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Nutritional properties, bioactive compounds, antioxidant activities, and consumer acceptance of butter cake enhanced with Sangyod rice (*Oryza sativa* L.) flour

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Abstract

Butter cake is a popular bakery product, and developing a formula with enhanced nutritional value would provide a beneficial alternative for health-conscious consumers. Sangyod rice, a local pigmented rice variety from Phatthalung Province, Thailand, offers potential nutritional benefits through its high antioxidant content and economic value for local farmers. This study aimed to develop butter cake using Sangyod rice flour as a wheat flour substitute and evaluate its properties and consumer acceptance. Using an experimental design, butter cakes were prepared with Sangyod rice flour substitutions (40%, 50%, and 60% w/w) and analyzed for their nutritional properties, physical properties, bioactive compounds, antioxidant activities, and consumer acceptance through sensory evaluation (n=100). Results showed that the 50% substitution maintained sensory qualities comparable to the control while improving nutritional profiles. Higher levels of Sangyod rice flour substitution increased fiber content, total phenolic content, total flavonoid content, and antioxidant activities as measured by DPPH and ABTS assays. Consumer surveys demonstrated strong support for local farmers, with 87% product acceptance. These findings suggest that Sangyod rice flour has the potential for developing healthier bakery products while also supporting local agriculture, offering practical implications for commercial product development, and contributing to sustainable income generation for farmers in Phatthalung Province.

Keywords: Antioxidant activities, Bioactive compounds, Butter cake, Consumer acceptance, Thai pigmented rice.

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1. Introduction

Rice (*Oryza sativa* L.) serves as an essential staple food crop for more than half of the global population, particularly in Asia [1-4]. Beyond being a crucial carbohydrate source, rice plays a significant economic role, especially in Thailand, a major global rice producer [5, 6]. Pigmented rice varieties have gained increasing popularity due to their bioactive compounds and antioxidant properties [7-9]. Various pigmented rice cultivars grown in Asia exhibit purple, red, and black colors, attributed to the anthocyanins in the outer layers of the grain, which belong to the flavonoid family [10, 11]. Pigmented rice possesses beneficial properties for reducing chronic disease risks, including cardiovascular disease, obesity, type 2 diabetes, and specific cancers [4, 12, 13].

Sangyod rice (*Oryza sativa* L.) is a traditional cultivar from Phatthalung Province, Thailand, with a cultivation history spanning over a century, holding the distinction of being Thailand's first Geographical Indication registered rice variety since 2006 [14-19]. Characterized by its small, slender grains, red to deep red husk, and soft texture when cooked [20] Sangyod rice has become a significant economic crop in southern Thailand, with an annual production of approximately 28-30 million tons, valued at over $5 billion USD [21, 22]. This variety has gained significant popularity in Thailand's health food market due to its unique characteristics and health-promoting properties [14, 15]. The grain contains high levels of antioxidants, phenolic compounds, anthocyanins, vitamins, minerals, and dietary fiber that may help prevent oxidative stress-related diseases such as diabetes, cardiovascular diseases, and cancer [17, 23, 24]. Due to its nutritional value, Sangyod rice has been successfully incorporated into various food products, particularly bakery items, where it can enhance both nutritional value and functional properties while maintaining consumer acceptance [19].

Nutritional studies have shown that Sangyod rice contains high levels of antioxidants, phenolic compounds, anthocyanins, vitamins, minerals, and dietary fiber [23, 25]. Its antioxidant content significantly exceeds that of white rice varieties [17, 24]. Epidemiological studies have established correlations between the consumption of high-antioxidant rice and the reduced incidence of chronic diseases, including cancer, cardiovascular disease, and diabetes [26, 27]. Furthermore, the antioxidant levels in Sangyod rice demonstrate a positive correlation with phenolic and flavonoid content [28].

Bakery products, particularly butter cake, enjoy widespread popularity across all age groups, with continuous product development to meet consumer demands [29, 30]. However, the primary ingredient, wheat flour, must be imported into Thailand and offers lower nutritional value compared to Sangyod rice flour [19]. There is a growing trend of incorporating Thai rice flour into food products, especially bakery items, to enhance their nutritional value and add value to the indigenous rice varieties [31, 32].

Previous research has demonstrated that Sangyod rice flour can successfully substitute wheat flour in bakery products [19]. However, further investigation is needed regarding the physical properties, nutritional value, and consumer acceptance of butter cake made with Sangyod rice flour. Therefore, this study aims to develop butter cake using Sangyod rice flour as a wheat flour substitute, examining its physical properties, chemical composition, bioactive compounds, and consumer acceptance. The findings will guide the development of healthier bakery products while adding value to Sangyod rice as a local economic crop in Phatthalung Province, ultimately contributing to sustainable income generation for farmers and local communities.

2. Literature Review

Sangyod rice is a traditional cultivar that has been grown in Phatthalung province for over a century, recognized for its taste, nutritional value, and health-promoting properties. Kitisin, et al. [33] studied the bioactive compounds and antioxidant activities of Thai colored rice extracts, finding that Sangyod rice from Phatthalung contained total phenolic content ranging from 0.806 to 0.817 mg GAE/mL and showed high lipid peroxidation inhibition, with values between 50.352 and 62.422%. This aligns with Itharat, et al. [10] who found that a 95% ethanol extract from Sangyod rice bran effectively inhibited nitric oxide production ($IC50 = 15.59 \pm 1.23$ μg/ml) and contained high levels of γ-oryzanol (317 mg%) and vitamin E (211 mg%). Additionally, Srisuk and Tudpor [34] reported that Sangyod rice showed the second-highest antioxidant activity after Riceberry rice and contained significant levels of vitamins B1 and B2.

Regarding bakery product development, Yampuang, et al. [19] investigated the effects of substituting wheat flour with Sangyod rice flour in butter cake. They found that increasing the Sangyod rice flour content led to higher cake density but lower specific volume. Electron microscopy revealed fewer air pockets in the microstructure as the Sangyod rice flour content increased, due to the lack of gluten for air retention, resulting in significantly higher hardness and chewiness values ($p \leq 0.05$) compared to the control. Furthermore, lightness ($L*$) and yellowness ($b*$) values decreased, while the redness ($a*$) value increased with higher Sangyod rice flour content.

Previous studies have demonstrated the feasibility of substituting wheat flour with Sangyod rice flour in various bakery products. Lekjing, et al. [35] found that Sangyod rice flour could substitute up to 50% of wheat flour in snack products, which is consistent with studies on bread [36] and cookies Wangpankhajorn, et al. [37]. Rakmai, et al. [23] developed gluten-free pancakes using Sangyod rice, which received consumer acceptance. Additionally, studies have shown successful development of biscuits made from colored rice flour with high nutritional value and antioxidant properties [38] as well as brownies made from black glutinous rice flour, which received high consumer acceptance at a 50% wheat flour substitution [39]. These studies demonstrate the potential of Thai rice as a substitute for wheat flour in bakery products, while maintaining sensory qualities and enhancing nutritional value.

3. Materials and Methods

3.1. Research Design

This study employed a mixed-methods research approach to investigate the incorporation of Sangyod rice flour in butter cake production and its effects on product quality and consumer acceptance. Unlike previous studies that focused solely on physical properties [19] or nutritional aspects [40] this research provides a comprehensive analysis combining physical, chemical, nutritional, and consumer acceptance evaluations. The research was conducted in two distinct phases to ensure a thorough investigation of both product development and market potential.

The first phase focused on product development and characterization, involving laboratory analyses of nutritional properties, bioactive compounds, antioxidant activities, and physical characteristics. This systematic approach extends beyond traditional food product development studies by incorporating detailed analysis of bioactive compounds and antioxidant properties, which were not extensively covered in previous butter cake studies Sae-Eaw, et al. [31] and Sae-Eaw, et al. [32]. The second phase concentrated on consumer acceptance and market potential, utilizing a field survey approach with 100 participants selected through accidental sampling. This consumer study was more comprehensive than similar previous research, incorporating not only sensory evaluation but also assessments of consumer attitudes toward health benefits and cultural preservation aspects. The integration of these two phases provides a more complete understanding of both technical and market aspects of product development.

3.2. Materials and Sample Preparation

3.2.1. Source of the Raw Materials

The materials used in butter cake preparation are wheat flour (UFM Flour Mill Co., Ltd., Thailand), Sangyod rice flour (produced and milled from Sangyod rice variety in Phatthalung Province, Thailand, as shown in Figure 1(a) and Figure 1(b)), baking powder (Best Foods Co., Ltd., Thailand), salted butter (Home Fresh Gold, CPF Trading Co., Ltd., Thailand), sugar (Lin Sugar Industry Co., Ltd., Thailand), eggs (Charoen Pokphand Foods PCL., Thailand), fresh milk (CP-Meiji Co., Ltd., Thailand), and vanilla extract (McCormick & Company, Inc., USA). Sangyod rice cultivation in Phatthalung Province spans 11 districts, covering a total area of 22,675 rai with a production volume of 9,011.09 tons in Table 1. The major producing areas are Khuan Khanun district with the largest cultivation area (6,814 rai) and highest production (2,759.67 tons), followed by Pak Phayun district (4,668 rai; 1,843.86 tons) and Mueang Phatthalung district (2,463 rai; 972.89 tons) [41].

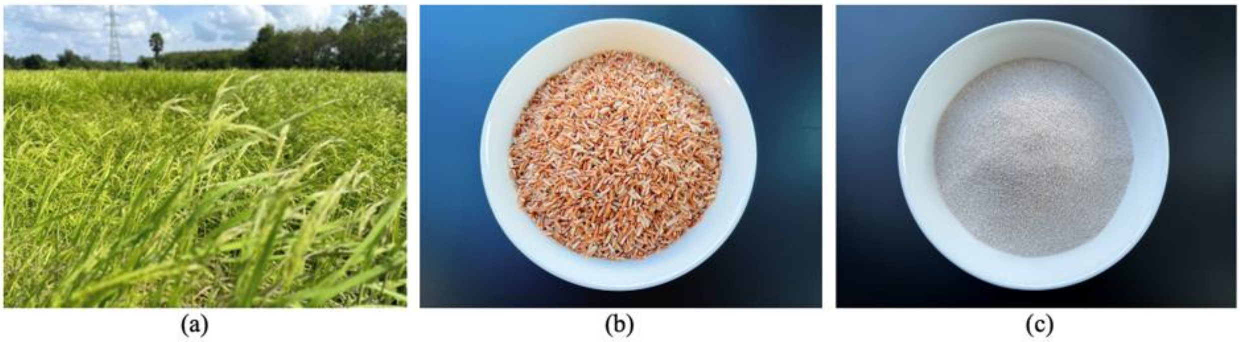


Figure 1.
Sangyod rice from Phatthalung Province: (a) Sangyod rice field in Phatthalung Province; (b) Milled Sangyod rice; (c) Sangyod rice flour for bakery products.

Table 1.
Cultivation area and production statistics of Sangyod rice by district in Phatthalung province [41].

District	Households	Cultivation area (rai)	Average yield (kg/rai)	Total production (tons)	Total value (USD)
Mueang Phatthalung	527	2,463	395	972.89	305,714
Khao Chai Son	334	1,915	395	756.43	280,857
Khuan Khanun	1,390	6,814	405	2,759.67	1,104,000
Pak Phayun	807	4,668	395	1,843.86	632,286
Kong Ra	48	236	399	94.16	32,286
Tamode	176	653	395	257.94	95,714
Sri Banphot	117	478	395	188.81	64,857
Pabon	735	3,906	390	1,523.34	522,286
Bangkaew	108	537	395	212.12	72,857
Pa Phayom	108	708	395	279.66	112,000
Srinakarin	81	297	394	117.02	36,857
Total	4,431	22,675	397	9,011.09	3,259,714

3.2.2. Processing of Sangyod Rice Flour

The processing of Sangyod rice flour, as shown in Figure 1, involved several steps. Initially, the Sangyod rice grains were cleaned and sorted to remove impurities, broken grains, and foreign materials to ensure the quality of the final product. The cleaned rice was weighed (300 g per batch) and spread evenly on stainless steel trays for uniform drying. The rice was then dried in a tray dryer at 60°C for 4 hours to achieve optimal moisture content for milling. After the drying process, the rice was cooled to room temperature to prevent moisture condensation. The rice sample was processed into flour by grinding at 25,000 rpm in a high-speed mill and screening through a 100-mesh sieve to ensure uniform particle size, as illustrated in Figure 1(c). The processed Sangyod rice flour was sealed in aluminum foil bags to prevent moisture absorption and was maintained under refrigeration at 4°C for subsequent analyses [42, 43].

3.2.3. Formulation and Production Process of Butter Cake

Four butter cake formulations were prepared in this study: Control formula (100% wheat flour) and three experimental formulas with Sangyod rice flour substitutions at 40% (SY40), 50% (SY50), and 60% (SY60) w/w of wheat flour. All butter cakes were prepared using the ingredients shown in Table 2. The preparation began with a standard creaming method. Initially, the wheat flour and baking powder for the control formula, or wheat flour, Sangyod rice flour, and baking powder for the substituted formulas (SY40, SY50, SY60), were sifted twice to ensure even distribution and set aside. Using a KitchenAid Professional Bowl-Lift Stand Mixer (Model 5KPM5EER, 4.8 L) fitted with a flat beater attachment, cold salted butter (cut into 1x1-inch cubes) was creamed at speed 4 while gradually incorporating sugar until the mixture became light, fluffy, and pale in color. Eggs were then added in three stages at speed 6, ensuring their thorough incorporation between each addition, followed by the vanilla extract. The mixer speed was reduced to 2 for the dry ingredient incorporation. The flour mixture was added alternately with fresh milk in five additions (three for flour and two for milk), beginning and ending with flour, mixing until combined enough to avoid overworking the batter. The batter was transferred into a parchment-lined aluminum loaf pan (8 × 16 × 5.5 cm) to approximately ¾ full. The cake was baked in a preheated Piron oven (Model PF5004F, Italy) at 160°C using both top and bottom heating elements for 50 minutes. After baking, the cake was cooled completely on a wire rack before being removed from the pan. The cooled cake was packaged in IPP (Injec polypropylene) bags, heat-sealed, and stored at 4°C for subsequent quality analysis. The cross-sectional appearances of the finished butter cakes are shown in Figure 2, where the control sample in Figure 2(a) shows a typical light-yellow color, while the substituted samples with 40% (SY40), 50% (SY50), and 60% (SY60) Sangyod rice flour (Figure 2(b), 2(c), and 2(d), respectively) exhibit a progressively darker crumb color due to the increasing levels of Sangyod rice flour incorporation.

Table 2.
Butter cake formulations with varying levels of wheat flour replacement using Sangyod rice flour (40%, 50%, and 60% w/w).

Ingredients (g)	Control	SY40	SY50	SY60
Wheat flour	150	90	75	60
Sangyod rice flour	-	60	75	90
Baking powder	2	2	2	2
Salted butter	125	125	125	125
Sugar	120	120	120	120
Eggs	165	165	165	165
Vanilla extract	10	10	10	10
Fresh milk	60	60	60	60

Note: Control: 100% wheat flour; SY40, SY50, and SY60: butter cakes prepared by substituting wheat flour with 40%, 50%, and 60% w/w Sangyod rice flour, respectively.

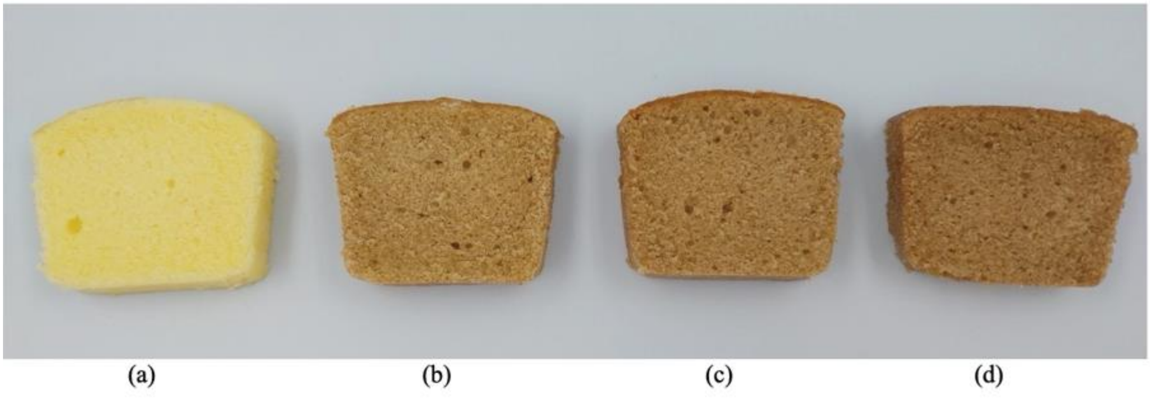


Figure 2.
Physical characteristics of butter cakes at different levels of wheat flour substitution with Sangyod rice flour: (a) Control (100% wheat flour); (b) 40% w/w Sangyod rice flour substitution; (c) 50% w/w Sangyod rice flour substitution; (d) 60% w/w Sangyod rice flour substitution.

3.3. Data Collection Methods

Data collection employed a mixed methods approach in two phases: laboratory analysis of product characteristics (nutritional properties, bioactive compounds, antioxidant activities, and physical properties) and consumer acceptance study involving 100 participants at RMUTT through accidental sampling. The data collection in each phase consisted of:

3.3.1. Nutritional Properties

3.3.1.1. Proximate Analysis

The chemical composition of the Sangyod rice flour and butter cake samples was analyzed in triplicate according to AOAC [44] standard methods. Moisture content was determined by drying the samples at 105°C until constant weight was achieved. Protein content was analyzed using the combustion method (LEGO EP-528, United States). Crude fat was determined by petroleum ether extraction using a soxhlet extraction unit (Tecator A Perstorp Analytical Company, Sweden). The ash and crude fiber content were analyzed using gravimetric methods. Total carbohydrate content was calculated using the following equation:

Carbohydrate (%) = 100 - (%moisture + %protein + %crude fat + %crude fiber + %ash)

3.3.1.2. Bioactive Compounds

Total phenolic content (TPC) and total flavonoid content (TFC) were analyzed for both the Sangyod rice flour and butter cake samples (control and 40%, 50%, 60% w/w Sangyod rice flour substitution) with three replications. The extraction process was conducted using methanol at a ratio of 2:1 (200 mL methanol per 100 g sample) over 48 hours. The extracted solutions were centrifuged at 6,000 rpm for 15 minutes, followed by filtration through a 0.45 µm syringe filter [45].

For the TPC determination, the analysis was performed by mixing 100 µL of sample solution with 100 µL methanol (95% v/v) and 200 µL of Folin-Ciocalteu reagent (10% v/v), followed by 5 minutes of agitation. Subsequently, 600 µL of 1 M sodium carbonate was incorporated into the mixture. The solution was then kept in darkness at room temperature for 60 minutes before measuring absorbance at 760 nm using a spectrophotometer. The results were expressed as micrograms of gallic acid equivalent per gram of dry weight (µg GAE/g dw) [45].

The TFC was measured by combining 500 µL of the sample solution with 340 µL of deionized water and 30 µL of 1 M sodium acetate, followed by 5 minutes of incubation. The mixture was then combined with 30 µL of 1 M AlCl3 and agitated for 5 minutes. Following the addition of 200 µL of 1 M NaOH, the solution was incubated at 30°C for 15 minutes. Absorbance was measured at 415 nm, and the results were expressed as micrograms of quercetin equivalent per gram of dry weight (µg QE/g dw) [45].

3.3.1.3. Antioxidant Activity

The antioxidant activity of the Sangyod rice flour and butter cake samples (control and 40%, 50%, 60% w/w Sangyod rice flour substitution) was evaluated using DPPH and ABTS radical scavenging assays with three replications. Sample extraction followed the same method as the bioactive compounds analysis using methanol (2:1 ratio). The extracts were centrifuged (6,000 rpm, 15 minutes) and filtered through a 0.45 µm syringe filter. The filtered solutions were evaporated at 50°C in a hot air oven to obtain crude extracts, which were stored at -20°C until analysis [45].

For the DPPH assay, the crude extracts (1 g) were dissolved in 10% (v/v) DMSO to prepare 1 mg/mL solutions. Equal volumes (50 µL) of sample solution and 0.1 mM DPPH solution were mixed to achieve a final concentration of 0.5 mg/mL. After 30 minutes incubation in darkness at room temperature, absorbance was measured at 517 nm using a UV/Vis spectrophotometer [45].

The ABTS assay was conducted by preparing ABTS·+ cation radical solution (mixing 7 mM ABTS with 2.45 mM potassium persulfate in a 1:0.5 v/v ratio). Sample solutions (50 µL) were combined with an equal volume of ABTS·+ solution (final concentration 0.5 mg/mL) and incubated for 30 minutes at room temperature before measuring absorbance at 734 nm [45].

For both assays, the radical scavenging activity was calculated as percentage inhibition using the formula: [(Ablank - Asample)/Ablank] × 100, where Ablank represents the absorbance of control and Asample represents the absorbance of test samples [45].

3.3.2. Physical Properties of Butter Cake

3.3.2.1. Color Analysis

The color parameters of butter cake samples were measured using a Hunter Lab Color Flex EZ Colorimeter with directional annular 45° illumination/0° viewing geometry, operating in the spectral range of 400-700 nm with a spectral resolution < 3 nm. Color was evaluated according to the CIE system (L^* a^* b^*), where L^* indicates brightness (0 = black, 100 = white), a^* represents the red-green axis (positive = red, negative = green), and b^* denotes the yellow-blue axis (positive = yellow, negative = blue) [46, 47]. The samples were finely ground, and 50 g of each sample was placed in a glass cup for measurement. Three measurements were taken for each sample: control (100% wheat flour) and butter cakes with 40%, 50%, and 60% w/w Sangyod rice flour substitution. The total color difference (ΔE) was calculated using a calibrated white tile as a reference standard [48].

$$\Delta E = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a)^2 + (b_1^* - b_2^*)^2}$$

3.3.2.2. Texture Analysis

Texture profile analysis (TPA) was performed using a Texture Analyzer (model TA-XT plus, Stable Micro Systems, Surrey, UK) equipped with a 36 mm diameter P36R cylindrical probe. The butter cake samples were cut into pieces with dimensions of 4 cm × 4 cm × 2 cm (width × length × thickness) before analysis. A double compression cycle was programmed with a compression rate of 1 mm/sec for 50 percent of the sample height. The second compression occurred 15 seconds after the first compression [47, 49]. The textural parameters determined were hardness (N), springiness, cohesiveness, chewiness (N), and gumminess (N) for the control (100% wheat flour) and butter cakes with 40%, 50%, and 60% w/w Sangyod rice flour substitution. Three measurements were taken for each sample.

3.3.3. Production Cost Analysis

The cost analysis of butter cake formulations was calculated using the following formula: Raw material cost = Actual weight (g) × Price (USD) / Total weight (g). The production costs were compared between the control formula (100% wheat flour) and the substituted formulas with different levels of Sangyod rice flour (40%, 50%, and 60% w/w) that received favorable evaluations following the sensory testing. All ingredient costs were based on current market prices in Pathum Thani Province, Thailand, during November 2024 [47].

3.3.4. Consumer Acceptance Study

The consumer acceptance study was conducted with 100 participants, comprising students, staff members, and members of the general public, who were randomly selected using accidental sampling within Rajamangala University of Technology Thanyaburi, Thailand and its vicinity. All participants were informed of the research objectives and provided written consent before participation, with no collection of national identification cards and with the right to withdraw at any time during data collection [47, 50, 51]. The survey was divided into four parts:

Part 1: Demographic characteristics including gender, age, education level, and occupation.

Part 2: Sensory evaluation involved four butter cake formulations: control (100% wheat flour) and samples with 40%, 50%, and 60% w/w Sangyod rice flour substitution. Each untrained panellists received 20 g samples served at room temperature in random order, with water provided for palate cleansing between samples. The evaluation used a 9-point hedonic scale was used for sensory evaluation where: 1 = dislike extremely, 5 = neither like nor dislike, and 9 = like extremely. Panellists assessed appearance, color, smell, taste, texture, and overall acceptability [47, 52, 53]. The interpretation criteria were categorized as: fair (2-4), good (5-6), and very good (7-8) [54].

Part 3: Consumer satisfaction assessment consisted of 8 questions regarding satisfaction with the butter cake product made with Sangyod rice flour, including product appeal, health benefits, product suitability for different consumer groups, product innovation, nutritional value, value addition, the promotion of Thai rice usage in bakery products, and support for Sangyod rice farmers. The assessment used a 5-point rating scale was applied: strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4), and strongly agree (5). For interpretation, the following ranges were established: strongly disagree (1.00-1.80), disagree (1.81-2.60), neither agree nor disagree (2.61-3.40), agree (3.41-4.20), and strongly agree (4.21-5.00) [55].

Part 4: Consumer acceptance and purchase intent evaluation to determine product marketability [47, 56].

3.4. Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics software (Version 22.0). For physical, chemical, and sensory evaluation analyses, results were expressed as mean ± standard deviation (SD), and differences were determined using one-way analysis of variance (ANOVA) followed by Duncan's new multiple range test (DNMRT) at 95% confidence level ($p<0.05$). For consumer survey data, demographic information was analyzed using frequency and percentage calculations, satisfaction ratings were presented as mean ± SD, and purchase intent was analyzed using frequency distribution. All measurements were performed in triplicate to ensure data reliability.

4. Results and Discussion

4.1. Nutritional Properties of Sangyod Rice Flour

The nutritional composition analysis of Sangyod rice flour in Table 3 revealed its potential as a nutritious ingredient for food product development. The flour had moisture content (9.67±0.16%) within the acceptable range for flour storage stability, ash content of 1.60±0.07%, and protein content of 9.92±0.09%, which aligns with the findings from the Bureau of Nutrition [57] that reported the high protein content (9.03%) of Sangyod rice compared to white rice (6.40%) and jasmine rice (6.20%). The flour contained moderate fat content (2.60±0.03%), which corresponds to the fat content of 4.25% reported by the Bureau of Nutrition [57] high carbohydrate content (70.95±0.58%) which is typical for rice flour, and a considerable amount of dietary fiber (5.26±0.11%). The dietary fiber content in Sangyod rice flour was notably higher than other colored rice varieties from Thailand, Sri Lanka, and China reported by Sompong, et al. [40] who found that the total dietary fiber content of most colored rice varieties ranged between 3.0% and 4.5%, while red rice varieties from Sri Lanka and China contained lower fiber content (2.5-2.9%). Additionally, the ash content of Sangyod rice flour was comparable to black rice varieties from Thailand and China (1.4-1.7%) reported in the same study, indicating its rich mineral content. These findings suggest that Sangyod rice flour not only provides essential nutrients but also offers potential health benefits through its high dietary fiber content, which could contribute to its functionality in food product development [40, 58-60].

Notably, Sangyod rice flour demonstrated significant bioactive compound content, with a total phenolic content of 95.43±1.51 µg GAE/g dw and total flavonoid content of 829.67±4.52 µg QE/g dw. These values are particularly significant as phenolic and flavonoid compounds are the primary contributors of antioxidant capacity in colored rice varieties [4, 59, 61]. Antioxidant activity was confirmed through the DPPH (138.23±1.18% inhibition) and ABTS (196.92±2.06% inhibition) assay results, which can be attributed to the characteristic red pigmentation of Sangyod rice that contains anthocyanins and other phenolic compounds [40, 58, 61]. The presence of these bioactive compounds suggests that Sangyod rice flour can enhance not only the nutritional value of food products but also provide potential health-promoting properties through its antioxidant activity, which is increasingly recognized as important for preventing oxidative stress-related diseases [8, 10, 26, 40].

Table 3.
Nutritional properties of Sangyod rice flour.

Nutritional properties	Sangyod rice flour
Moisture (%)	9.67±0.16
Ash (%)	1.60±0.07
Protein (%)	9.92±0.09
Fat (%)	2.60±0.03
Carbohydrate (%)	70.95±0.58
Fiber (%)	5.26±0.11
Total phenolic content (µg GAE/g dw)	95.43±1.51
Total flavonoid content (µg QE/g dw)	829.67±4.52
DPPH assay (% inhibition at 0.5 mg/mL)	138.23±1.18
ABTS assay (% inhibition at 0.5 mg/mL)	196.92±2.06

Note: Results are expressed as mean ± SD with three replications (n = 3).

4.2. Physical Properties of Butter Cakes

Physical properties analysis of butter cakes with Sangyod rice flour substitution demonstrated significant modifications ($p<0.05$) in color and textural profiles in Table 4. Instrumental color measurement revealed that higher levels of Sangyod rice flour incorporation resulted in progressively darker products, evidenced by the L^* value reduction from 80.77±0.03 (control) to 50.31±0.06 (SY60). The enhancement of red hues was confirmed by increasing a^* values (6.06±0.05 to 9.15±0.01), while yellowness diminished as shown by the decreasing b^* values (38.39±0.03 to 20.07±0.02). The findings align with Lekjing, et al. [35] showing when brown Sangyod rice flour substitution was increased in snack products, L^* and b^* values significantly decreased while a^* values increased. The magnitude of the overall color variation (ΔE) expanded significantly with the increasing substitution rates, ranging from 29.92±0.05 (SY40) to 35.68±0.08 (SY60), representing readily perceptible visual differences compared to the control formulation ($\Delta E > 3$) [62]. The observed color development can be attributed to dual mechanisms: thermal processing effects and inherent pigmentation. Research has shown that baking operations typically diminish product brightness [63] through melanoidin formation via Maillard reactions between amino compounds and proteins [64]. Furthermore, the intensified coloration in Sangyod-substituted samples stems from their anthocyanin content, which imparts characteristic red-purple hues. The findings correspond with Yampuang, et al. [19] who documented that elevated rice flour substitution levels yielded darker products with enhanced red tonality, attributed to oxidation-induced proanthocyanidin modifications and the thermal transformation of anthocyanins to chalcone derivatives during baking.

Analysis of texture profiles showed significant differences ($p<0.05$) in the textural characteristics of the butter cake with increasing levels of Sangyod rice flour substitution. Hardness values significantly increased from 1553.12±32.06 N in the control sample to 2596.75±42.59 N in SY60, indicating a denser crumb structure formation. These results are consistent with the findings of Aydogdu, et al. [65] that baked products with a lower volume exhibit firmer texture due to decreased air incorporation, while those with a higher volume maintain a softer texture due to greater air retention. This relationship is clearly demonstrated in Figure 2, where the cake containing 60% Sangyod rice flour substitution (SY60) shows the most significant reduction in height. Changes in texture can be attributed to reduced gluten elasticity, which limits the ability of the dough to retain expanding air during baking [66]. Increasing levels of Sangyod rice flour substitution leads to gluten dilution, interfering with gluten network formation during mixing and resulting in an irregular protein matrix [19]. The texture parameter analysis demonstrated increasing trends in springiness and cohesiveness, from 0.19±0.01 and 0.17±0.01 in the control to 0.22±0.01 and 0.22±0.01 in SY60, respectively. Similarly, both chewiness and gumminess values showed significant increases with higher substitution levels, with chewiness increasing from 55.07±2.95 N to 243.60±5.47 N and gumminess rising from 284.56±6.06 N to 693.79±9.59 N in SY60. These results are consistent with Yampuang, et al. [19] who reported increased hardness values in butter cakes with higher Sangyod rice flour content. Additionally, the increased chewiness values correspond with the findings of Gómez, et al. [67] on dietary fiber effects in cake quality, where a higher fiber content resulted in significantly increased hardness and chewiness values.

Table 4.
Physical properties of butter cakes prepared by the substitution of wheat flour with Sangyod rice flour (40%, 50%, and 60% w/w).

Physical properties	Control	SY40	SY50	SY60
Color analysis				
L^*	80.77^a±0.03	55.88^b±0.10	54.70^c±0.04	50.31^d±0.06
a^*	6.06^d±0.05	7.95^c±0.01	8.22^b±0.02	9.15^a±0.01
b	38.39^a±0.03	21.89^b±0.01	20.67^c±0.05	20.07^d±0.02
ΔE	-	29.92^c±0.05	31.60^b±0.02	35.68^a±0.08
Texture analysis				
Hardness (N)	1553.12^d±32.06	1904.33^c±41.10	2117.54^b±38.70	2596.75^a±42.59
Springiness	0.19^b±0.01	0.21^a±0.01	0.21^a±0.01	0.22^a±0.01
Cohesiveness	0.17^b±0.01	0.21^a±0.01	0.21^a±0.01	0.22^a±0.01
Chewiness (N)	55.07^d±2.95	87.09^c±2.51	155.30^b±4.98	243.60^a±5.47
Gumminess (N)	284.56^d±6.06	412.69^c±8.44	664.39^b±8.72	693.79^a±9.59

Note: Control: 100% wheat flour; SY40, SY50, and SY60: butter cakes prepared by substituting wheat flour with 40%, 50%, and 60% w/w Sangyod rice flour, respectively. Results are expressed as mean ± SD (n = 3). Different superscript letters within the same row indicate means that are significantly different (p<0.05).

4.3. Nutritional Properties of Butter Cakes

The proximate composition analysis of butter cakes with Sangyod rice flour substitution demonstrated significant changes (p<0.05) in the assessed nutritional values in Table 5. The moisture content decreased with increasing substitution levels, from 17.32±0.08% in the control to 16.27±0.24% in SY50. Ash content significantly increased from 3.60±0.02% to 4.37±0.06% at 60% substitution level, while the protein content slightly decreased from 3.93±0.03% to 3.66±0.02%, and fat content increased from 55.05±0.30% to 58.02±1.04%. These variations can be attributed to the different nutritional composition of wheat flour and Sangyod rice flour. A significant aspect of this study was the change in dietary fiber content. The analysis of the raw materials in Table 2 revealed that Sangyod rice flour contains significantly higher dietary fiber (5.26%) compared to wheat flour which contains only 0.42% [68]. This difference resulted in butter cakes with Sangyod rice flour substitution showing a significant increase in dietary fiber content from 0.33±0.02% to 2.54±0.05%. This increase in fiber content aligns with the findings from Sompong, et al. [40] who reported that pigmented rice contains dietary fiber ranging from 3.0-4.5%, which is higher than regular wheat flour [68]. These results are also consistent with Sirichokworrakit, et al. [69] who found increased fiber content when wheat flour was substituted with pigmented rice flour in noodle products.

The analysis of the bioactive compounds in butter cake with Sangyod rice flour substitution showed significant increases (p<0.05) in total phenolic compounds (11.48±0.50 to 25.20±0.33 µg GAE/g dw) and total flavonoid content (126.87±3.24 to 485.97±4.29 µg QE/g dw). This increase stems from Sangyod rice's unique bran layer, which is rich in phenolic compounds and anthocyanins, as confirmed by Kitisin, et al. [33]. The enhanced bioactive content improved the antioxidant properties, with the DPPH and ABTS radical scavenging activities increasing from 24.72±0.81% to 31.35±0.30% and 32.03±0.80% to 46.38±1.41%, respectively. These findings align with Srisawat, et al. [28]; Ratseewo, et al. [58] and Lang, et al. [63] who both demonstrated strong correlations between phenolic compounds and antioxidant activity in Sangyod rice. Epidemiological studies by Goufo and Trindade [26] and Hudson, et al. [27] have linked the consumption of antioxidant-rich rice to reduced chronic disease incidence in Asia. Sangyod rice demonstrates superior antioxidant activity compared to white rice, with documented benefits in preventing oxidative stress-related diseases [15, 17, 25]. Multiple studies confirm its high antioxidant content [20, 70] and abundance of essential minerals [34]. The findings suggest that there is significant potential for developing functional foods with health-promoting properties. Pradipta, et al. [61] emphasizes the importance of these antioxidant properties in health food development, while Yodmanee, et al. [60] noted the influence of genotype and environment on antioxidant content. These results align with trends in functional food development and support value addition to Thai indigenous rice through innovative processing [25].

Table 5.
Nutritional properties of butter cakes with Sangyod rice flour substitution of wheat flour at 40%, 50%, and 60% (w/w).

Nutritional properties	Control	SY40	SY50	SY60
Moisture (%)	17.32^a±0.08	17.05^a±0.34	16.27^b±0.24	16.75^{ab}±0.51
Ash (%)	3.60^d±0.02	3.97^c±0.05	4.08^b±0.04	4.37^a±0.06
Protein (%)	3.93^a± 0.03	3.80^b±0.03	3.74^c±0.01	3.66^d±0.02
Fat (%)	55.05^c±0.30	56.16^{bc}±1.13	57.42^{ab}±0.91	58.02^a±1.04
Carbohydrate (%)	19.77^a±0.15	18.05^b±0.05	16.64^c±0.04	14.66^d±0.04
Fiber (%)	0.33^d±0.02	0.97^c±0.01	1.85^b±0.03	2.54^a±0.05
Total phenolic content (µg GAE/g dw)	11.48^d±0.50	18.17^c±0.63	22.56^b±0.48	25.20^a±0.33
Total flavonoid content (µg QE/g dw)	126.87^d±3.24	285.05^c±1.29	367.92^b±2.80	485.97^a±4.29
DPPH assay (% inhibition at 0.5 mg/mL)	24.72^d±0.81	28.12^c±0.51	30.09^b±0.34	31.35^a±0.30
ABTS assay (% inhibition at 0.5 mg/mL)	32.03^d±0.80	40.19^c±0.51	44.23^b±0.56	46.38^a±1.41

Note: Control: 100% wheat flour; SY40, SY50, and SY60: butter cakes prepared by substituting wheat flour with 40%, 50%, and 60% w/w Sangyod rice flour, respectively. Results are expressed as mean ± SD (n = 3). Different superscript letters within the same row indicate means that are significantly different (p<0.05).

4.4. Production Cost Analysis

The cost analysis of the butter cake formulations in Figure 3 revealed a progressive increase in production costs with higher levels of Sangyod rice flour substitution. The control formula (100% wheat flour) had the lowest production cost at $2.62 USD per formulation, while the substitutions with 40%, 50%, and 60% Sangyod rice flour resulted in increased costs of $2.75, $2.78, and $2.81 USD respectively. This upward trend in cost can be attributed to the higher market price of Sangyod rice flour compared to regular wheat flour [47]. The total cost difference between the control and 60% substitution (SY60) was approximately $0.19 USD (7.25% increase), which is relatively modest considering the potential nutritional benefits and added value of incorporating this specialty rice flour. Despite the higher ingredient cost, the use of Sangyod rice flour could be justified by its unique properties and potential market positioning as a premium or healthier alternative to conventional butter cakes.

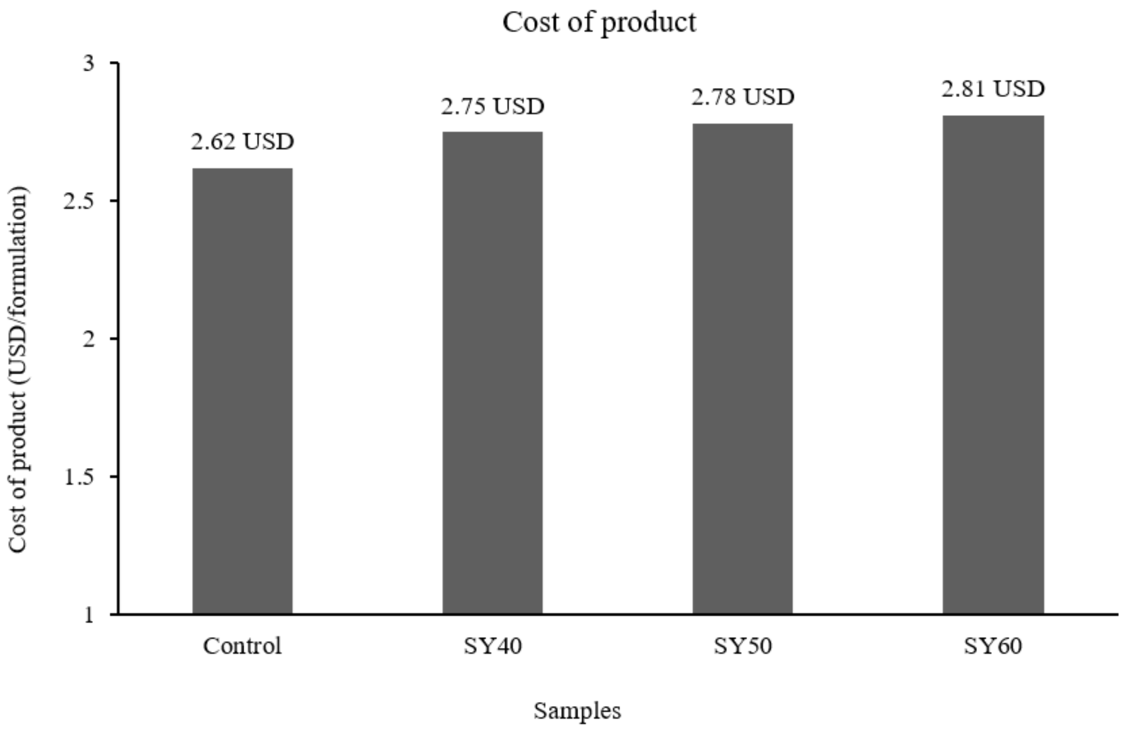


Figure 3.
Product cost comparison of butter cake formulations with Sangyod rice flour substitution of wheat flour (40%, 50%, and 60% w/w).

4.5. Consumer Acceptance Study

The demographic characteristics of the consumers participating in the acceptance study (n = 100) are shown in Table 6. The majority of participants were female (64%), while male participants accounted for 36%. Regarding age distribution, more than half of the participants (56%) were between 20-30 years old, followed by those aged 31-40 years (24%), and 41-50 years (10%). The youngest (under 20 years) and oldest (over 50 years) age groups each represented 5% of participants. In terms of education level, most participants held a bachelor's degree (75%), followed by higher than a bachelor's degree (17%), and below a bachelor's degree (8%). For occupation, nearly half of the participants were students (48%), followed by government officers (20%), business owners (14%), private company employees (12%), and merchants (6%).

Table 6.
Demographic characteristics of consumers (n = 100).

Characteristics	Frequency	Percentage
Gender		
Male	36	36.00
Female	64	64.00
Total	100	100.00
Age		
Under 20 years	5	5.00
20-30 years	56	56.00
31-40 years	24	24.00
41-50 years	10	10.00
Over 50 years	5	5.00
Total	100	100.00
Education		
Below a bachelor’s degree	8	8.00

Characteristics	Frequency	Percentage
Bachelor's degree	75	75.00
Higher than a bachelor's degree	17	17.00
Total	100	100.00
Occupation		
Student	48	48.00
Government officer	20	20.00
Private company employee	12	12.00
Merchant	6	6.00
Business owner	14	14.00
Total	100	100.00

The sensory evaluation results for the butter cakes with different levels of Sangyod rice flour substitution showed statistically significant differences in acceptance levels ($p<0.05$) in Table 7. The 50% substitution formula (SY50) received scores comparable to the control in several attributes, with no significant differences ($p\geq0.05$) from the control sample in appearance (7.39±0.91 vs 7.40±0.95), taste (7.59±1.02 vs 7.61±1.23), texture (7.34±1.04 vs 7.44±0.94), and overall acceptance (7.27±1.14 vs 7.32±0.96). However, the 60% substitution (SY60) resulted in significantly lower scores across all attributes, with the lowest scores in appearance (5.66±1.20), texture (5.61±1.28), and overall acceptance (5.65±1.32). The 40% substitution (SY40) showed acceptance levels between SY50 and SY60. These findings indicate that Sangyod rice flour can effectively substitute wheat flour up to 50% without significantly affecting the sensory characteristics, while higher substitution levels may negatively impact consumer acceptance. This finding corresponds with Lekjing, et al. [35] who determined that replacing 50% of wheat flour with Sangyod brown rice flour was the most appropriate ratio for snack production based on its highest overall liking score. This is consistent with the previous studies on Thai pigmented rice flour substitution in bakery products, where partial substitution up to certain levels-maintained product acceptability [71]. Similar findings were reported for noodles with 30% Riceberry flour substitution, which achieved comparable sensory qualities to the control samples [69]. These studies demonstrate that Thai pigmented rice varieties can successfully replace wheat flour in various food products while maintaining sensory acceptance when appropriate substitution levels are used.

Table 7.
Sensory evaluation of butter cakes containing wheat flour substitution with Sangyod rice flour (40%, 50%, and 60% w/w).

Characteristics	Control	SY40	SY50	SY60
Appearance	7.40^{a}±0.95	6.42^{b}±1.19	7.39^{a}±0.91	5.66^{c}±1.20
Color	7.43^{a}±1.08	6.89^{b}±1.17	7.02^{b}±1.15	5.73^{c}±1.32
Smell	7.27^{a}±1.32	6.19^{c}±1.04	6.91^{b}±1.18	5.92^{c}±1.31
Taste	7.61^{a}±1.23	6.13^{b}±1.14	7.59^{a}±1.02	6.24^{b}±1.75
Texture	7.44^{a}±0.94	6.38^{b}±1.19	7.34^{a}±1.04	5.61^{c}±1.28
Overall acceptability	7.32^{a}±0.96	6.40^{b}±1.08	7.27^{a}±1.14	5.65^{c}±1.32

Note: Control: 100% wheat flour; SY40, SY50, and SY60: butter cakes prepared by substituting wheat flour with 40%, 50%, and 60% w/w Sangyod rice flour, respectively. Results are expressed as mean ± SD (n = 100). Different superscript letters within the same row indicate means that are significantly different ($p<0.05$).

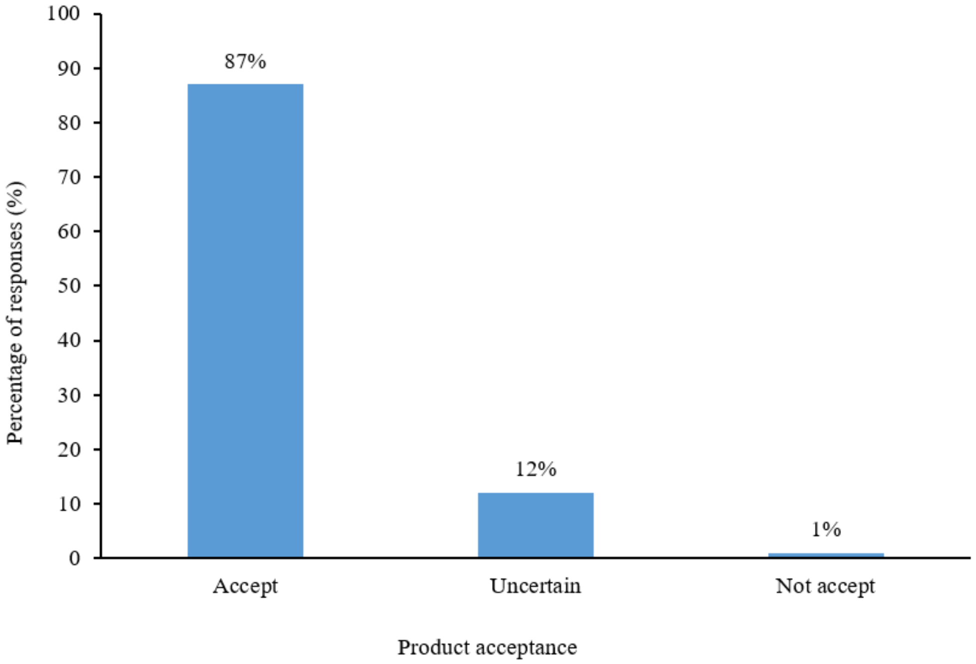
The consumer satisfaction survey revealed highly positive responses across multiple evaluation criteria in Table 8. Satisfaction was measured using a 5-point rating scale. Most items received strongly agree ratings, with the highest satisfaction for supporting Sangyod rice farmers in Phatthalung Province (4.90±0.30) and promoting Thai rice usage in the bakery industry (4.87±0.33). Product innovation due to Sangyod rice flour incorporation (4.77±0.48), health benefits (4.73±0.56), added value (4.54±0.71), product appeal (4.53±0.68), suitability for general consumers (4.49±0.62), and suitability for health-conscious consumers (4.22±0.50) all received strongly agree ratings, with an overall mean satisfaction of 4.63±0.46. These positive responses align with the growing global demand for bakery products, which has been driven by factors such as easy availability, reasonable cost, and comparatively higher shelf life. Furthermore, with increasing health awareness among today's consumers, these results demonstrate that fortifying bakery products with healthy ingredients like Sangyod rice flour can successfully meet the evolving needs of health-conscious consumers [72, 73]. These high satisfaction ratings, particularly for supporting local farmers and promoting Thai rice usage, demonstrate that products with quality standards and effective marketing strategies can successfully drive both sales and market share [74]. The development of such rice-based products is supported by previous research showing the potential for Thai rice flour substitution in bakery products, particularly in butter cakes, which not only achieves consumer acceptance but also expands the utilization possibilities of Thai rice resources [31, 32]. This approach of Value addition through product development enhances consumer awareness and purchasing decisions, while promoting both local economic development and healthy eating habits.

Table 8.
Consumer satisfaction levels.

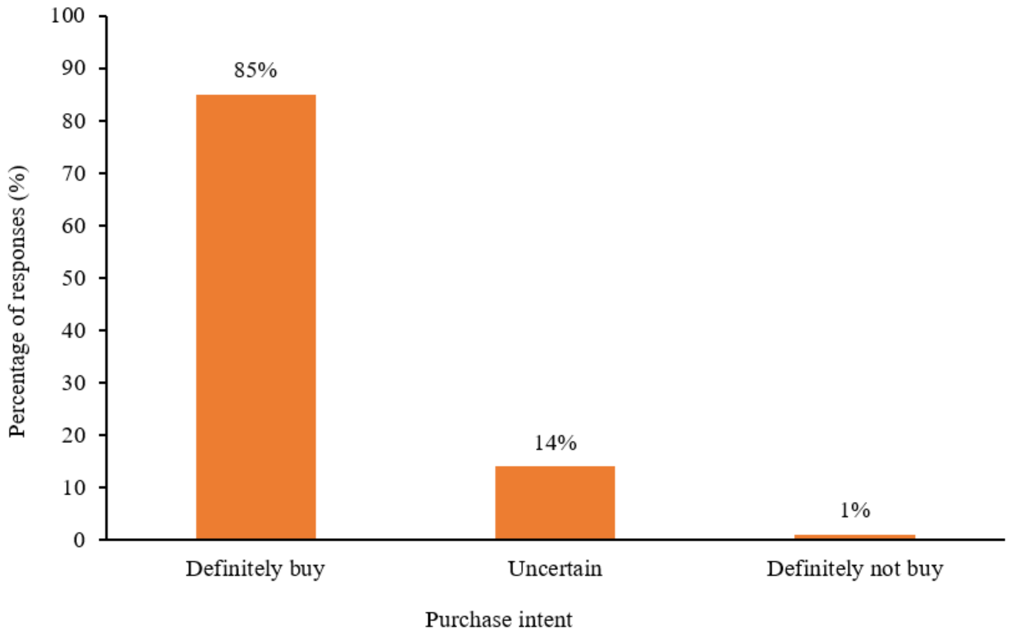
Satisfaction Items	Frequency (Percentage)					$\bar{x} \pm$ (SD)	Level of agreement
	SD	D	N	A	SA		
1. Product is appetizing			11 (11%)	25 (25%)	64 (64%)	4.53±0.68	Strongly agree
2. Product is suitable for health-conscious consumers			4 (4%)	70 (70%)	26 (26%)	4.22±0.50	Strongly Agree
3. Product is suitable for general consumers			7 (7%)	37 (37%)	56 (56%)	4.49±0.62	Strongly agree
4. Product is innovative due to Sangyod rice flour incorporation			3 (3%)	17 (17%)	80 (80%)	4.77±0.48	Strongly agree
5. Product provides health benefits due to Sangyod rice flour incorporation			6 (6%)	15 (15%)	79 (79%)	4.73±0.56	Strongly agree
6. Product has added value due to Sangyod rice flour incorporation			13 (13%)	20 (20%)	67 (67%)	4.54±0.71	Strongly agree
7. Product promotes the use of Thai rice in bakery industry				13 (13%)	87 (87%)	4.87±0.33	Strongly agree
8. Product supports Sangyod rice farmers in Phatthalung Province				10 (10%)	90 (90%)	4.90±0.30	Strongly agree
Total						4.63±0.46	Strongly agree

Note: SD = Strongly disagree (1), D = Disagree (2), N = Neither agree nor disagree (3), A = Agree (4), SA = Strongly agree (5); $\bar{x}$ = mean, (SD) = standard deviation (n = 100).

The consumer acceptance analysis for butter cake made with Sangyod rice flour demonstrated highly positive responses in Figure 4(a). The product acceptance level reached 87% of consumers, with 12% uncertain and only 1% not accepting the product. Similarly, the purchase intent analysis also showed promising results in Figure 4b, with 85% of consumers indicating they would definitely buy the product if available in the market, while 14% were uncertain and only 1% would definitely not buy. These high acceptance and purchase intent rates suggest that incorporating Sangyod rice flour into butter cakes has strong market potential. These findings align with the previous research on pudding products by Punfujinda, et al. [47] and sweet fish sauce development by Punfujinda, et al. [56] both of which demonstrated similar trends in high consumer acceptance and purchase intent. Purchase intent reflects consumer confidence and their willingness to pay for products, and when consumer attitudes align with expectations, purchase behavior tends to follow, especially when products receive widespread acceptance [75]. This study demonstrates how various factors, including consumer knowledge, food perception, and consumer attitudes, influence the Thai consumers' purchase intent for innovative foods through structural relationship analysis.



(a)



(b)

Figure 4.
Evaluation of butter cakes containing Sangyod rice flour: (a) Level of product acceptance; (b) Market purchase intent (n=100)

5. Conclusions

This study successfully developed butter cake using Sangyod rice flour as a partial substitute for wheat flour. The optimal substitution level was found to be 50%, which maintained sensory acceptability while improving nutritional properties, including increased fiber content and bioactive compounds. Although the production costs increased slightly with incorporation of Sangyod rice flour, the added nutritional value and strong consumer acceptance suggest market potential.

5.1. Implications

The product not only offers a healthier alternative to conventional butter cakes but also supports local agriculture by promoting the use of Sangyod rice, a valuable economic crop from Phatthalung Province. The successful incorporation of Sangyod rice flour into bakery products could encourage broader utilization of this local economic crop across various food industries, potentially creating new market opportunities and strengthening the agricultural economy of Phatthalung Province. This product development also adds value throughout the Sangyod rice supply chain, benefiting everyone from farmers and processors to food product manufacturers, contributing to the economic sustainability of local communities.

5.2. Limitations Recommendations and Future Research

The study has some limitations that should be addressed in future research. Specifically, the storage stability and shelf life of the developed product were not evaluated in this study. Future studies should investigate the effects of storage conditions on product quality, as well as determine appropriate packaging materials and storage recommendations. Additionally, the cost analysis was based on current market prices in Pathum Thani Province; future research should consider broader market analysis across different regions. Future research opportunities include exploring the development of other bakery products using Sangyod rice flour, optimizing processing conditions to enhance bioactive compound retention, investigating consumer willingness to pay for premium health-oriented bakery products, and examining the potential for scaling up production for commercial applications. These research directions could further advance the understanding and application of Sangyod rice flour in food product development, while also supporting sustainable local agriculture.

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