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Low-fat, Plant-based Ice Creams Formulated with Rice Bran Oil and Rice Bran Oil Organogel

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Abstract

Low-fat, plant-based ice creams were novelty formulated by replacing milk with rice bran oil and rice bran oil organogel emulsion. The protein in milk was substituted by soy protein. The viscosity and emulsion stability of the plant-based ice cream mixtures were measured and compared with conventional milk ice cream. Frozen ice cream properties, including overrun, firmness and melt down rate were investigated as well as nutritional and sensory properties. Result found that the viscosity of the plant-based ice cream mix including organogel (398 mPa·s) and rice bran oil (363 mPa·s) exhibited higher value than those of conventional ice cream mix (289 mPa·s). The emulsion stability of milk, organogel and rice bran oil ice cream mixtures were 88.72±0.80, 88.00±0.10 and 80.12±0.65, respectively. The overrun of organogel ice cream (38.31± 0.91) showed lower quality characteristics than the milk ice cream (39.40±1.03) while rice bran oil ice cream had the lowest overrun (37.02±0.01) ($P<0.05$). The reduction of overrun related with texture of ice cream. The firmness of rice bran oil ice cream (16.4±0.91) showed lower quality characteristics than organogel ice cream (15.3± 0.87) followed by the milk ice cream (14.4±0.91). The melt down rate of plant-based ice creams (organogel: 0.46±1.75, rice bran oil: 0.45±1.65) are improved when compared with the milk ice cream (0.67±1.65) may be because of high viscous of ice cream mix and the properties of soy protein. The nutritional properties were improved for plant-based ice cream formulations. Especially, total fat content of organogel was lower than rice bran oil because of the lower fat of organogel. Sensory testing scores of the taste and flavors was decreased as well as appearance and color characteristics. Texture and body of the organogel ice creams were not different when compared to the conventional milk ice cream. Although, firmness of organogel was higher than conventional ice cream but panelists cannot perceive the difference. Nevertheless, rice bran oil ice cream had the lowest score ($P<0.05$) in texture and body which may be due to the high firmness value. Therefore, low-fat, plant-based ice cream formulated with rice bran oil organogel is a successful approach in order to obtain lower fat without compromising their qualities except the taste and flavor because of soy protein flavor.

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Introduction

Plant-based foods have gained research interest because of problems associated with saturated fat and cholesterol contents in animal-based foods. Consuming high saturated fat diet is a well-accepted cause for increasing risk of cardiovascular and coronary heart diseases (Bhupathiraju & Tucker, 2011; Willett, 2012; DiNicolantonio et al., 2016).

Ice cream is a frozen dessert which usually contains 10–12% of fat. Fat plays a significant role in ice cream mix behavior during freezing and the final structure of ice cream (Harte et al., 2003). The major structural components of ice cream are fat globules, air and ice crystals that are dispersed in a frozen solution concentrated with proteins, salts and polysaccharides (Muse & Hartel, 2004). Formulating a low saturated fat ice cream with 2–4% of fat that have comparable properties with conventional fat containing products is a challenging task. The major drawbacks of using fat replacers in ice cream is the poor sensory quality (Akbari et al., 2019). Nevertheless, numerous attempts in reducing saturated fat content of ice cream by using fat replacers or components imitating fat have been reported (Hatipoğlu &Türkoğlu, 2020).

Organogels are novel oil-based materials formed by structuring liquid oils or emulsion with organogelators such as wax, plant sterol and policosanol, rendering them as crystalline solid fats (Sawalha et al., 2021; Mandu et al., 2020; Adulpadungsak et al., 2020). Organogelation does not alter the fatty acid composition of the entrapped liquid oil/emulsion (Jaroennon et al., 2021) and no *trans* fats are generated (Stortz et al., 2012). There were few studies on the applications of organogel in low-fat ice cream. Zulim-Botega et al., (2013a, 2013b) demonstrated the potentials of rice bran wax organogel in developing fat structure in ice cream with high fat concentration (15 g/100 g) in the presence of glycerol monooleate as emulsifier. Moriano & Alamprese (2017) reported that organogels with plant sterol in ice creams with quality characteristics comparable to milk ice cream and even better overrun and melting starting time.

The aim of this research is to explore the possibility of producing plant-based and low-fat ice creams by replacing milk fat with rice bran oil and rice bran oil organogels with policosanol. The milk protein was also substituted with soy protein. The viscosity and emulsion stability of the formulated ice cream mix were measured. Overrun, firmness, melt down rate, nutritional and sensory properties of the frozen ice cream were measured and compared with conventional milk ice creams.

Materials and methods

1. Materials

The rice bran organogels with policosanol were prepared by our previous method (Manakla et al., 2020) and stored in a refrigerator at 4°C before ice cream production. Rice bran oil (Thai Edible Oil Co., Ltd., Thailand), fresh milk (whole milk 100%, Meiji, Thailand), soy protein (FITWHEY, Thailand), white sugar (Wangkanai Corporation., Ltd, Thailand) and vanilla extract (McCormick, USA) for ice cream preparation were purchased from a local supermarket. Rice bran oil utilized for ice cream and organogel production contained 31.81% of saturated fatty acid (SFA), 40.56% of monounsaturated fatty acid (MUFA) and 21.64% of polyunsaturated fatty acid (PUFA). Fresh pasteurized milk contained 3% of fat, 2% of protein and 2% of carbohydrate (Manakla et al., 2020).

2. Ice cream preparation

Low-fat, plant-based and conventional milk-based ice creams were formulated as shown in Table 1. The type of fat was varied, while the quantities of fat, protein (milk and soy protein), sugar and vanilla extract were fixed. In a typical plant-based ice cream preparation, a mixture of water and soy protein was poured into the rice bran oil-based organogel phase while homogenizing with a high-speed disperser (Ultra-Turrax T-25 basic, IKA) at 8000 rpm for 5 minutes. The resulting emulsion (240 mL) was subsequently homogenized with sugar and vanilla extract. The homogeneous ice cream mixture was allowed to cool at 5°C for 12 hours The ice cream was formed by an Ice Cream Maker (ICM-F15K, Factory Ice Cream Machine, Thailand) with a duration time of 20 minutes. All samples were kept at -18°C for 24 hours before analyzing.

Table 1 Formulations of ice creams

Ingredient (%)	Ice cream formulations		
	Conventional	Organogel	Rice bran oil
Water	0	69.28	69.28
Fresh milk	74.5	0	0
Sugar	25	25	25
Soy protein	0	2.24	2.24
Rice bran oil	0	0	2.98
Organogel	0	2.98	0
Vanilla extract	0.5	0.5	0.5

3. Ice cream mixture properties

The viscosity (in mPa·s) of the ice cream mixture was measured using a Brookfield Viscometer DV-II Pro with spindle 64S for 15 and 30 s at 120 rpm. The emulsion stability index of an ice cream mixture was measured using the reported method (Wu, 2001). Typically, a freshly prepared ice cream mixture (11.0 ± 0.5 g) was weighted in a test tube (1.5 cm in diameter and 10 cm in height) and centrifuged at 8000g for 15 minutes with a centrifuge (Universal 32, Hettich Instruments, Tuttlingen, Germany). The height of the formed free oil-phase was measured using a Vernier caliper. The emulsion stability (%) was calculated according to Equation 1.

$$\text{\% Emulsion stability} = \frac{H_t - H_o}{H_t} \times 100 \qquad \text{(Eq. 1)}$$

where H_o is the height of oil phase and H_t is the total height of the sample in the test tubes.

4. Frozen ice cream properties

4.1 Overrun

The amount of air incorporated in the frozen ice cream samples was measured by filling a fixed volume container with the frozen ice cream immediately after finishing the total freezing/whipping time of 10.5 minutes. The density of ice cream mix was 1.1 kg/L. The container's volume and weight were 227 mL and 40.5 g, respectively (Adapa et al., 2000). The overrun percentage was calculated by the Equation 2:

$$\text{\% Overrun} = \frac{W_m - W_f}{W_f} \times 100 \qquad \text{(Eq. 2)}$$

W_m is weight of ice cream mix and W_f is weight of frozen ice cream in the container

4.2 Melting rate

The melting rates of the ice cream samples were measured using a drip-through test, according to Soukoulis et al., (2008). The ice cream samples were kept in a freezer at −20°C for approximately 12 hours before measurement. Ice cream (50 g) were transferred to a 2 mm sieve at room temperature (approximately at 25°C). The dripped portion was evaluated for 90 minutes with a 5-minute interval. The melt down rate test was conducted in triplicate.

4.3 Firmness

The firmness was determined by a texture analyzer CT3 (Ametek, Brookfield, USA). The penetration tests on 50-mL samples were performed. A stainless-steel cylindrical probe (8 mm in diameter) connected to a 100 N load cell was used. The ice cream samples were penetrated for 18 mm using a crosshead speed of 50 mm/min. The reported results expressed as the maximum loads (N) opposed by ice creams to a 15-mm penetration were averaged values of at least 10 measurements for each ice cream formulation (Moriano & Alamprese, 2017).

4.4 Energy, protein, carbohydrate and fat content of ice cream samples

Standard methods of the Association of Official Analytical Chemists were used to determine protein (AOAC, 1990), fat (AACC, 2000) and carbohydrate content. Each analysis was carried out in triplicate. The energy content of ice cream samples were calculated by energy yielding nutrient content including fat carbohydrate and protein (Osborne & Voogt, 1978) according to the following equations:

$$\text{Food energy (kCal/g)} = (CP \times 4) + (F \times 9) + (CHO \times 4)$$

CP is crude protein (%) F is fat (%) and CHO is carbohydrate content (%)

4.5 Sensory test

Sensory characteristic and overall acceptability of ice cream samples were evaluated by 50 untrained panelists (20-35 year; 15 males, 35 females), using a sensory rating scale of 1–10 for taste and flavor, texture and body and 1–5 for appearance and color. The properties evaluated contained (a) three characteristics for appearance and color (no criticism: 5, dull color: 4–1, unnatural color: 3–1), (b) seven properties for taste and flavor (no criticism: 10, cooked flavor: 9–7, lack of sweetness and too sweet: 9–7, lack of flavor: 8–6, rancid and oxidized:6–1 and other: 5–1), and (c) seven terms describing texture and body (no criticism: 10, coarse: 9-7, crumbly: 9-7, weak: 8-6, fluffy: 8-6, gummy: 6-1, sandy: 5-1). Ice cream samples were placed into 100-mL transparent cups. The 30g ice cream samples were adequate for scooping up the teaspoonful and sensory characteristics of the samples could be evaluated. All samples were labelled with 3-digit random code numbers and randomly served to panelists.

4.6 Statistical analysis

The mean values recorded for each test were compared using analysis of variance (ANOVA). Tukey's test was applied to detect the significant differences among the ice cream samples ($P < 0.05$). The Completely Randomized Design or CRD was applied to create the different formulations of ice cream for properties measurements. Three replications were performed for each sample.

Results and discussion

1. Ice cream mix properties

1.1 Viscosity

Viscosity of ice cream mixtures have relationship with melt down rate, texture and overrun of ice cream after freezing. The viscosities of the ice creams mixtures are shown in Table 2. Viscosity of milk, organogel and rice bran oil ice cream mixtures were 289, 398 and 363 mPa·s, respectively. The conventional ice cream mixture exhibits a lower apparent viscosity than other samples. The viscosities of rice bran oil and organogel ice cream mixtures that contain soy protein were significantly different. They were higher than milk ice cream mixture that might be due to soy protein properties. Soy protein could provide several functionalities, such as water holding and emulsifying properties. In addition, soy proteins in rice bran oil ice cream mixtures might form a stable gel-like network structure, creating a greater resistance to flow (Batista et al., 2005). Our results were aligned with the study by Aboulfazli et al. (2014) which showed that soymilk ice cream increased apparent viscosity of melted ice cream.

Table 2 Viscosity and emulsion stability of ice cream mixtures

Ice cream formulation	Viscosity (mPa. s)	Emulsion stability (%)
Milk ice cream	289 ± 1.01c	88.72± 0.80a
Organogel	398 ± 2.01a	88.00± 0.10a
Rice bran oil	363 ± 1.32b	80.12± 0.65b

Remark: Values with different letters in the same column are significantly different ($p < 0.05$) (Tukey's test)

1.2 Emulsion stability

All ice cream samples were prepared by emulsion of rice bran oil and cow milk which is oil in water emulsion and should be stable during freezing, but unstable enough so that partial coalescence occurs during the dynamic freezing (Goff et al., 1989). The emulsion stability of milk, organogel and rice bran oil ice cream mixtures were 88.72±0.80, 88.00±0.10 and 80.12±0.65, respectively (Table 2). Organogel could improve the emulsion stability by increasing the viscosity of the water phase because of its water absorption properties. Its continuity could also hold oil droplets, leading to increased stability of emulsion. The emulsion stabilities were not significantly different ($P < 0.05$) between conventional ice cream and organogel ice ceam mixture, suggesting that the emulsion stability contributed by the gelled oil in the organogel ice cream mixture was comparable to that of crystalline milk fat in the conventional ice cream mixture.

2. Frozen ice cream properties

2.1 Overrun

The overrun of conventional, organogel and rice bran oil ice cream samples were 39.40 ±1.03, 38.31±0.91 and 37.02±0.01, respectively (Table 3). Conventional milk ice cream had the highest overrun indicating larger incorporation of air. This related with the softest texture of milk ice cream. No significant difference was observed between the overrun values of conventional and organogel ice cream samples ($p>0.05$). For plant-based ice cream, organogel formulation produced higher levels of overrun when compared to rice bran oil ($p<0.05$), implying the larger incorporation of air in the organogel-based ice cream. The results suggested that the presence of organogel could improve the overrun of plant-based ice cream with respect to the use of non-structured rice bran oil. Similar results were also observed by Zulim-Botega et al. (2013a) that the application of a rice bran wax organogel instead of high oleic sunflower oil improved overrun of ice cream.

2.2 Melt down rates

The melt down rates is an indicator of the structure development and the resistance to collapse (Goff & Hartel, 2013). Melt down rates of various ice creams are presented in Table 3. The corresponding digital photographs are presented in Fig 1. All ice cream samples in this study melted within 90 minutes. The conventional ice cream had the highest melt down rate of 0.67±1.65. The rice bran oil ice cream possessed the lowest melt down rate of 0.45±1.65, which was not significantly different from the melt down rate of organogel ice cream samples, i.e., 0.46±1.75. Basically, overrun and melt down rates have a relationship because a large amount of air affected the heat transfer during melting. Hartel et al. (2004) found that higher air cooperation led to the melted ice cream having a more difficult flow, resulting in lower melt down rate. According to the overrun result, conventional ice cream incorporated more air than the plant-based ice creams and showed a higher rate of melting. Therefore, melt down rate increasing of plant-based ice cream is not related with the overrun. That could be due to the viscosity of plant-based ice creams were higher than milk ice cream. Nuwongsri et al. (2021) noted the mobility limitation of water molecules in high viscose ice cream mixture because the space between the particles in the mixture was getting narrower, resulting in lower melt down rate. Furthermore, soy protein may be adsorbed on to the surface of the droplets and emulsifiers were effective at displacing the proteins from the droplet surfaces. The utilization of soy protein in plant-based ice creams could improve the melt down properties with respect to the milk protein.

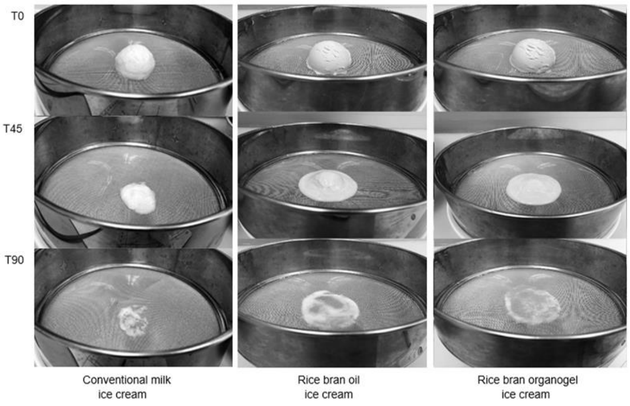

Fig. 1 Examples of pictures taken during melting test of ice creams, produced with milk, rice bran oil and rice bran oil organogel. The pictures are taken at the beginning of the test (T0) and after 45 (T45) and 90 (T90) minutes

2.3 Firmness

The results in Table 3 shows the firmness of conventional, organogel and rice bran oil ice cream were 14.4± 0.91, 15.3± 0.87 and 16.4± 0.91, respectively. The firmness values of the plant-based ice creams were significantly higher than the conventional ice cream because of high overrun value. Ice cream with air cooperated lead to softer texture found in conventional milk ice cream (Hartel et al., 2004). The rice bran oil ice cream demonstrated the highest firmness value due to the lowest overrun (Nuwongsri et al., 2021). Organogel ice cream firmness was higher than conventional milk ice cream and may be due to organogel network being recreated in the frozen ice cream, enhancing the firmness. Similar results were reported by measuring the hardness of the low-fat ice creams containing organogel (Moriano & Alamprese, 2017). It was possible the organogel accounted for an improvement in low-fat, plant-based ice cream quality characteristics when compared to the non-structured rice bran oil.

2.4 Energy, protein, carbohydrate and fat content of ice cream

Energy, fat, carbohydrate and protein contents of three ice cream formulations are presented in Table 4. Energy of conventional milk ice cream, rice bran oil and organogel ice creams (per 100 g) were 147±0.97, 135±0.67 and 126 ±0.81 kcal, respectively. Significant

Table 3 Overrun, firmness and melt down rate of frozen ice cream

Ice cream formulation	Overrun (%)	Firmness (N)	Melt down rate
Milk	39.40± 1.03^{a}	14.4± 0.91^{c}	0.67± 1.65^{a}
Organogel	38.31± 0.91^{a}	15.3± 0.87^{b}	0.46± 1.75^{b}
Rice bran oil	37.02± 0.01^{b}	16.4± 0.91^{a}	0.45± 1.65^{b}

Remark: Values with different letters in the same column are significantly different ($p < 0.05$) (Tukey's test)

reductions in energy of 8.16% and 14.29% were observed in rice bran oil ice cream and organogel ice cream, respectively. Carbohydrate content in milk, rice bran oil and organogel ice creams were 28.01±0.23, 25.12±0.53, and 25.13±0.77 g, respectively. Replacement of milk fat with the rice bran oil and organogel resulted in decreasing total calories per serving. The higher value of carbohydrate content observed in conventional ice cream was due to lactose in milk. The protein contents of all ice creams were 2.12-2.20 g. Fat contents in conventional, rice bran oil and organogel ice cream were 3.14±1.17, 3.07±0.33 and 2.58±0.21 g, respectively.

Table 4 Energy, protein, carbohydrate and fat content of ice cream (100 g)

Nutritional composition	Milk ice cream	Rice bran oil ice cream	Organogel ice cream
Energy (kcal)	147±0.97^{a}	135±0.67^{b}	126±0.81^{c}
Protein (g)	2.20±0.17^{a}	2.12±0.05^{a}	2.12±0.90^{a}
Carbohydrate (g)	28.01±0.23^{a}	25.12±0.53^{b}	25.13±0.77^{b}
Fat (g)	3.14±1.17^{a}	3.07±0.33^{a}	2.58±0.21^{b}

Remark: Values with different letters in the same row are significantly different ($p < 0.05$) (Tukey's test)

The results revealed that the nutritional properties were improved for plant-based ice cream formulations. Especially, total fat content of organogel was lower than rice bran oil because of the lower fat organogel. Organogel is structured emulsion by organogelation of water in oil emulsion (30:70). Furthermore, according to fatty acid composition of rice bran oil and organogel rice bran. There were decrease in SFA contents for both formulations, up to 53% and 74% in rice bran oil and rice bran organogel ice creams, respectively. Moreover, the organogel was prepared by policosanol (4% (w/w)) (Manakla et al., 2020). Policosanol is long chain alcohols extracted from rice bran wax. It is used as a dietary supplement for lowering blood cholesterols. Therefore, rice bran organogel ice creams not only contained lower SFA but healthy functional compound was also added.

2.5 Sensory characteristic

The results of the sensory evaluation of the ice cream samples are shown in Table 5. Replacement of milk by rice bran oil and rice bran oil organogel decreased scores of the taste and flavors as well as appearance and color characteristic. Conventional milk ice cream (4.77±1.17) had the higher appearance and color values than rice bran oil (3.86±1.07) and rice bran oil organogel (3.87±1.27). Taste and flavors of milk, rice bran oil and rice bran oil organogel were 8.00±0.51, 7.06±1.01 and 7.05±1.6, respectively. The rice bran oil-based ice creams exhibited higher color intensity compared to the conventional milk ice cream. This was due to the typical color of the rice bran oil used, which added a yellow note to the ice cream. The taste and flavor of conventional milk ice cream were significantly different from the rice bran oil-based ice creams ($p<0.05$). The sensory score of rice bran oil ice cream and rice bran organogel ice cream samples were decreased with replacing milk in ice creams because of their beany off flavors (Abdullah et al., 2003).

Texture and body of the organogel ice creams were not different when compared to the conventional milk ice cream. Although, firmness of organogel was higher than conventional ice cream but panelists could not perceive the difference. Nevertheless, rice bran oil ice cream had the lowest score ($P<0.05$) in texture and body that may be because it had the highest firmness value. None of the ice creams were judged to be weak, crumbly, sandy, or fluffy.

Table 5 Sensory properties

Sensory Characteristics	Ice cream formulation		
	Milk	Organogel	Rice bran oil
Appearance and color (1-5)*	4.77±1.17[a]	3.86±1.07[b]	3.87±1.27[b]
Taste and flavour (1-10)**	8.00±0.51[a]	7.06±1.01[b]	7.05±1.61[b]
Texture and body (1-10)***	7.68±1.31[a]	7.60±1.29[a]	6.72±1.60[c]

Remark: Values with different letters in the same row are significantly different ($p < 0.05$) (Tukey test)
* Appearance and color (no criticism: 5, dull color: 4-1, unnatural color: 3-1)
** Taste and flavor (no criticism: 10, cooked flavor: 9-7, lack of sweetness and too sweet: 9-7, lack of flavor: 8-6, rancid and oxidized: 6-1 and other: 5-1)
*** Texture and body (no criticism: 10, coarse: 9-7, crumbly: 9-7, weak: 8-6, fluffy: 8-6, gummy: 6-1, sandy: 5-1)

Conclusion

Low-fat, plant-based ice cream novelty formulated with rice bran oil and rice bran oil organogel is successful. The rice bran oil organogel ice creams posed similar overrun and firmness characteristics with respect to conventional milk ice cream. Significant reductions of SFA were observed in the developed plant-based ice cream formulations. Novel plant-based ice cream with organogel is a successful approach in order to obtain a healthy product without compromising their qualities except taste and flavor characteristic because of the beany flavor. Therefore, further investigations could determine the new plant protein for milk protein replacement for avoiding undesirable flavor. Moreover, the partial replacement of milk fat with organogel by keeping constant the amount of total fat should also be a focus in further studies.

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