The Effects of Using Pregelatinized Red Jasmine Rice Flour as a Substitute for Wheat Flour on the Quality of Sponge Cupcakes

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Abstract

This study was an investigation of the effects on the physical and chemical properties, bioactive compounds, and nutritional value of sponge cupcakes when wheat flour was substituted by pregelatinized red jasmine rice flour, at various percentages of substitution. The results showed that the 20% substitution maintained a similar appearance and texture to the control (0% substitution), while the lightness (L^*) of both the crust and crumb decreased. Notably, the redness (a^*) of the crumb significantly increased ($p \leq 0.05$) with higher substitution levels, resulting in a darker color in all substituted samples than in the control. The total color difference (ΔE) also increased, indicating noticeable visual changes. As substitution levels increased, the specific volume significantly decreased from 6.49 mL/g in the control to 3.63 mL/g at 100% substitution. Additionally, hardness decreased from 1070.3 g-forces in the control to 862.5 g-forces at 20% substitution, resulting in a softer texture. The antioxidant capacity improved significantly, with DPPH scavenging activity increasing from 35.26% in the control to 36.30-67.99% at higher substitution levels. This enhancement correlated with the anthocyanin content, which ranged from 1.53 to 2.86 mg/kg in cakes made with red jasmine rice flour. Nutritional analysis indicated that the 20% substitution provided 342.77 kcal, 8.36 g of protein, 14.57 g of fat, 44.55 g of carbohydrates, and 1.21 g of crude fiber per 100 g. These findings suggest that pregelatinized red jasmine rice flour can be used to develop a healthier option for health-conscious consumers and has the potential for development as a gluten-free bakery product in the future.

Keywords: pregelatinized flour, red jasmine rice, substitution, sponge cupcake, antioxidant activity

Introduction

Cakes are sweet baked goods that are widely consumed around the world, primarily consisting of flour, sugar, eggs, leavening agents, and sometimes fat sources (Godefroidt et al., 2019). Among the various types of cakes, sponge cake is particularly popular, made with eggs, flour, and sugar. Successful sponge cake preparation yields a soft, airy, and light texture that melts in the mouth (Gladys et al., 2021). However, despite its popularity, a primary concern arises from the use of wheat flour in traditional recipes, which contains gluten, posing limitations for those with gluten intolerance or those wishing to avoid gluten. Therefore, producing gluten-free sponge cakes requires techniques to adjust recipes and select suitable substitutes for wheat flour to achieve a soft and fluffy texture akin to regular cakes. Currently, some bakers are exploring new alternative flours, such as rice flour, corn flour, millet flour, and flours from pseudo-cereals like buckwheat and quinoa as substitutes for wheat flour (Šmídová & Rysová, 2022). One promising option is rice flour, which has gained popularity as a wheat flour substitute in gluten-free cake products (Ronie et al., 2021). Numerous studies have focused on modifying cake recipes by replacing wheat flour with rice flour, including varieties made from brown rice flour, black rice flour, and red rice flour. Examples include chiffon cakes made with colored rice flour (Fuengkajornfung, 2023) and Hom Nil rice flour (Phuapaiboon et al., 2022), as well as sponge cakes using brown rice flour (Ayutthaya et al., 2018).

Rice (*Oryza sativa* L.) is a staple food crop of significant importance in Southeast Asia (Kim & Shin, 2014) that contains very low levels of gluten, sodium, protein, and fat but is high in easily digestible carbohydrates and fiber. It is one of the most used cereals as a wheat substitute in gluten-free food products (Turabi et al., 2008). Colored rice refers to rice varieties with pigmented bran layers, including black, purple, and red, which result from the deposition of anthocyanins in the pericarp, seed coat, and aleurone layer (Chaudhary, 2003). These rice varieties have been cultivated for centuries, particularly in Asia (Prom-u-thai et al., 2013). Colored rice, particularly red jasmine rice (*O. Sativa* L.), is increasingly valued for its antioxidant potential in functional foods (Sinthorn et al., 2015). This native variety, developed from the Hom Mali 105 strain, is characterized by its seed coat color ranging from pinkish red to deep brown while maintaining the distinctive texture and aroma of jasmine rice, making it popular among consumers. It is a richer source of phosphorus, iron, copper, and vitamins A, B1, B2, and C than white rice (Chantaraponpan et al., 2019; Thanasukarn et al., 2021). Additionally, its phytochemicals, particularly anthocyanins and gamma-oryzanol, exhibit antioxidant properties that may support circulation, reduce cellular degeneration, and help regulate blood sugar levels (Chamnansilp & Aromrit, 2011).

Native red jasmine rice flour, despite its nutritional benefits, presents limitations in cake formulations due to its lower air-trapping and moisture-retention capabilities, affecting texture and volume. Pregelatinization is a processing technique that enhances the functional properties of flour by cooking it with steam and then drying it, improving its water absorption, swelling capacity, and viscosity (Aulia et al., 2024). In bakery products, pregelatinized flour enhances ingredient cohesion, forming a film that aids in water absorption and air retention, resulting in moist cakes with a softer texture, increased volume, and uniform consistency (Aulia et al., 2024; Carillo-Navas et al., 2016). Pregelatinized red jasmine rice flour differs from native red jasmine rice flour in its enhanced water-binding ability, improved gel formation, and increased stability during baking. This modification allows for better moisture retention, reducing cake staling and extending shelf life. Additionally, it maintains key bioactive compounds, including anthocyanins and gamma-oryzanol, preserving its antioxidant properties even after processing. However, substitution of wheat flour with excessive amounts of rice-based alternatives can negatively impact cake texture, resulting in lower specific volume and increased firmness (Turabi et al., 2008).

Previous studies have mainly used local rice flour for cake making, with limited research on pregelatinized rice flour, especially red jasmine rice. The effects of pregelatinized red jasmine rice flour on the texture, physical, chemical and antioxidant properties of sponge cupcakes remain unexplored. The objective of this study was to address this gap by evaluating the use of rice flour as a substitute for wheat flour to develop high-quality, gluten-free cupcakes that meet the needs of health-conscious consumers while maintaining desirable properties.

Methods and Materials

Materials

All-purpose wheat flour (Blue Bell, Thailand), eggs (medium size, no.2), red jasmine rice grains (*O. sativa* L.) from Phichit Province (Moon farm, Thailand), unsalted butter (Allowrie, Thailand), evaporated milk

(Carnation, Thailand), baking powder (Imperial, Thailand), vanilla extract (McCormick, USA), granulated white sugar (Mitr Phol, Thailand), and salt (Prung Thip, Thailand) were purchased from a local supermarket in the Thonburi district of Bangkok.

Preparation of pregelatinized red jasmine rice flour

Pregelatinized red jasmine rice flour was prepared according to the method of Hongpan et al. (2019), with slight modifications. The red jasmine rice grains were cleaned and soaked in tap water overnight. After soaking, the water was drained, and the grains were left to air dry at 25±2°C for 20 min. The soaked grains were then steamed at 100°C for approximately 30 min and allowed to cool at 25±2°C. The grains were then dried using a tray dryer (ULM 500, Memmert, Germany) for 4 hr at 70±2°C, with a final moisture content not exceeding 12±2%. The dried grains were ground into a fine powder using an electric grinder (Damai, China) and sieved through a 100-mesh sieve (Horeka, Thailand). The rice flour was packed in vacuum-sealed plastic bags with vacuum sealer (DZ280A Brother, Thailand) and stored at room temperature (25±2°C) until further use.

Research Method

This research employed a basic formula for sponge cupcakes based on the methodology of Leuangskul & Nuankhakul (2021), of which wheat flour was substituted with pregelatinized red jasmine rice flour at substitution levels of 0 (control), 20, 40, 60, 80, and 100% (w/w) of all-purpose wheat flour. The sponge cupcakes were produced according to the formulations detailed in Table 1.

Table 1 Ingredients of control and substituted formulas for sponge cupcakes with pregelatinized red jasmine rice flour at different levels

Ingredients (g/100 g)	Levels of Substitution (%)					
	0	20	40	60	80	100
All-purpose wheat Flour	16.18	12.95	9.71	6.47	3.24	0.00
Pregelatinized red jasmine rice flour	0.00	3.24	6.47	9.71	12.95	16.18
Eggs	46.24	46.24	46.24	46.24	46.24	46.24
Granulated white sugar	16.18	16.18	16.18	16.18	16.18	16.18
Unsalted butter	9.25	9.25	9.25	9.25	9.25	9.25
Evaporated milk	7.40	7.40	7.40	7.40	7.40	7.40
SP	2.31	2.31	2.31	2.31	2.31	2.31
Baking powder	1.16	1.16	1.16	1.16	1.16	1.16
Vanilla extract	1.16	1.16	1.16	1.16	1.16	1.16
Salt	0.12	0.12	0.12	0.12	0.12	0.12
Total (%)	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**	**100.00**

Note: 0% refers to the control formula, which uses 100% wheat flour

Preparation of sponge cupcakes with pregelatinized red jasmine rice flour

Initially, all ingredients were combined in a mixing machine (Kitchen Aid, KMX51 Kenwood, Havant, UK), and the mixture was beaten at maximum speed until it became light and fluffy, resulting in a smooth consistency. Subsequently, the mixer speed was reduced to low, and the sifted cake flour and baking powder were gradually incorporated until the mixture was smooth. The batter was transferred to baking cups and baked at 170°C for 20 min or until fully cooked. After baking, the cupcakes were removed from the oven and allowed to cool on a wire rack. Cupcakes that were freshly prepared were analyzed within 24 hr of baking for their physical and chemical properties. To determine their nutritional value, the samples were stored in airtight containers and frozen at -18°C until required for further analysis.

Analysis of physical and chemical properties of sponge cupcakes.

The physical characteristics of the sponge cupcakes with or without pregelatinized red jasmine rice flour were analyzed by measuring the color values, specifically lightness (L^*), redness (a^*), and yellowness (b^*), using a Minolta colorimeter (CR-400, Japan). Measurements were taken from both the surface crust and the crumb of the cupcakes, with five random points selected for each cupcake. The average color values were then calculated from these measurements. The specific volume (SV, mL· g^{-1}) of the cupcakes was determined by replacing it with sesame seeds, following the AACC method 10-05 (AACC, 2000). This was calculated based on the ratio of the apparent volume (mL) to the mass (g) after baking. The texture characteristics of the sponge cupcakes were analyzed, using a texture analyzer (Stable Micro Systems, TA-XT Plus) equipped with a P50 cylinder probe Measurements were conducted under controlled conditions, applying a compression speed of 10 mm/s. The compression was performed to a depth of 50% of the sample height, measured from the top crust of the cupcake. This method was employed to evaluate the hardness (g-force), springiness (mm), and cohesiveness of the cake crumb after the products had been stored for 24 hr.

The moisture content (MC) of the sponge cupcakes was determined by cutting the crust and crumb portions into small pieces, which were then dried in a convection oven according to the AOAC method (AOAC, 2019) at a temperature of 105°C until a constant weight was reached. The percentage of moisture content in the cake samples was subsequently calculated. The water activity (a_w) of the cupcake samples was analyzed using the Water Activity Meter (AQUALAB, Series 4TE, USA). Each measurement was conducted in triplicate.

Analysis of antioxidant activity and the contents of total anthocyanins of sponge cupcakes

The antioxidant activity was analyzed using the 2,2-Diphenyl-1-picrylhydrazyl (DPPH) scavenging assay according to the method of Loypimai et al. (2009) with some modifications. Pipette 22 microliters of the prepared sample extract was mixed with 200 microliters of DPPH solution (DPPH dissolved in 80% methanol at a concentration of 150 micromoles). The resulting mixture was then kept in the dark at room temperature (25±2°C) for 30 min. The absorbance was measured at a wavelength of 517 nm using a spectrophotometer (UV-vis model 1601, Shimadzu, Japan). The antioxidant activity is calculated using the following formula:

$$\text{Inhibition activity } (\%) = [(A_o - A_e) / A_o] \times 100$$

where: A_o = Absorbance of the DPPH solution without the sample extract

A_e = Absorbance of the sample extract solution.

Total anthocyanin content was analyzed using the pH-differential method, adapted from Harakotr et al. (2014). A sample of 1 gram was extracted with 70% methanol and 1.5 mol/L hydrochloric acid for 24 hr. The mixture was then filtered using No.1 filter paper, resulting in a concentration of 1 mg/mL of the extract. To measure the absorbance, 2 mL of the prepared extract was mixed with 8 mL of pH 1.0 buffer (0.025 mol/L), and another 2 mL of the extract was mixed with 8 mL of pH 4.5 buffer (0.40 mol/L). The absorbance was measured at wavelengths of 510 and 700 nm using a spectrophotometer (Analytik Jena AG, model SPECORD®200PLUS), with distilled water as the blank. The measured absorbance values were used to calculate the total anthocyanin content, expressed as cyanidin-3-glucoside in milligrams per kilogram, according to the following equation:

$$\text{Total Anthocyanin (mg/kg)} = (A \times MW \times DF \times 10^{3}) / \varepsilon \times l$$

where: A = $(A_{510}-A_{700})_{pH\ 1.0} - (A_{510}-A_{700})_{pH\ 4.5}$

MW = 449.2 g/mol (molecular weight of cyanidin-3-glucoside)

ε = 26,900 L/mol/cm (molar absorptivity)

L = 1 cm (path length of the cuvette)

DF = Dilution Factor of the sample solution

Analysis of nutritional values of sponge cupcakes with pregelatinized red jasmine rice flour

Samples of sponge cupcakes with pregelatinized red jasmine rice flour were selected for nutritional analysis according to AOAC methods (AOAC, 2019), including measurements of protein, fat, carbohydrates, vitamins, minerals, and total energy.

Statistical analysis

The experimental data collected in three replicates were analyzed using a one-way analysis of variance (ANOVA) with SPSS software (version 16.0; SPSS Inc., Chicago, IL, USA). Post-hoc comparisons of mean differences were performed using Duncan's New Multiple Range Test at a 95% confidence level.

Results and Discussion

Effect of using pregelatinized red jasmine rice flour on physical and chemical properties of sponge cupcakes

The substitution of wheat flour with varying levels of pregelatinized red jasmine rice flour affected the physical and chemical properties of sponge cupcakes, as shown in Table 2 and Fig. 1.

Table 2 Physical and chemical properties of sponge cupcakes with different levels of pregelatinized red jasmine rice flour substitution

Parameter	Levels of Substitution (%)					
	0	20	40	60	80	100
Color values (crust)						
*L**	48.73±2.47^{a}	42.27±1.93^{a}	39.89±2.78^{b}	35.74±2.36^{b}	35.16±2.70^{b}	24.09±2.17^{c}
*a**	13.36±0.54^{a}	11.14±0.89^{b}	10.80±0.77^{b}	10.83±0.48^{b}	10.27±0.89^{bc}	9.00± 0.32^{c}
*b**	30.29±0.59^{a}	20.85±0.67^{c}	23.50±0.86^{bc}	24.64±0.42^{b}	22.55±0.38^{bc}	17.28±0.22^{d}
ΔE	-	10.48±0.96^{d}	11.00±2.67^{d}	15.71±2.33^{c}	19.30±3.51^{b}	28.06±2.80^{a}
Color values (crumb)						
*L**	78.20±1.40^{a}	56.85±1.91^{b}	53.48±1.33^{b}	46.91±1.09^{c}	38.11±1.11^{d}	26.00±1.95^{e}
*a**	0.78±0.35^{e}	4.58±0.30^{d}	9.28±0.86^{c}	10.08±0.60^{bc}	10.65±1.23^{b}	12.38±0.59^{a}
*b**	32.73±0.34^{a}	15.35±0.49^{d}	21.53±0.47^{c}	24.61±0.72^{b}	16.89±0.34^{d}	15.07±0.45^{d}
ΔE	-	27.81±1.72^{d}	28.56±3.02^{d}	34.37±1.77^{c}	41.40±3.97^{b}	55.93±4.15^{a}
SV (mL/g)	6.49±0.19^{a}	6.08±0.11^{a}	5.92±0.43^{a}	4.31±0.29^{b}	3.87±0.44^{c}	3.63±0.64^{c}
Hardness (g)	1070.30±0.23^{a}	862.50±0.21^{b}	779.88±0.56^{c}	686.80±0.97^{d}	675.53±0.57^{d}	602.39±0.48^{d}
Springiness(mm)	0.69±0.46^{a}	0.32±0.03^{d}	0.48±0.27^{b}	0.41±0.04^{c}	0.32±0.02^{d}	0.31±0.05^{d}
Cohesiveness	0.69±0.012^{d}	0.73±0.019^{cd}	0.72±0.020^{cd}	0.75±0.015^{bc}	0.78±0.022^{b}	0.82±0.059^{a}
MC (%)^{ns}	25.57±2.05^{b}	26.54±2.01^{ab}	27.32±2.37^{ab}	28.23±2.25^{ab}	29.32±2.30^{ab}	30.37±2.27^{a}
a_w	0.84±0.010^{ns}	0.84±0.002^{ns}	0.85±0.004^{ns}	0.86±0.002^{ns}	0.85±0.005^{ns}	0.85±0.015^{ns}

Note: Mean values ± SD from three replications with different letters in the same row that are statistically significantly different ($p \leq 0.05$), ns indicates not significantly different ($p > 0.05$)

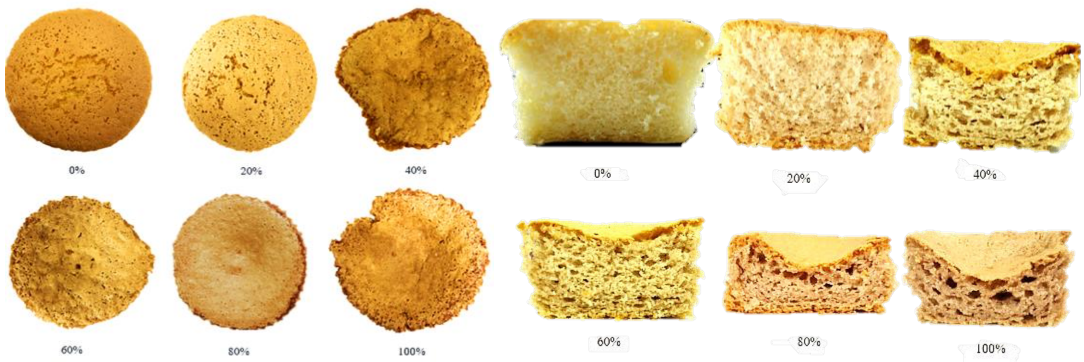

Figure 1 Sponge cupcakes with various levels of pregelatinized red jasmine rice flour substitution (0%–100%) (left: top crust of the whole cupcake, right: cross-section of the cake crumb)

Crust and crumb color values

The results shown in Table 2 indicate that replacing wheat flour with pregelatinized red jasmine rice flour significantly ($p \leq 0.05$) affected the color of the cupcakes. As the substitution level increased, the L^*, a^*, and b^* values of the cupcake crust decreased, leading to a darker appearance. The L^* value dropped from 48.73 in the control sample to 24.09 at 100% substitution, while the a^* decreased from 13.86 to 9.00 and the b^* values decreased from 30.29 to 17.28. This resulted in a transition from a light-yellow crust in the control sample to a light to a dark-brown crust as substitution levels increased, with the total color difference (ΔE) rising to 28.06, reflecting a noticeable color change. A similar trend was observed in the cupcake crumb. The L^* and b^* values decreased as the substitution level increased, while the a^* value significantly increased. The L^* value decreased from 78.20 in the control sample to 26.00 at 100% substitution, indicating intensified coloration. Unlike the crust, the a^* value of the crumb increased from 0.78 to 12.38, suggesting that anthocyanins contributed to the reddish-brown hue. Meanwhile, the b^* value decreased from 32.73 to 15.07, though less prominently than in the crust. The total color difference (ΔE) reached 55.93, demonstrating a clear transition from a light-yellow control sample to a reddish-brown crumb.

These color changes are attributed to anthocyanins in pregelatinized red jasmine rice flour, which impart red to purple hues and are influenced by pH and thermal conditions. The decrease in L^* in both crust and crumb suggests anthocyanin degradation at high temperatures, contributing to a darker product. The contrasting trends in a^* values indicate differential anthocyanin stability, with oxidation likely reducing a^* in the crust, whereas moisture in the crumb may help preserve anthocyanins, maintaining the red hue. The decline in b^* suggests reduced yellow intensity, potentially due to anthocyanins masking yellow pigments. Additionally, the Maillard reaction between proteins and reducing sugars further intensified browning, reinforcing color changes. These findings align with studies on Hom Nil rice flour in cakes, which also reported reductions in L^*, a^*, and b^* due to pigment composition and oxidation (Phuapaiboon et al., 2022; Fuengkajornfung, 2023).

Specific volume

The specific volume of a baked cake reflects the amount of air retained in the final product, significantly impacting its texture and overall quality. A higher specific volume indicates better gas retention and expansion during baking, resulting in a lighter and fluffier cake (Gomez et al., 2007). This study found significant differences ($p \leq 0.05$) in the specific volumes of the control sponge cupcakes and those substituted with pregelatinized red jasmine rice flour at various levels. The specific volume of the control sponge cupcakes was

6.49 cm^3/g and for those with a 20% substitution level was 6.08 cm^3/g and 5.92 cm^3/g for the 40% substitution levels. These values at 20% and 40% substitution were higher than those of the cupcakes substituted with pregelatinized red jasmine rice flour with substitution levels at 60% (4.31 cm^3/g), 80% (3.87 cm^3/g), and 100% (3.63 cm^3/g). Increasing the substitution level of pregelatinized red jasmine rice flour reduced protein content, weakening gluten network formation and gas retention, which ultimately decreased cake volume (Turabi et al., 2008). This aligns with findings by Tongtangwong & Suwansichon (2010), who reported a significant ($p \leq 0.05$) reduction in butter cake volume when wheat flour was replaced with Sinin rice flour due to impaired air retention. Similarly, higher substitution levels in sponge cupcakes compromised structural integrity, leading to collapse and limited rise (Figure 1).

Additionally, the high-water absorption of pregelatinized red jasmine rice flour altered batter viscosity and starch gelatinization, producing a denser crumb with smaller, irregular air cells. This further supports the relationship between gluten dilution, reduced gas retention, and decreased cake volume (Turabi et al., 2008; Tongtangwong & Suwansichon, 2010). To mitigate these effects, hydrocolloids (e.g., guar gum, xanthan gum) and emulsifiers such as lecithin could improve water retention and foam stability, enhancing cake texture (Gomez et al., 2007). These findings emphasize the need for formulation optimization when substituting wheat flour with pregelatinized red jasmine rice flour in sponge cupcakes.

Texture characteristics

Texture analysis showed significant differences ($p \leq 0.05$) in the hardness, springiness, and cohesiveness between the control sponge cupcakes and those substituted with varying levels of pregelatinized red jasmine rice flour. As the substitution level of pregelatinized red jasmine rice flour increases, the firmness and springiness values of sponge cupcakes show a noticeable decline, while cohesiveness values increase. The results showed that sponge cupcakes substituted with red jasmine rice pregelatinized flour at levels of 20, 40, 60, 80, and 100% had lower hardness values than the control. A clear trend of decreasing hardness was observed with increasing substitution levels. The measured hardness values were: 862.5 g-force (20%), 779.88 g-force (40%), 686.8 g-force (60%), 675.53 g-force (80%), and 602.39 g-force (100%). In contrast, the control cupcake had a significantly higher hardness of 1070.3 g-force ($p \leq 0.05$). The findings indicate that replacing wheat flour with pregelatinized red jasmine rice flour in sponge cupcakes significantly reduces gluten protein content. This reduction negatively affects the cake's structure, leading to a softer texture and a reduced ability to maintain shape, as gluten is essential for strength and elasticity. Consequently, lower gluten levels impair air trapping and carbon dioxide retention, which can cause the cake to collapse, as well as reduce hardness and springiness. In contrast, the higher proportion of pregelatinized rice flour improves moisture retention and cohesiveness due to its excellent water-absorbing properties, resulting in a softer cake. However, if the formulation of sponge cupcakes is not balanced with other ingredients, such as protein or other quality enhancers, cupcakes with pregelatinized rice flour as a substitute for wheat flour may be more likely to collapse during baking (Shih and Daigle, 2002).

Moisture content (MC) and water activity (a_w)

The results presented in Table 2 indicate that the moisture content and water activity values of both the control sponge cupcakes and those substituted with pregelatinized red jasmine rice flour did not show statistically significant differences ($p > 0.05$). Specifically, the formulations with pregelatinized red jasmine rice flour substitution of 20% had moisture content of (26.54%), 40% (27.325), 60% (29.235), 80% (29.325), and 100% (30.375), while the control formulation had a moisture content of 25.57%. The water activity (a_w) values ranged from 0.84 to 0.86, indicating that higher substitution levels of pregelatinized red jasmine rice flour did not significantly affect the moisture content or a_w in the sponge cupcakes.

The experimental results indicate that substituting wheat flour with pregelatinized red jasmine rice flour in sponge cupcakes does not significantly affect the moisture content or a_w. Pregelatinized flour is known for its excellent water absorption properties, which can enhance moisture retention in cakes Aulia et al. (2024). The analysis showed that overall moisture content did not significantly increase compared to the control, which may be due to the even distribution of water absorbed by the pregelatinized flour throughout the cake. This uniformity prevents the accumulation of excess moisture, stabilizing the free water content and enhancing product stability. Research by Hesso et al. (2015) confirms that interactions among starches, sugars, and other ingredients affect moisture retention and cake structure. Similarly, Carillo-Navas et al. (2016) demonstrated how pregelatinized flour reduces water loss, supporting texture and moisture stability.

Antioxidant activity and total anthocyanin contents of sponge cupcakes with pregelatinized red jasmine rice flour

The analysis of antioxidant activity through the DPPH radical scavenging assay and total anthocyanin content in sponge cupcakes substituted with varying levels of pregelatinized red jasmine rice flour, as presented in Table 3, revealed significant statistical differences ($p \leq 0.05$). The antioxidant activity values of sponge cupcakes substituted with pregelatinized red jasmine rice flour at levels of 20, 40, 60, 80, and 100% were 36.30, 46.38, 56.44, 56.15, and 67.99%, respectively. These values were higher than that of the control (0%), which recorded the lowest value at 35.26%. This indicates that increasing the amount of pregelatinized red jasmine rice flour in the sponge cupcake mixture significantly enhanced the DPPH radical scavenging activity.

Table 3 Antioxidant activity and total anthocyanin contents of control and substituted formulas for sponge cupcakes with pregelatinized red jasmine rice flour at different levels

Parameter	Levels of Substitution (%)					
	0	20	40	60	80	100
Inhibition activity (%)	35.26±0.94[d]	36.30±0.62[d]	46.38±0.64[c]	56.44±0.52[b]	56.15±0.73[b]	67.99±0.36[a]
Total anthocyanin (mg/kg)	ND	1.53±0.12[d]	2.08±0.38[c]	2.53±0.57[b]	2.60±0.10[b]	2.86±0.11[a]

Note: Mean values ± SD from three replications with different letters in the same row that are statistically significantly different ($p \leq 0.05$), ND indicates Not detected

The sponge cupcakes substituted with pregelatinized red jasmine rice flour at levels of 20, 40, 60, 80, and 100% exhibited anthocyanin levels of 1.53, 2.08, 2.53, 2.80, and 2.86 mg/kg, respectively. In contrast, the control cake made from wheat flour showed no detectable anthocyanin levels, as wheat flour lacks this compound. The increase in anthocyanin content with higher proportions of red jasmine rice flour can be attributed to the rich anthocyanin content of red jasmine rice, which is recognized for its antioxidant properties. By incorporating more red jasmine rice flour into the cake formulation, the final product benefits from an increased concentration of these valuable compounds, which can enhance health benefits such as reducing inflammation and combating oxidative stress. These effects are linked to the prevention of various chronic diseases, including heart disease and cancer (Mau et al, 2017).

The addition of pregelatinized red jasmine rice flour to cakes boosts antioxidant activity due to the anthocyanins in red jasmine rice, which have strong antioxidant properties (Mau et al., 2017). Additionally, pregelatinized flour reduces oxidative reactions in the cake, potentially extending shelf life by inhibiting ingredient deterioration (Aulia et al., 2024). Pregelatinized flour can also enhance nutrient absorption in the gastrointestinal tract, potentially allowing the body to utilize the antioxidants from the cake more effectively (Aulia et al., 2024; Mau, 2017).

Nutritional values of sponge cupcakes with pregelatinized red jasmine rice flour

In this study, the formulation of sponge cupcakes with a 20% substitution of pregelatinized red jasmine rice flour was selected for nutritional analysis, as this level of substitution was determined to achieve an appearance comparable to that of the control sample. The results are presented in Table 4. The nutritional of sponge cupcakes substituting 20% of the flour with pregelatinized red jasmine rice flour per 100 grams showed a total energy content of 342.77 kcal, with 131.13 kcal from fat. The cupcakes contained 14.57 g of fat, 8.36 g of protein, 44.55 g of carbohydrates, 1.21 g of crude fiber, and 25.62 g of sugars. Sodium was present at 283.29 mg, vitamin A at 80.41 μg, vitamin B1 at 0.049 mg, and vitamin B2 at 0.241 mg. Additionally, they provided 34.82 mg of calcium and 1.73 mg of iron.

Therefore, the sponge cupcakes incorporating a 20% substitution of pregelatinized red jasmine rice flour demonstrated a balanced nutritional profile, offering essential macronutrients such as carbohydrates and proteins, along with vital micronutrients like calcium and iron. The total energy content and specific nutrient levels indicate that this formulation is not only visually comparable to traditional cupcakes but also enhances their nutritional value, making them an appealing choice for health-conscious consumers.

Table 4 Nutritional value of sponge cupcakes substituted with pregelatinized red jasmine rice flour

Nutritional values	per 100 g	per serving unit	Unit
Total Energy	342.77	160	Kilocalories (kcal)
Energy from fat	131.13	60	Kilocalories (kcal)
Total Fat	14.57	7	grams (g)
Protein	8.36	4	grams (g)
Carbohydrates	44.55	20	grams (g)
Crude Fiber	1.21	< 1	grams (g)
Sugar	25.62	12	grams (g)
Sodium	283.29	125	milligrams (mg)
Vitamin A	80.41	36.18	micrograms (μg)
Vitamin B1	0.049	0.02	milligrams (mg)
Vitamin B2	0.241	0.11	milligrams (mg)
Calcium	34.82	15.67	milligrams (mg)
Iron	1.73	0.78	milligrams (mg)

Conclusion and Suggestions

This study examined the effects of substituting wheat flour with pregelatinized red jasmine rice flour at levels of 0, 20, 40, 60, 80, and 100% on the physical and chemical properties, bioactive compounds, and nutritional value of sponge cupcakes. The results indicated that sponge cupcakes with a 20% substitution had appearance, color, and texture properties like the control formula (0% substitution), which used only wheat flour. The lightness values (L^*) of the crust and crumb decreased to 42.27 and 56.85, respectively. The redness (a^*) and yellowness (b^*) values of the crust also decreased as substitution levels increased, while the redness of the crumb intensified. The overall color of the cupcakes darkened with higher levels of pregelatinized red jasmine rice flour, attributed to the natural anthocyanin pigments, enhancing nutritional value, and giving the cupcakes a more visually appealing hue. Additionally, the structure and texture were impacted by the substitution. The specific volume of sponge cupcakes decreased with higher substitution levels, from 6.49 mL/g in the control to 6.08 mL/g at 20% and down to 3.63 mL/g at 100% substitution. Replacing 20% of the flour with red jasmine rice flour significantly softened the cupcakes, reducing their hardness from 1070.3 g to 862.5 g. This substitution also resulted in a moister texture and increased cohesiveness, from 0.69 to 0.73, demonstrating the flour's ability to absorb water. Red jasmine rice flour substitution increased the antioxidant capacity of sponge cupcakes, with DPPH scavenging activity rising from 35.26% to 36.30%-67.99%, consistent with the increased anthocyanin content (1.53-2.86 mg/kg). Nutritionally, the 20% substitution level yielded a product with 342.77 kcal, 8.36 g of protein, 14.57 g of fat, 44.55 g of carbohydrates, and 1.21 g of crude fiber per 100 g. It also provided higher levels of sodium, vitamins A and B2, calcium, and iron. These findings suggest that incorporating 20% pregelatinized red jasmine rice flour into sponge cupcakes preserves a texture and appearance similar to the control. Future research should focus on optimizing the formulation to improve product texture and shelf-life while maintaining its health benefits. Furthermore, investigating consumer preferences and market potential will provide valuable insights for commercial applications.

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Author Contributions

Nawaporn Hongpan: contributed to the conceptualization, development of methodology, experimental design, investigation and data collection, critical review and revision of key intellectual content, and manuscript writing.

Phirawit Rattanadarachok: contributed to the investigation, data collection, and data analysis.

Soontreeya Kalawong: contributed to the provision of raw materials and manuscript review and editing.

Conflict of Interests

All authors declare that they have no conflicts of interest.

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References

AACC. (2000). *Approved methods of the American Association of Cereal Chemists* (10th ed.). St. Paul.

AOAC. (2019). *Official methods of analysis* (21st ed.). The Association of Official Analytical Chemists.

Aulia, L.P., Muchlisiyah, J., Andini, R., & Murtini, E.S. (2016). Physical, chemical, and organoleptic characteristics of chiffon cake with pregelatinized candi banana flour substitution (*Musa paradisiaca* L.). *Food Research, 8*(4), 327-335.

Ayutthaya, K., Phota, K., & Nanta, N. (2018). Effect of wheat flour substitution with brown rice flour on sponge cake's qualities. *Journal of Food Health and Bioenvironmental Science (September- December), 11*(3), 6-11.

Carillo- Navas, H., Guadarrama- Lezama, A.Y., Vernon- Carter, E.J., Garcia- Diaz, S., Reyes, I, & Alvarez- Ramirez, J. (2016). Effect of Gelatinized Flour Fraction on Thermal and Rheological Properties of Wheat- Based Dough and Bread *Journal of Food Science Technology*, *53*(11), 3996- 4006. https://doi.org/10.1007/s13197-016-2399-1

Chamnansilp, P., & Aromrit, A. (2011, February 12-13). *Changes of degree of gelatinization, gamma-oryzanol content and antioxidant activity of coloured rice after heating*: Proceedings *of the 12th Khon Kaen University Graduate Research Conference* (pp. 750-756). Khon Kaen.

Chantaraponpan, A., Sakunwiwat, W., & Meekeaw, M. (2019). Physical and chemical properties of Hom Mali Deang brown rice at three stages of grain development. *Khon Kaen Agriculture Journal*, *47*(Suppl.1), 671-678.

Fuengkajornfung, S. (2023). Effect of various colored rice flours on the quality of cricket protein powder fortified chiffon cake. *Christian University Journal, 29*(1), 68-79.

Gladys, C. C. T, Rocío, M. P. Y, & Angélica, S. L. N. (2021). Quality evaluation through sensory and image analysis of sponge cake crumb with three thermal egg pre-treatments. *International Journal of Gastronomy and Food Science, 25*, 100390. https://doi.org/10.1016/j.ijgfs.2021.100390

Godefroidt, T., Ooms, N., Pareyt, B., Brijs, K., & Delcour, J. A. (2019). Ingredient functionality during foam-type cake making: A review. *Comprehensive Reviews in Food Science and Food Safety*, *18*, 1550-1562.

Gomez, M., Ronda, F., Caballero, P. A., Blanco, C., & Rosell, C. M. (2007). Functionality of different hydrocolloids on the quality and shelf-life of yellow layer cakes. *Food Hydrocolloids*, *21*, 167-173.

Harakotr, B., Suriharn, B., Tangwongchai, R., & Lertrat, K. (2014). Effects of harvesting times and cooking methods on anthocyanin content and antioxidant activity in purple waxy corn hybrids. *Khon Kaen Agriculture journal*, *42*(3), 337-346.

Hesso, N., Loisel, C., Chevallier, S., Marti, A., Le-Bail, P., Le-Bail, A., & Seetharaman, K. (2015). The role of ingredients on thermal and rheological properties of cake batters and the impact on microcake texture. *LWT-Food Science and Technology*, *63*(2), 1171-1178.

Hongpan N., Ngensombat, K., & Rattanaphiboon, I. (2019). Development of Kanom Ar-lua products from Riceberry flour. *Burapha Science Journal*, *24*(2), 782-794.

Kim, J. M., & Shin, M. (2014). Effect of particle size distributions of rice flour on the quality of gluten-free rice cupcakes, *LWT-Food Science and Technology*, *59*, 526-532.

Liu, R., Sun, W., Zhang, Y., Huang, Z., Hu, H., Zhao, M., & Li, W. (2019). Development of a novel model dough based on mechanically activated cassava starch and gluten protein: Application in Bread. *Food Chemistry*, *300*, 125196. https://doi.org/10.1016/j.foodchem.2019.125196

Lueangsakun, N., & Nuankhaekul, S. (2020). *Cooking Bible: Bakery* (7th ed.). Amarin Cuisine Publishing.

Loypimai, P., Moongngam, A., & Chottanom, P. (2009). Effects of Ohmic heating on lipase activity, bioactive compounds, and antioxidant activity of rice bran. *Australian Journal of Basic and Applied Sciences*, *3*(4), 3642-3652.

Mau, J. L., Lee, C. C., Chen, Y. P., & Lin, S. D. (2017). Physicochemical, antioxidant and sensory characteristics of chiffon cake prepared with black rice as a replacement for wheat flour. *LWT-Food Science and Technology*, *75*, 434-439.

Phuapaiboon, P., Thancharoen, K., Thamaduangsri, S., Boonsrichana, T., Polphim, K., & Tanaiyasi, A. (2022). Effects of substitution of wheat flour with Hom-Nil rice flour on the quality of chiffon cake. *Phra Varun Agriculture Journal*, *19*(2), 128-137. https://doi.org/10.14456/paj.2022.27

Prom-u-thai, C., Jamjod. S., & Rerkasem, B. (2013, March 26-27). Nutritional values of local Thai colored rice: *The Seminar of the Upper Northern and Lower Northern Rice Research Centers* (pp. 91-100). Bangkok: Rice Research and Development Bureau.

Ronie, M. E., Zainol, M. K., & Mamat, H. (2021). A review of the recent applications of gluten-free flour, functional ingredients, and novel technologies approaches in the development of gluten-free bakery products. *Food Research*, *5*(5), 43-54.

Shih, F., & Daigle, K. (2002). Preparation and characterization of low oil uptake rice cake donuts. *Cereal Chemistry*, *79*(5), 745-748.

Sinthorn, W., Chatuphonprasert, W., & Jarukamjorn, K. (2015, January 28-30). In vitro antioxidant potentials of four Thai colored rice cultivars. In *Proceedings of the 1st International Conference on Herbal and Traditional Medicine (HTM 2015)* (pp. 133-137). Pullman Khon Kaen Raja Orchid Hotel, Khon Kaen, Thailand.

Šmídová, & Rysová. (2022). Gluten-Free Bread and Bakery Products Technology. *Foods*, *11*(3), 480. https://doi.org/10.3390/foods11030480

Thanasukarn, P., Petlomtnog, P., Ratanatriwong, N., Prachaiyo, O., & Ratanatriwong, P. (2021). Effect of storage conditions on the qualities of red jasmine rice. *Naresuan University Agricultural Journal*, *18*(1), 1-12.

Tongtangwong, U., & Suwansichon, S. (2010). Effects of wheat flour substitution with Sinin rice flour on qualities of butter cake: *Proceedings of 48th Kasetsart University Annual Conference: Agro-Industry* (pp. 195-202). Bangkok: Kasetsart University.

Turabi, E., Sumnu, G., & Sahin, S. (2008). Rheological properties and quality of rice cakes formulated with different gums and an emulsifier blend. *Food Hydrocolloids*, *22*, 305-312.