A30) (*w/w*) of the fat ingredients.

Parameter		A0 (control)	A10	A20	A30
Viscosity (cP)		175.50±1.25^{d}	212.49±1.09^{c}	250.15±0.96^{b}	296.29±0.38^{a}
Melting rate (g/min)		7.85±0.63^{a}	3.54±0.29^{b}	1.23±0.20^{c}	0.42±0.18^{d}
Overrun (%)		21.05±0.21^{a}	19.90±1.18^{b}	17.46±0.14^{c}	10.89±1.17^{d}
Hardness (N)		9.74±0.54^{d}	13.16±0.88^{c}	16.87±0.25^{b}	18.48±0.13^{a}
Color	*L**	86.08±0.23^{a}	69.29±1.50^{b}	67.19±0.45^{c}	61.48±0.61^{d}
	*a**	−0.43±0.39^{a}	−1.71±0.28^{b}	−2.80±0.21^{c}	−3.34±0.49^{c}
	*b**	13.28±0.25^{d}	30.10±0.80^{c}	33.36±0.25^{b}	36.77±0.21^{a}

Data are presented as mean ± standard deviation (n=3). $^{a-d}$ superscripts represent a significant difference within the same row (p<0.05) according to Duncan's multiple range test. *L**, lightness; *a**, greenness to redness; *b**, blueness to yellowness.

be attributed to the gelling properties of avocado fibers which favor the ability to bind water molecules and form a particle gel network improving the firmness of the ice cream [Akalın *et al.*, 2018]. This was consistent with the findings of Crizel *et al.* [2014], who used orange fiber as a fat replacer in ice cream; the result showed that the greater amount of the orange fiber significantly increased ice cream's hardness compared to the control. For the texture perception, it can be concluded that ice cream enrichment with fiber may contribute to the improvement of melting rate and the formation of tiny ice crystals favoring the stability of ice crystals during frozen storage.

The color of ice cream brings visual attractiveness, which is relevant to the acceptability of a product for consumers. The images and color parameters of ice cream incorporated with avocado pulp are presented in Figure 1 and Table 3, respectively. Adding avocado pulp created a green-colored ice cream, and adding higher ratios of it caused less brightness along with changes in yellow and green hues, which were visually perceptible to the naked eyes. The L^* values of ice cream color decreased as the ratio of avocado was increased, and the hue of yellow (b^*) increased significantly (p<0.05). The green hue of the ice cream was less dark when the ratio of avocado pulp was increased (A20 and A30) and compared with the control (A0).

Total phenolic content and antioxidant capacity of avocado ice cream

The antioxidant capacity of avocado ice cream was evaluated as $DPPH^•$ and $ABTS^{•+}$ scavenging activities and as ferric reducing antioxidant power (FRAP). The DPPH assay is based on an electron transfer mechanism to stabilize radicals with a high affinity to lipophilic antioxidants, whereas more polar antioxidant compounds are easily determined by FRAP and/or ABTS assays [Martysiak-Żurowska & Wenta, 2012]. A significant relationship between antioxidant potential and phenolic compounds which are the major contributors to antioxidant activity is seen in Table 4. The TPC and antioxidant capacity of the ice cream incorporated with avocado pulp were significantly (p<0.05) higher than those without avocado pulp. It is not surprising as the strong antioxidant potential of avocado pulp was reported in previous studies [Chuacharoen *et al.*, 2021; Lyu *et al.*, 2023; Nguyen *et al.*, 2022]. The TPC of the ice cream with incorporated avocado ranged from 5.25 to 12.19 GAE mg/g ice cream, and the highest value was determined in the sample with the highest amount of avocado pulp (A30). The $DPPH^•$ scavenging activity ranged from 32.3 to 45.7 µmol TE/g of avocado ice cream with increasing values as avocado pulp ratio was increased. This was attributed to the fact that fresh avocado pulp contains the bioactive compounds, which possessed the stronger antioxidant capacities when incorporated in higher amount proportionally [Chimuti *et al.*, 2021]. $ABTS^{•+}$ scavenging activity and FRAP of avocado ice cream ranged from 73.0 to 104.9 µmol TE/g and 240 to 325 µmol TE/g, respectively. The results of ABTS and FRAP assays, demonstrate again higher antioxidant capacity of ice cream with higher amounts of avocado pulp mixed into the ice cream. Martysiak-Żurowska & Wenta [2012] reported that the ABTS test was more precise and sensitive to characterize the total antioxidant capacity in milk-based products compared to the DPPH test. In our study, all assays were useful to show the antioxidant capacity of avocado ice cream. In general, the addition of avocado pulp as a fat replacement ingredient can enhance the content of health-promoting phenolic compounds and antioxidant characteristics of ice cream.

Assessment of consumer acceptability of avocado ice cream

Consumer ratings of the avocado ice cream samples are shown in Table 5. Adding avocado pulp affected the sensory properties of the ice cream and decreased the overall acceptability of the product due to the grassy smell of the avocado pulp. The higher content of avocado pulp added into ice cream samples resulted in significantly (p<0.05) lower scores for odor and taste. The taste property is one of the most important sensory criteria for food products, especially for ice cream.

A significant (p≥0.05) difference was not detected regarding the appearance and color of the samples except for A20, which received the highest score on both attributes. Texture score became lower as the ratio of avocado pulp was increased. The lower texture score was related to the ice cream's resistance to melting.

Figure 1. The appearance of ice cream (**A**) and ice cream incorporated with avocado pulp at different levels: 10%, *w/w* (**B**), 20%, *w/w* (**C**), and 30%, *w/w* (**D**).

Table 4. Total phenolic content (TPC) and antioxidant capacity of ice cream (A0) and ice cream with avocado pulp as a substitute of 10% (A10), 20% (A20), and 30% (A30) (*w/w*) of the fat ingredients.

Parameter	A0 (control)	A10	A20	A30
TPC (mg GAE/g)	3.57±0.08^{d}	5.25±0.02^{c}	8.56±0.10^{b}	12.19±0.07^{a}
DPPH$^{•}$ scavenging activity (μmol TE/g)	24.2±3.5^{c}	32.3±8.6^{b}	39.3±6.7^{ab}	45.6±11.8^{a}
ABTS$^{•+}$ scavenging activity (μmol TE/g)	62.1±0.7^{d}	73.0±1.2^{c}	83.5±5.2^{b}	104.9±3.1^{a}
FRAP (μmol TE/g sample)	169±18^{d}	240±21^{c}	290±11^{b}	325±20^{a}

Data are presented as mean ± standard deviation (*n*=3). $^{a-d}$ superscripts represent a significant difference within the same row (*p*<0.05) according to Duncan's multiple range test. DPPH$^{•}$, 1,1-diphenyl-2-picrylhydrazyl radical; ABTS$^{•+}$, 2,2'-azino-bis(3-ethylbenzothiazoline-6-sulfonic acid) radical cation; FRAP, ferric reducing antioxidant power; GAE, gallic acid equivalent; TE, Trolox equivalent.

Table 5. Consumer ratings of ice cream (A0) and ice cream with avocado pulp as a substitute of 10% (A10), 20% (A20), and 30% (A30) (*w/w*) of the fat ingredients.

Attribute	A0 (control)	A10	A20	A30
Appearance	7.17±1.05^{b}	7.23±1.19^{b}	7.57±0.86^{a}	7.10±1.06^{b}
Color	7.15±1.18^{b}	7.23±1.10^{b}	7.43±0.86^{a}	7.37±0.93^{b}
Odor	7.07±1.06^{a}	7.17±1.23^{a}	7.13±1.17^{a}	6.57±1.17^{b}
Taste	7.36±1.17^{a}	7.47±1.19^{a}	7.47±1.59^{a}	6.00±1.66^{b}
Texture	7.66±1.05^{a}	7.33±0.99^{b}	7.27±1.11^{b}	6.70±1.18^{c}
Resistance to melting	6.06±1.66^{c}	6.22±1.05^{c}	6.69±1.09^{b}	7.35±1.66^{a}
Overall acceptability	7.43±0.94^{a}	7.47±0.99^{a}	7.39±1.07^{a}	6.47±1.38^{b}

Data are presented as mean ± standard deviation (*n*=30). $^{a-c}$ superscripts represent a significant difference within the same row (*p*<0.05) according to Duncan's multiple range test.

The incremental increase in avocado pulp ratio provided resistance to melting, confirmed by the consumer ratings. The higher the amount of avocado pulp added to ice creams, the greater the amount of dietary fiber was retarding the melting rate of the ice cream. It was also confirmed by physical measurements of the melting rate and hardness. The highest amount of avocado pulp (A30) incorporated caused the ice cream to melt slowest and be difficult to consume. Thus, the consumers preferred the ice cream with a good combination of a medium green, a moderate rate of melting, and a texture with a slightly high overrun level, which were found from the characteristics of the ice cream samples incorporated avocado pulp at 10–20%.

CONCLUSIONS

Fresh avocado pulp could be used as a fat-replacing ingredient in dairy products (*e.g.*, ice cream), which would alter their physical and chemical aspects as a function of avocado content in the ice cream. Regarding the proximate composition, avocado ice cream showed a healthier content of crude fiber and was low in total lipid content, compared with a standard milk ice cream formulation. The substitution of milk fat with avocado pulp affected the texture perception in the ice cream mixture. In addition, the effect of avocado pulp compositions on air content in the ice cream mixture also contributed to the physical properties of the ice cream such as melting properties, overrun, hardness, and other sensorial characteristics. Health-promoting phenolic compounds and antioxidant capacity of the avocado ice cream increased as the ratio of avocado content was increased. To produce antioxidant-rich avocado ice cream, the incorporation of avocado pulp at contents higher than 20% increased the potential functional properties of the ice cream, but reduced some desirable physical properties, which significantly decreased the overall acceptability of the ice cream.

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CONFLICT OF INTERESTS

Authors declare no conflict of interests.

ORCID IDs

T. Chuacharoen https://orcid.org/0000-0002-2668-942X

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