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Physical characteristics of low-dairy, partial sucrose-substituted rice ice cream using young rice grain flour

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Abstract Low-dairy and low-sugar products have gained in popularity as people become aware of health issues. In addition, some individuals choose to limit dairy due to milk protein allergy or lactose intolerance. Immature rice grains or young rice grains might be used a milk alternative as they can contain higher levels of protein and lower allergenicity than mature rice grains. The experimental results showed that pH decreased and viscosity increased with higher young rice grain flour (YRF) content. Ice cream with added YRF tended to be lower overrun, and higher color difference (ΔE) as compared to the control (without YRF addition). The hardness and first dripping time of the young rice ice cream were significantly increased with increasing YRF content. Ice cream with 3.5% YRF was melted faster than other formulas. This research demonstrated the potential of using young rice grain flour in low-dairy, low-sugar ice cream products for the first time. It is introduced to be a novel application of young rice grain.

Keywords: Immature rice, Milky rice, Dairy milk substitution, Polyol, Whey protein

Introduction

Ice cream is a delectable treat characterized by various compositions in the ice cream, for example sugar for sweetness, protein for smooth texture, air for lightness, ice for freshness and cooling sensation (Goff and Hartel, 2013; Syed *et al.*, 2022). Traditionally, milk, milk powder and dairy cream are chosen as sources of protein and fat in ice cream formulation. However, dairy-based ice cream may not be suitable for people who have milk allergy or milk intolerance. Common signs and symptoms include stomach discomfort, nausea, vomiting, diarrhea, skin rash or nasal congestion (Bahna, 2002). Previous research have been conducted with the aims to reduce or eliminate milk products used in the dairy-based (El-Batawy *et al.*, 2019) or dairy-free ice cream formula (Ghaderi *et al.*, 2021; Pungboonya and Kusump, 2023).

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Rice (*Oryza sativa* L.) serves as a staple food for over half the world's population, particularly in Asia (Fairhurst and Dobermann, 2002). Rice is a good choice for milk substitution due to its low-allergenic property (Pantoa *et al*., 2020). However, incorporation of rice flour into ice cream led to higher viscosity and limited whipping ability, resulting in low overrun (Swarup and Poonia, 2022). Inadequate overrun caused defect of the ice cream such as soggy, heavy and pudding-like body (Thaochalee *et al*., 2018). Low overrun also affected production expenses since the air content in ice cream reflected profitability (Azari-Anpar *et al*., 2017). Furthermore, excessive viscosity could result in undesired melting characteristics, heavy and sticky mouthfeel. The incorporation of 2-6% rice flour in milk ice cream resulted in a significant increase in hardness, chewiness, gumminess, and flour flavor, as observed in descriptive analysis (Cody *et al*., 2007).

Young rice is an immature milky-state rice grain aged 8-14 days after flowering. Young rice grains composed of approximately 70-80% starch. When compared to mature rice, young rice had higher amylose content and smaller starch granules (Ranathunga *et al*., 2023), which led to lower swelling value and lower viscosity in the final product. The reduced viscosity could be advantageous for ice cream applications. In addition, the low swelling value in young rice starch contributed to different rheological properties (Ranathunga *et al*., 2023). G' and G" values of young rice was higher than that of mature rice, suggesting different characteristics of the final product could be found when using different rice grain stage.

Although rice proteins are less likely to trigger hypersensitive reactions (Jeon *et al*., 2011), it has been reported that low prolamin digestibility could be the reason for allergenicity of rice protein (Kubota *et al*., 2014). Prolamin was found in mature rice in larger quantity, bigger molecular size and more complicated form when compared to that in young rice (Pantoa *et al*., 2020; Li *et al*., 2023). Gastric digestion of young rice prolamin could be completed since young rice prolamin was highly accessible for enzymatic reactions (Pantoa *et al*., 2020). This suggested very low to no allergenicity of young rice. Additionally, young rice contained higher lipid, protein, ash, thiamine, nicotinic acid, nicotinamide, and soluble and insoluble dietary fiber contents when compared to mature rice (Miraji *et al*., 2020). Therefore, young rice could be considered as a good alternative raw material for ice cream.

Sugar serves as a freezing point depressor in ice cream, causing the reduction of ice crystal formation, leading to ice cream soft texture (Geilman, and Schmidt, 1992). However, a decrease in freezing point may result in a faster melting rate of the ice cream (Goff and Hartel, 2013). Ice cream generally contains high level of sugar not only for colligative property but also for sensorial perception. Research revealed that cold temperature reduced taste buds sensitivity (Green and Nachtigal, 2015) therefore; more sugar was added into ice cream to achieve the desired sweetness. Since food with high sugar content had negative effects on health by increasing risk of non-communicable diseases (NCDs) such as diabetes, cardiovascular diseases, obesity, and hypertension (Prada *et al*., 2022), there have been efforts to reduce sugar content in ice cream to make it a healthier option. However, sugar reduction led to harder body of the ice cream and several defects such as iciness, coarse texture and low overrun (Goff and Hartel, 2013) and a decrease in acceptability of the ice cream (Syed *et al.*, 2022). Many research have investigated a sucrose substitution in dairy-based ice cream. Soukoulis *et al*. (2010) found that partial substitution of inulin, fructooligosaccharides (FOS) and maltodextrins for sucrose led to increases in instrumental hardness of vanilla milk ice cream whereas partial substitution of polyols (xylitol, sorbitol, maltitol, and manitol) for sucrose led to decreases in instrumental hardness of the ice cream. Descriptive sensory analysis (Soukoulis *et al*., 2010) revealed that iciness and coarseness of ice cream substituted sucrose with polyols was higher than that of the ice cream without sucrose substitution. While iciness and coarseness of ice cream substituted sucrose with inulin, FOS and maltodextrin was lower than that of the ice cream without sucrose substitution. Pintor *et al*. (2017) found that increasing inulin for sucrose substitution increased viscosity, overrun and melting time in reduced-fat, reduced-sugar milk ice cream. However, there is few research has been done on using sucrose substitution in non-dairy ice cream (Pungboonya and Kusump, 2023).

Limited research has been conducted on young rice grains and their potential applications. Therefore, the aim of this study was to investigate the use of young rice grain flour prepared in our laboratory to produce low-dairy, and partial sucrose-substituted rice ice cream.

Materials and methods

Materials

Rice bran oil was bought from Thai Edible Oil Co., LTD. (Thailand). Glucose syrup and xylitol were purchased from Chemipan Corporation Co., LTD. (Thailand). Sugar was supplied from Mitr Phol sugar Co., LTD. (Thailand). Benecel™ MX was acquired from Ashland (Thailand) Co., LTD. Whey protein isolate (90% protein) was gifted from CF Chem Co., LTD. (Thailand). Emulga® (emulsifier-stabilizer mix) was supported from Nine Line Co., LTD. (Thailand). Young rice grain flour (YRF) prepared by proprietary method was obtained from Faculty of Science and Technology, Thammasat

University. YRF consisted of 1.14% (wet basis) moisture, 13.39% (dry basis) protein, 7.50% (dry basis) fat, 1.47% (dry basis) crude fiber, 3.28% (dry basis) ash and 74.36% (dry basis) carbohydrate with water activity of less than 0.03 and pH value of 5.64.

Pasting profile determination

Rapid Visco Analyzer (RVA) (RVA Tecmaster, Perten, Australia) was used for pasting analysis. A YRF slurry was prepared by dispersing 2.57 g of YRF powder in 25.00 g of distilled water in an RVA canister. The slurry was heated from 50°C to 95°C and maintained at 95°C for 2.7 minutes. After that, it was cooled down to 50°C and held at that temperature for 2 minutes. Pasting temperature, peak viscosity, trough viscosity, final viscosity, breakdown viscosity, and setback viscosity were recorded.

Preparation of young rice ice cream

Young rice ice cream was formulated as shown in Table 1. The ice cream was prepared by mixing sugar, xylitol, Emulga®, Benecel™ MX, whey protein isolates and young rice grain flour. The mix was made into suspension by combining with water, glucose syrup, and rice bran oil. The suspension was pasteurized at 85°C for 5 minutes, followed by homogenized (Ergomixx, Bosch, Germany) at 65°C for 2 minutes. After homogenizing, the mix temperature was then immediately reduced to 4°C, prior to aging at 4°C for 24 hours. The ice cream mix was frozen in an ice cream machine (Njoy ice, N2ice, Thailand) for 35 minutes then hardened at -18°C for 24 hr. The ice cream was kept at -18°C until analysis.

Measurement of young rice ice cream mix properties

pH of the ice cream mix was determined at 25°C using a pH meter (Lab850, SI Analytics, Germany). Viscosity was measured after 24 hr. aging of ice crem mix. Five hundred milliliter of young rice ice cream mix was taken out and left in the control temperature environment until reached 25°C. Then the viscosity of the mix was determined using a Brookfield viscometer (DV-II, Brookfield, USA) with spindle number 3 at 50 rpm.

Table 1. Young rice ice cream formula

Ingredient	YRF (%)			
	0 (control)	2.5	3.0	3.5
Rice bran oil	10	10	10	10
Young rice grain flour	0	2.5	3	3.5
Sugar	5	5	5	5
Xylitol	5.44	5.44	5.44	5.44
Glucose syrup	6.54	6.54	6.54	6.54
Emulga®	0.10	0.10	0.10	0.10
Benecel™ MX	0.53	0.53	0.53	0.53
Whey protein isolate	1	1	1	1
Water	71.39	68.89	68.39	67.89

Measurement of physical properties of young rice ice cream

The overrun of the ice cream was calculated by comparing the weight of the mix before freezing to the weight of an equivalent volume of the ice cream after freezing, using the equation:

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

Color of the young rice ice cream was measured by a colorimeter (CX2678, HunterLab, USA). Parameters assessed using the CIELAB system including L* (lightness), a* (red/green), and b* (yellow/blue). The color difference (ΔE) compared between the color values of the control and the sample were calculated using the equation:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

The hardness of young rice ice creams was recorded as the compression force (g) during penetration of the sample using a texture analyzer (TA.XT plusC, Stable micro systems, USA) equipped with a 1 inch diameter cylindrical probe (P/1). The ice cream sample in four-ounce containers with a 7.5 cm diameter was placed at 4°C for 7 minutes before measurement. The conditions for hardness analysis were penetration depth, 10 mm; force, 5 g; probe speed during penetration, 3.3 mm-s^{-1}; probe speed before and after penetration, 3 mm-s^{-1} (Akalın *et al.*, 2008).

The melting properties including first dripping time and melting behavior were assessed on a 25-gram ice cream sample (2.5x2.5x2.5 cm^3). The ice cream cube was placed on a 20-mesh wire screen put above a beaker. The time used for the first melted ice cream dropped in a beaker was recorded as the first drip. Pictures were taken with a digital camera every 5 min until the ice cream was completely melted.

Statistical analysis

The data was statistically analyzed using Analysis of Variance (ANOVA) for determination of the main effects with a Completely Randomized Design. Differences between different treatment means were determined using Duncan's New Multiple Range Test. Significant differences were defined using a p-value of less than 0.05.

Results

RVA pasting profile of YRF

Pasting properties of YRF are shown in Table 2. The RVA pasting profile revealed that pasting temperature of YRF was 78.63°C and peak viscosity, final viscosity and setback viscosity of YRF were respectively 1,384, 1,271 and 435 cP, indicating dissociation and re-association of amylose and amylopectin molecules caused by heating and cooling steps in the analysis. It suggested that during ice cream production in this current study, starch granules of the YRF were gelatinized by heating process used for ice cream mix pasteurization and starch retrogradation started during cooling process, followed by aging process.

Table 2. Pasting parameters of YRF

Parameter	Quantity
Pasting temperature (°C)	78.63 ± 0.25
Peak viscosity (cP)	1,383.67 ± 16.86
Trough viscosity (cP)	835.67 ± 11.50
Final viscosity (cP)	1,271.00 ± 14.73
Breakdown viscosity (cP)	548.00 ± 21.28
Setback viscosity (cP)	435.33 ± 7.37

Young rice ice cream mix properties

pH of the rice ice cream mix decreased with increasing YRF content (Table 3). The pH of the ice cream mix was highest in the control formula (7.25), while in the YRF-added formulation, it ranged from 6.53-6.69.

Table 3. pH and viscosity of young rice ice cream mixes

YRF (%)	pH	Viscosity (cP)
0	7.25^{a} ± 1.12	139.42^{d} ± 3.65
2.5	6.69^{b} ± 0.02	1,015.08^{c} ± 69.32
3	6.55^{c} ± 0.14	1,130.67^{b} ± 35.78
3.5	6.53^{c} ± 0.01	1,444.44^{a} ± 42.28

^{a,b,c} indicate significant differences ($p<0.05$) in the same column.

When considering the viscosity of ice cream mix at 25°C from the experimental results, it was found that increasing concentration of YRF increased rice ice cream viscosity (Table 3). The maximum viscosity was found in the 3.5% YRF formula (1,444 cP), followed by 3% (1,130 cP), 2.5% (1,015 cP) and 0% YRF (139 cP).

Young rice ice cream properties

Overrun refers to the amount of air that is incorporated into the ice cream during the freezing process (Goff and Hartel, 2013). A higher overrun generally results in a lighter and softer texture, while a lower overrun produces a denser, creamier texture. The overrun of rice ice cream varied from 30.31 to 59.59% with a maximum value found in the ice cream control (Table 4).

Hardness of the ice cream increased with increasing YRF (Table 4). The minimum hardness value was found in the control (8,095 g), but the maximum value was observed in the formulation with 3.5% YRF concentration (16,060 g).

Table 4. Overrun, Hardness and first dripping time of young rice ice cream

YRF (%)	Overrun (%)	Hardness (g)	First dripping time (min)
0	59.59^{a} ± 12.48	8,095.22^{c} ± 3,637.65	12.09^{c} ± 0.97
2.5	37.60^{b} ± 6.78	10,328.51^{bc} ± 2,760.11	17.07^{b} ± 4.61
3.0	32.70^{b} ± 4.71	13,838.03^{ab} ± 3,708.26	20.03^{b} ± 2.10
3.5	30.31^{c} ± 6.63	16,060.14^{a} ± 4,193.26	31.11^{a} ± 2.67

^{a,b,c} indicate significant differences ($p<0.05$) in the same column.

Melting properties of the ice cream in this current study was reported as first dripping time (Table 4) and melting behavior of the ice cream (Figure 1). First dripping time increased with increasing level of YRF (Table 4). The 3.5% YRF formulation took the longest first dripping time (31 min), followed by 3.0% (20 min), 2.5% (17 min), and 0% YRF (12 min).

Pictures of the ice cream cube placed on a wire screen at room temperature were recorded every 5 min. The results showed that after 15 min ice cream with higher amount of YRF appeared to melt faster (Figure 1). From the pictures, it was evident that the control ice cream maintained its shape better, while the structure of the YRF-added ice cream collapsed. The structural collapse occurred rapidly after 25 min. The ice cream containing 3.5% YRF had completely meltdown time of 40 min. Among the tested samples, 2.5% YRF exhibited the most similar melting behavior to the control which completely melted within 45 min.

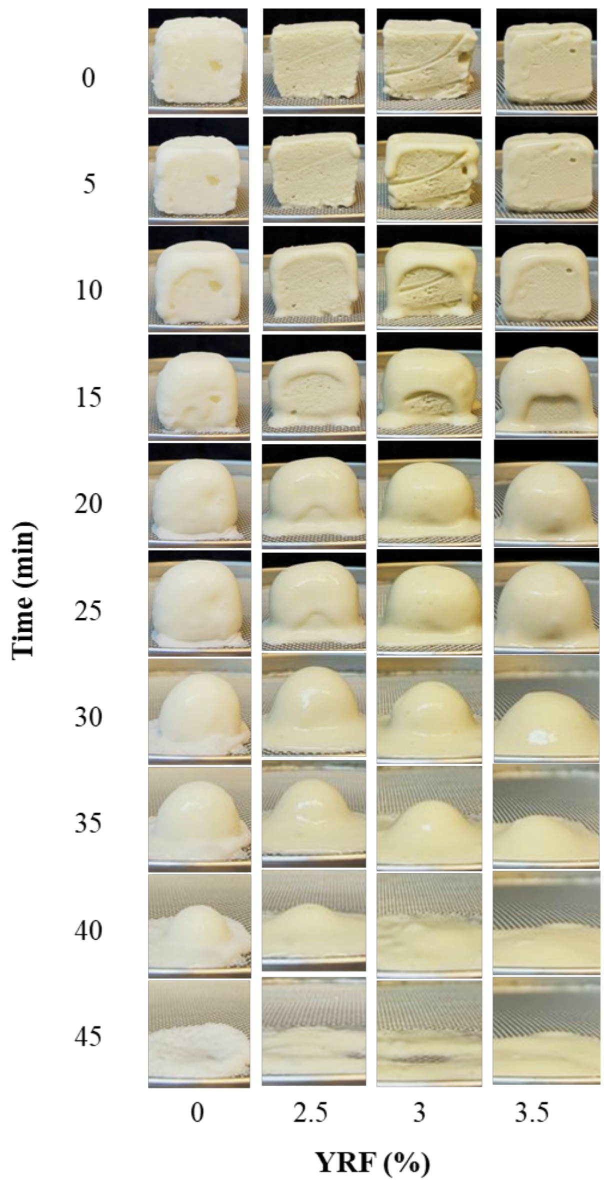

Figure 1. Young rice ice cream during the melting test

When YRF concentration increased in the formulation, young rice ice cream had decreased L*, but increased a*, b* and ΔE values (Table 5). The 3.5% YRF addition had the lowest L* value, while the highest a* and b* values. When compared to the control, the addition of YRF resulted in a significant color difference (ΔE values). The higher the YRF content, the more greenish yellow color of the ice cream (Figure 2).

Table 5. Color values of young rice ice cream

YRF (%)	L*	a*	b*	ΔE
0	$79.04^{a} \pm 0.84$	$-1.06^{c} \pm 0.44$	$3.83^{c} \pm 0.36$	-
2.5	$70.00^{b} \pm 1.46$	$-0.79^{b} \pm 0.14$	$9.63^{b} \pm 0.82$	$9.99^{c} \pm 0.82$
3.0	$68.58^{b} \pm 0.95$	$-0.57^{a} \pm 0.19$	$9.38^{b} \pm 0.84$	$11.07^{b} \pm 0.48$
3.5	$63.84^{c} \pm 3.11$	$-0.54^{a} \pm 0.21$	$10.92^{a} \pm 1.12$	$14.73^{a} \pm 1.23$

^{a,b,c} indicate significant differences ($p<0.05$) in the same column.

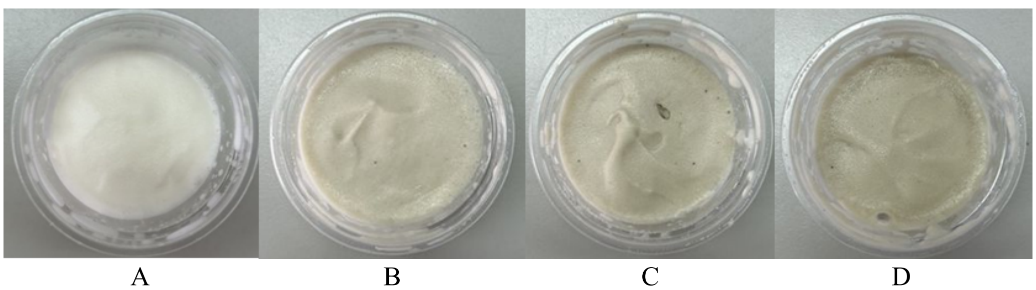

Figure 2. Young rice ice cream made with addition of YRF (A) 0%, (B) 2.5%, (C) 3.0% and (D) 3.5%

Discussion

Young rice grain flour (YRF) was prepared from immature (aged 7-12 days after flowering) Khao Dawk Mali 105 variety (KDML 105) rice grains using proprietary process. When compared with mature KDML 105 rice flour of which pasting temperature, peak viscosity and breakdown viscosity were respectively 72.75 °C, 3,395.50 cp and 1,684.50 cp (Phapumma *et al*., 2020), YRF exhibited a higher pasting temperature, lower peak viscosity and lower breakdown viscosity. These results indicated that different characteristics of a product might be found when using different stage of rice grain. The differences of these parameters between YRF and mature rice flour could be because of different quantity of fat and protein (Jia *et al*., 2023; Sun *et al*., 2021; Suh *et al*., 2004; Singh *et al*., 2003). The mature stage rice flour contained 0.65% fat and 7.55% protein (Petchalanuwat *et al*., 2000) whereas YRF consisted of 7.50% fat and 13.39% protein. It has been confirmed that protein in rice flour significantly affected starch swelling characteristics. The interaction between endogenous proteins and starch increased granule rigidity and enhanced granule integrity, thereby restricting starch swelling (Jia *et al*., 2023). Experimental results demonstrated that the removal of endogenous proteins increased granule swelling properties (Sun *et al.*, 2021). Moreover, fat also played a significant role in the swelling properties of starch granules (Jia *et al*., 2023). An increased amount of amylose-lipid complex inhibited granule swelling by preventing water absorption of amylose molecules (Suh *et al.*, 2004; Singh *et al*., 2003). Some studies suggested that the amylose-lipid complex may form a hydrophobic layer on the surface of granules, reducing the interaction between water and starch granules (Chang *et al.*, 2013). Additionally, uncomplexed lipids on the granule surface restricted starch swelling and reduced amylose leaching (Wang *et al*., 2020). Therefore, higher protein and higher fat contents in YRF led to a higher pasting temperature and decreases in peak viscosity and breakdown viscosity.

YRF had a pH value of 5.64; therefore, the more YRP was added into the rice ice cream mix, the lower the pH of the mix. This decrease in pH values might come from proteins in YRP. The protein content of YRP was 13.23%. Previous study showed that pH of rice protein concentrates from different sources was found to be in the range of 4.71-5.87 (Amagliani *et al*., 2017). The finding in this current study was in good accordance with previous study which demonstrated that addition of rice proteins into rice ice cream lowered the pH of the ice cream (Pungboonya and Kusump, 2023).

Since carbohydrate was a primary component of YRF, an increase in YRF was an increase in carbohydrate especially, rice starch. It has been observed that starch contributed to increased viscosity of the ice cream mix through a process of starch gelatinization and retrogradation (Fawzia *et al*., 2017; Elkot *et al*., 2022). In addition, RVA pasting profile of YRF showed evidence of increases in viscosity. Furthermore, proteins, a second abundant component of YRF could unfold during pasteurization and bind with water in the formula (Ruger *et al*., 2002). Water in the ice cream mix was trapped in the matrix of starch and proteins network, resulting in an increase in viscosity of the ice cream mix. This result was similar to those obtained by Cody *et al*. (2007); Abd Rabo and Dewidar (2017) and Swarup and Poonia (2022) who produced rice ice cream and found that addition of rice flour increased viscosity of the ice cream mix.

An increase in YRF caused a decrease in the ice cream overrun. This might be because the impact of viscosity of the mix restricted the amount of air trapped in the ice cream (Udabage *et al*., 2005). The higher the viscosity, the harder the air integration in the ice cream.

An increase in hardness might be because the starch retrogradation occurred during aging and freezing processes, causing complicated networks throughout the ice cream which could resist the force applied during the measurement. The higher the concentration of YRF, the denser the amylose and amylopectin network. In addition, ice cream mix with high viscosity could cause viscous unfrozen phase in the ice cream and this high viscosity increased the hardness of ice cream by increasing the probe penetration resistance (Muse and Hartel, 2004). Furthermore, lower overrun resulted in denser ice cream, making it harder, while higher overrun created a lighter texture (Sofjan and Hartel, 2004). The 3.5% YRF ice cream had highest concentration of rice starch, highest mix viscosity and lowest overrun, resulting in highest ice cream hardness.

Numerous factors affecting melting property of the ice cream, for example mass and heat transfer, viscosity of the unfrozen phase, viscosity of the lamella gaps and freezing point of the ice cream (Goff and Hartel, 2013; Muse and Hartel, 2004; Soukoulis *et al*., 2008). Water holding capacity of the ingredients used in ice cream formulation had an impact on the viscosity. When an ice cream cube was left at a room temperature, heat from the environment penetrated into the ice cream and made the ice cream melted. The melted liquid moved from top of the ice cream downward. Viscosity of the unfrozen phase and of the lamella gaps slowed down the melted liquid mobility (Pungboonya and Kusump, 2023; Muse and Hartel, 2004). Ice cream with greater concentration of ingredients that had high water holding capacity could resist the melted liquid more than ice cream with lower concentration of the same. Therefore, the melted liquid from 3.5% YRF ice cream, which had more quantity of starch and proteins passed through the wire screen more slowly than other samples, resulting in the longest first dripping time.

The behavior of faster melting might be because the higher %YRF ice cream had lower overrun. Air is a good heat insulator and can retard heat transfer (Faghri and Zhang, 2020). Thus, ice cream with low overrun had high heat transfer, leading to a rise of the temperature in the ice cream. As the temperature increased, ice crystals could melt easily. The more the ice crystals melted, the more the ice cream structure destabilized and ultimately, leading to the collapse of the ice cream. Therefore, the 3.5% YRF ice cream which had the lowest overrun showed the most rapid completely meltdown although it possessed the highest viscosity.

When there was YRF addition, the color of the ice cream changes. This color changes were influenced by the color of YRF added into the ice cream. Because YRF, obtained from immature rice grains, had dark greenish color of the rice in milky stage. The dark greenish color of the milky rice grain came from chlorophyll which was abundant in immature milk grains (Jiamyangyuen *et al*., 2017) The color of the rice appeared to be green from the flowering stage to dough stage before turning into white in fully ripe grains. Furthermore, air cells in the ice cream reflected light that passed through the ice cream (Goff and Hartel, 2013), making the ice cream appeared to be lighter in color. Therefore, 3.5% YRF rice ice cream with lowest overrun had lowest L* value and darkest color.

The current study demonstrated the use of young rice grain flour (YRF) in low-dairy, low-sugar ice cream. Low-dairy, low-sugar ice cream containing YRF showed different characteristics from the ice cream without YRF. The incorporation of YRF caused the ice cream mix more viscous, which raised the hardness value and delayed the first dripping time of the ice cream. Furthermore, increasing YRF concentration darkened the ice cream color, lowered the overrun value and sped up the melting process. This study suggests the potential use of immature rice as an ingredient for novel low-sugar, low-dairy ice cream product. Furthermore, the development of young rice ice cream enhances the opportunity of value-added immature rice product.

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