International Food Research Journal 32(1): 92 - 107 (February 2025)
Journal homepage: *http://www.ifrj.upm.edu.my*

Effects of Thai pigmented rice (Riceberry and Hom Nil; *Oryza sativa* L.) flours on quality of *kanom piak poon* (traditional Thai dessert)

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Article history

Received:
26 May 2024
Received in revised form:
18 November 2024
Accepted:
29 November 2024

Keywords

Riceberry rice flour,
Hom Nil rice flour,
black rice,
Thai pigmented rice flour,
Thai traditional dessert

Abstract

The present work investigated Riceberry rice flour (RBF) and Hom Nil rice flour (HNF) as potential replacements for rice flour in *kanom piak poon* (KPP), a traditional Thai dessert. The present work aimed to determine the optimal substitution levels of RBF and HNF, to evaluate the physicochemical properties and nutritional value of the modified KPP, and to assess consumer acceptance. RBF and HNF were used to replace rice flour at ratios of 25, 50, 75, and 100% (w/w). Sensory evaluation using a 9-point hedonic scale revealed that KPP with 25% RBF (RBF25) and 25% HNF (HNF25) received the highest acceptance scores. Physical properties, such as colour values (L* and b*) and texture (hardness and springiness), decreased with increasing RBF and HNF contents. Nutritional analysis showed that RBF25 and HNF25 had significantly higher ($p \leq 0.05$) dietary fibre content (9.22 and 10.00%, respectively), bioactive compounds (TPC: 88.56 and 95.24 µg GAE/g dw; TFC: 65.12 and 68.35 µg QE/g dw, respectively), and antioxidant activity (DPPH: 54.46 and 57.23%; ABTS: 92.71 and 98.04%, respectively) compared to the control. Consumer acceptance tests indicated high approval ratings for RBF25 and HNF25. Consumers also expressed that using Thai rice varieties as ingredients in Thai desserts would add uniqueness to KPP, and help preserve the knowledge of Thai dessert making. These findings demonstrates the potential of RBF and HNF in enhancing the nutritional value and consumer appeal of traditional Thai desserts.

DOI
https://doi.org/10.47836/ifrj.32.1.07

Introduction

Kanom piak poon (KPP) is a traditional Thai dessert. It is named after the characteristics of the dessert and the ingredients in it: *piak* refers to its wet characteristic, and *poon* refers to the clear lime water used as ingredient in it. KPP has three main ingredients: rice flour, palm sugar, and clear lime water. A stirring method is used until the dough achieves a thick consistency, which is then poured into a tray, allowed to cool, and cut into square pieces. It is eaten together with shredded coconut mixed with salt. Some versions of KPP have the green colour of pandan leaves if pandan juice is added to give it a nice aroma, while some versions are black. This is because water from burnt coconut husks is used to give it colour and aroma. The texture of KPP is soft and chewy. It has a sweet taste from palm sugar, and slight saltiness and oiliness from the coconut. Therefore, KPP has a perfect balance of contrasting flavours (Khwandutsadee, 2012; Wongtong, 2015).

Rice (*Oryza sativa* L.) is an important cash crop for more than half of the world's population, especially in Europe, the Americas, and Asia (Sripo *et al*., 2016; Kukusamude and Kongsri, 2018; Li *et al*., 2020; Manaois *et al*., 2020; Kukusamude *et al*., 2021; Huluka and Kumsa, 2022; Kongsri and Kukusamude, 2023). Rice is an important source of energy, providing carbohydrates, vitamins, and essential trace elements (Reddy *et al*., 2017; Kukusamude and Kongsri, 2018; Kukusamude *et al*., 2021). Research has discovered that the various rice cultivars exhibited differences in both their nutritional compositions and phytochemical levels (Sivamaruthi *et al*., 2018). Thailand grows two types of rice: non-pigmented rice, such as Jasmine rice

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(105), and pigmented rice, such as Riceberry rice and Hom Nil rice (Thitipramote *et al*., 2016; Prasertwattanakul and Ongkunaruk, 2018; Settapramote *et al*., 2021a). Riceberry rice is a healthy purple-black rice that was created in Thailand by crossbreeding Hom Nil rice and jasmine rice (105) (Settapramote *et al*., 2018; Sivamaruthi *et al*., 2018; Thongkaew and Singthong, 2020; Raungrusmee *et al*., 2022). Meanwhile, Hom Nil rice is a purple-black coloured, native Thai jasmine rice cultivar that yields a soft texture and pleasant aroma upon cooking (Wongklom *et al*., 2016). Therefore, both Riceberry and Hom Nil rice are considered pigmented rice varieties of Thailand (Sarak *et al*., 2024).

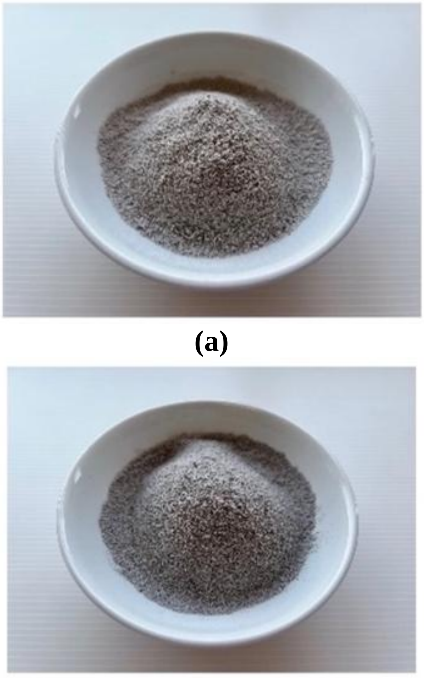
Riceberry rice and Hom Nil rice are rice species that contain a black pigment. Research has found that black rice has important nutritional components and biologically active substances, including essential amino acids, functional lipids, vitamins, dietary fibres, minerals, phenolic compounds, flavonoids, and anthocyanins. It also has the potential to be developed into a health food product to further benefit the health of consumers (Ti *et al*., 2015; Ito and Lacerda, 2019; Zhong *et al*., 2023). It can reduce the risk of developing chronic diseases such as obesity, cardiovascular diseases, and certain types of cancer (Mattei *et al*., 2015; Shao and Bao, 2015; Ti *et al*., 2015; Pratiwi and Purwestri, 2017). These bioactive compounds have the potential to exhibit antioxidant properties, and may help in diminishing the levels of harmful reactive free radicals that can cause cellular damage (Sadh *et al*., 2017; Wiriyawattana *et al*., 2018; Sarak *et al*., 2024). Nowadays, Riceberry rice and Hom Nil rice are used to produce flour as an ingredient to be used in food such as Thai desserts or bakery products. Furthermore, in past research, Riceberry flour and Hom Nil rice flour have been used in the development of many different food products, such as yogurt (Anuyahong *et al*., 2020), noodles (Sirichokworrakit *et al*., 2015), breads (Wongklom *et al*., 2016; Thiranusornkij *et al*., 2018; 2019), and chiffon cakes (Mau *et al*., 2017). Therefore, pigmented rice has become a healthy choice for health-conscious consumers, thus influencing their purchasing decisions (Kraithong *et al*., 2018). As consumer health awareness increases, novel processed foods incorporating pigmented rice must contain bioactive compounds to meet the demands of health-conscious consumers (Ti *et al*., 2015; Thanuja and Parimalavalli, 2022).

For these reasons, the present work aimed at using pigmented Thai rice, namely, Riceberry rice and Hom Nil rice, to produce flour, and using it as an ingredient in a Thai dessert, namely KPP. This application would be innovative, as the present work is the first to incorporate Thai pigmented rice flour into KPP, which traditionally uses only white rice flour. The modification is particularly important as it enhances the nutritional value of traditional Thai desserts while preserving cultural heritage, and supporting local rice farmers. Replacing white rice flour with Riceberry and Hom Nil rice flours could improve the nutritional quality and health-promoting properties of KPP, as indicated by previous studies on rice-based products (Sirichokworrakit *et al*., 2015; Thiranusornkij *et al*., 2018; 2019). This is to provide a healthy choice for consumers since the original KPP has only rice flour which is made from white rice (non-pigmented rice) as the main ingredient. This is in line with research that has shown that pigmented rice has more antioxidant activity than non-pigmented rice (Shao *et al*., 2018). The knowledge gained from the present work would enable the development of KPP to be more prominent, promote the beneficial use of Thai pigmented rice, and encourage Thai farmers to produce pigmented rice. In addition, it is a continuation and extension of the knowledge in making KPP along with Thai dessert culture. The present work ultimately aimed to investigate the optimal amounts of Riceberry rice flour and Hom Nil rice flour as substitutes for rice flour in KPP, while also evaluating the physicochemical properties, nutritional value, and consumer acceptance of the final product.

Materials and methods

Preparation of Riceberry rice flour and Hom Nil rice flour

The preparation of RBF and HNF, as shown in Figure 1, was adapted from the method of Khumkhom (2020). Impurities such as rice husks were separated from the Riceberry rice and Hom Nil rice, then the Riceberry rice and Hom Nil rice were put into trays, with each tray weighing 300 g. The trays were then put into tray dryers at 60°C for 4 h. After drying, the moisture content of both RBF and HNF was 7.50%. The trays were then removed from the heat, and both types of rice were allowed to cool down. The rice was then ground with a fine grinder at a speed of 25,000 rpm. When finished, it was sieved through a 100-mesh sieve. Both types of rice flour were stored in heat-sealed aluminium foil bags, and stored in a refrigerator at 4°C until further analyses.



(a)

(b)

Figure 1. (a) Riceberry rice flour (RBF) and **(b)** Hom Nil rice flour (HNF) from rice that has been baked and ground extremely fine.

Formulation and production of kanom piak poon

Table 1 presents nine formulas for KPP: control (100% rice flour), RBF25, RBF50, RBF75, and RBF100 (25, 50, 75, and 100% RBF replacing rice flour, respectively), and HNF25, HNF50, HNF75, and HNF100 (25, 50, 75, and 100% HNF replacing rice flour, respectively).

The production process began by weighing the ingredients based on Table 1, and mixing all types of flour. The mixture was then kneaded together with palm sugar and water, which was added gradually. The dough was kneaded for 15 min while simultaneously incorporating the remaining water and clear lime water until fully dissolved. The mixture was then strained once and transferred to a brass pan for stirring. The mixture was repeatedly lifted over high heat, and stirred with a spatula until it thickened. Pandan juice was then added, and stirring continued over low-medium heat until the mixture thickened further, and no longer stuck to the producer's hands. The mixture was stirred for an additional 45 min before being removed from the heat. The dessert was poured into a tray, allowed to cool, and then cut into square pieces. The experiment was designed such that each type of product was replicated three times.

Table 1. Formulations of *kanom piak poon* (KPP) from Riceberry rice flour and Hom Nil rice flour.

Ingredient (g)	Control	RBF25	HNF25	RBF50	HNF50	RBF75	HNF75	RBF100	HNF100
Rice flour	165	123.75	123.75	82.5	82.5	41.25	41.25	-	-
Riceberry rice flour	-	41.25	-	82.5	-	123.75	-	165	-
Hom Nil rice flour	-	-	41.25	-	82.5	-	123.75	-	165
Arrowroot flour	25	25	25	25	25	25	25	25	25
Tapioca starch	20	20	20	20	20	20	20	20	20
Palm sugar	200	200	200	200	200	200	200	200	200
Pandan juice	254	254	254	254	254	254	254	254	254
Clear lime water	910	910	910	910	910	910	910	910	910
Water	235	235	235	235	235	235	235	235	235

Control formula was modified from Chumkaew (2020). Control: *kanom piak poon* (KPP) with 100% rice flour; RBF25, RBF50, RBF75, and RBF100: KPP with 25, 50, 75, and 100% Riceberry rice flour, respectively; HNF25, HNF50, HNF75, and HNF100: KPP with 25, 50, 75, and 100% Hom Nil rice flour, respectively.

Sensory evaluation

A sensory evaluation experiment was designed to assess KPP prepared with two Thai pigmented rice flour varieties, RBF and HNF, as replacements for rice flour in varying proportions (w/w). Two sensory evaluation sessions were conducted. The first sensory evaluation session was conducted over two separate testing days using the same panel. To avoid sensory fatigue and maintain the validity of the evaluation, the samples were divided into two groups: group 1 consisted of control and RBF formulations (RBF25, RBF50, RBF75, and RBF100) tested on the first day, and group 2 consisted of control and HNF formulations (HNF25, HNF50, HNF75, and

HNF100) tested on the second day, meaning that five samples were tested per day. This approach ensured that the panellists could properly evaluate all sensory properties without experiencing fatigue or sensory overload. Sensory evaluation was performed using a questionnaire based on a 9-point hedonic scale: 1 (dislike extremely), 2 (dislike very much), 3 (dislike moderately), 4 (dislike slightly), 5 (neither like nor dislike), 6 (like slightly), 7 (like moderately), 8 (like very much), and 9 (like extremely) (Rune *et al*., 2022; Zulu *et al*., 2023). A panel of 50 untrained panellists, consisting of food and nutrition students, evaluated the samples for appearance, colour, smell, taste, texture, and overall acceptability. A randomised complete block design (RCBD) was employed to select the formula with the highest acceptance for further nutritional analysis in the subsequent stage of the research (Songpranam *et al*., 2022). Before conducting the sensory evaluation, the panellists were given an informed consent form to be completed, and explained with the research objectives (Pasqualone *et al*., 2020; Olaimat *et al*., 2023).

Colour analysis

Colour analysis was performed using a Minolta CR-300 colorimeter (Minolta Co., Ltd., Osaka, Japan) based on the CIE L* a* b* colour space. The L* value represents lightness, ranging from 0 (black) to 100 (white). The a* value represents the red-green colour component, with positive values representing red, and negative values representing green. The b* value represents the yellow-blue colour component, with positive values representing yellow, and negative values representing blue (Hamzah *et al*., 2021; Liu *et al*., 2024). The colour values were measured to compare and identify differences among the control sample (100% rice flour) and the samples containing various levels of RBF and HNF. Three replicated measurements were conducted for each sample.

Texture analysis

Texture profile analysis (TPA) was conducted using a TA.XTplus Texture Analyser (Stable Micro Systems, Surrey, UK) to evaluate hardness, springiness, and cohesiveness. These texture properties were selected because hardness indicates product's firmness, springiness indicates product's chewy texture, and cohesiveness indicates product's structural integrity when cut and served. Samples were cut into 30-g square pieces, and analysed using a P36R cylindrical probe with a 36-mm diameter. The probe applied pressure to the sample in a double-cycle program, compressing the sample to 50% of its original height at a rate of 1 mm/s. The initial compression was followed by a second compression 15 s later (Chumkaew and Punfujinda, 2019). TPA was performed to compare the textural differences among the control sample (100% rice flour) and the samples containing various levels of RBF and HNF. Three replicated measurements were conducted for each sample.

Nutritional value

The proximate and antioxidant properties of the three KPP samples, namely the control (100% rice flour) and the samples prepared with RBF and HNF that received the highest sensory acceptance scores, were analysed to compare their nutritional values. Nutritional values per 100 g, including fat, carbohydrate, protein, dietary fibre, moisture, and ash, were determined following the AOAC method (AOAC, 2019).

For the determination of total phenolic content (TPC) and total flavonoid content (TFC), sample extraction was conducted over a 2-d period. Powdered samples weighing approximately 100 g each were extracted using 200 mL of methanol (2:1 ratio). The extraction solutions were centrifuged at 6,000 rpm for 15 min, and the resulting supernatants were filtered through a 0.45 µm syringe filter prior to the quantification of bioactive compounds. The methods described by Archanachai *et al*. (2021) were modified and employed for the determination of TPC and TFC. To measure TPC, 100 µL of each sample solution was combined with 100 µL of methanol and 200 µL of 10% (v/v) Folin-Ciocalteu reagent, then shaken for 5 min. Subsequently, 600 µL of 1 M sodium carbonate was added to the mixture. The reaction mixture was incubated in the dark at room temperature for 60 min, and the final product was analysed using a spectrophotometer at 760 nm. TPC was quantified using a calibration curve of gallic acid (micrograms of gallic acid equivalent per gram of dry weight). For TFC determination, 500 µL of each sample solution was mixed with 340 µL of deionised water and 30 µL of sodium acetate (1 M), then incubated for 5 min. The reaction solution was then combined with 30 µL of $AlCl_3$ (1 M) and shaken for 5 min. Next, 200 µL of NaOH (1 M) was added, and the mixture was incubated for 15 min at 30°C. Finally, the absorbance of the final product was measured at 415 nm using a spectrophotometer. TFC was quantified using a calibration curve of quercetin (micrograms of quercetin equivalent per gram of dry weight).

For the antioxidant assay, sample extraction was performed over a 2-d period using 200 mL of methanol to extract powdered samples weighing approximately 100 g each (2:1 ratio). The extraction solutions were centrifuged at 6,000 rpm for 15 min, and the supernatants were filtered through a 0.45 µm syringe filter. The solvent solutions were evaporated in a hot air oven at 50°C to obtain crude extracts, which were stored at -20°C until further use. The methods of Archanachai *et al.* (2021) were adapted for the determination of antioxidant capacity using DPPH and ABTS assays. Crude samples (approximately 1 g each) were dissolved in 1 mL of DMSO (10% (v/v)) to obtain solutions with a concentration of 1 mg/mL. For the DPPH assay, 50 µL of each sample solution was mixed with 50 µL of DPPH solution (0.1 mM), resulting in a final concentration of 0.5 mg/mL. The reaction mixtures were stored in the dark at room temperature for 30 min, and radical inhibition absorbance was measured at 517 nm using a UV/Vis spectrophotometer. The percentage of inhibition was calculated using [(Ablank - Asample) / Ablank] × 100, where Ablank = absorbance of blank, and Asample = absorbance of sample. For the ABTS assay, $ABTS^{+}$ cation solution was prepared by mixing ABTS (7 mM) and potassium persulphate (2.45 mM) in a 1:0.5 (v/v) ratio. Next, 50 µL aliquot of each sample was mixed with 50 µL of $ABTS^{+}$ solution to a final concentration of 0.5 mg/mL. The mixed solution was allowed to stand for 30 min at room temperature, and the inhibition potential was measured at 734 nm. The inhibition percentage was calculated using a similar method to the DPPH assay.

Consumer acceptance

Consumer acceptance of the final KPP products prepared with RBF and HNF that received the highest sensory acceptance scores was investigated. The consumer acceptance study was carried out with 100 participants, selected using accidental sampling, and consisted of two parts. First, a sensory test of the final products was performed using a questionnaire based on a 9-point hedonic scale: 1 (dislike extremely), 2 (dislike very much), 3 (dislike moderately), 4 (dislike slightly), 5 (neither like nor dislike), 6 (like slightly), 7 (like moderately), 8 (like very much), and 9 (like extremely). Participants then evaluated the appearance, colour, smell, taste, texture, and overall acceptability of the products (Rune *et al*., 2022; Olatoye *et al*., 2023; Zulu *et al*., 2023). The interpretation of the score levels was as follows: fair (2, 3, 4), good (5, 6), and very good (7, 8) (Kohli *et al*., 2023). Second, consumer attitudes toward KPP were assessed using five statements, with respondents allowed to choose more than one statement that they agreed with. Before conducting the sensory evaluation, the participants were given an informed consent form to be completed, and explained with the research objectives (Pasqualone *et al*., 2020; Olaimat *et al*., 2023).

Statistical analysis

The data obtained from the experiment were analysed by ANOVA. Results were expressed as mean ± standard deviation. The means were compared using Duncan's new multiple range test (DNMRT) at a confidence level of 95%. Consumer acceptance in the final-product tasting test was analysed using mean values, and consumer attitudes toward KPP were analysed using frequency values and percentage values with SPSS Version 22.

Results and discussion

Sensory evaluation

In the analysis of the sensory evaluation results (Table 2), when comparing the means between the control, RBF25, RBF50, RBF75, and RBF100, and comparing the means between the control, HNF25, HNF50, HNF75, and HNF100, it was found that HNF25 and RBF25 KPP received the highest acceptance scores in all characteristics, including appearance, colour, smell, taste, texture, and overall acceptability, with a significant difference ($p \leq 0.05$). The acceptance scores of RBF25 and HNF25 KPP were higher than the control formula. From Figure 2, it can be seen that the RBF25 and HNF25 KPP have good KPP characteristics. When cut into pieces, they maintained their structural integrity, with clean-cut edges and a uniform shape, indicating appropriate texture characteristics. This was consistent with Sirichokworrakit *et al*. (2015), who substituted of wheat flour with RBF in noodle products at ratios of 0, 10, 20, 30, and 40%, and showed that when substituting wheat flour with RBF in an increased

Table 2. Results of sensory evaluation of *kanom piak poon* (KPP) with rice flour substituted with Riceberry rice flour and Hom Nil rice flour in different ratios.

Parameter	Control	RBF25	RBF50	RBF75	RBF100
Appearance	6.56 ± 1.16[b]	7.94 ± 1.23[a]	6.54 ± 1.38[b]	3.52 ± 1.11[c]	2.54 ± 1.01[d]
Colour	6.56 ± 1.16[b]	8.00 ± 0.90[a]	6.92 ± 1.22[b]	3.14 ± 1.24[c]	3.20 ± 1.01[c]
Smell	6.86 ± 1.29[b]	8.04 ± 0.88[a]	7.52 ± 1.01[a]	3.50 ± 1.29[c]	3.16 ± 1.26[c]
Taste	6.28 ± 1.19[b]	7.92 ± 0.90[a]	6.06 ± 1.33[b]	3.90 ± 1.31[c]	2.88 ± 1.18[d]
Texture	7.60 ± 1.14[a]	7.92 ± 0.94[a]	5.64 ± 0.87[b]	3.50 ± 1.35[c]	2.72 ± 1.12[d]
Overall acceptability	6.70 ± 1.23[b]	7.52 ± 0.93[a]	5.44 ± 0.83[c]	2.50 ± 1.03[d]	2.50 ± 1.01[d]
Parameter	**Control**	**HNF25**	**HNF50**	**HNF75**	**HNF100**
Appearance	6.52 ± 1.24[b]	8.00 ± 0.90[a]	6.56 ± 1.16[b]	6.92 ± 1.22[b]	2.44 ± 1.18[c]
Colour	6.50 ± 1.29[b]	8.04 ± 0.88[a]	7.52 ± 1.01[a]	6.86 ± 1.29[b]	3.16 ± 1.26[c]
Smell	6.67 ± 1.31[b]	7.92 ± 0.90[a]	6.28 ± 1.19[b]	6.16 ± 1.33[b]	2.88 ± 1.18[c]
Taste	6.42 ± 1.26[b]	7.96 ± 0.90[a]	6.28 ± 1.19[b]	6.24 ± 1.32[b]	2.88 ± 1.18[c]
Texture	6.90 ± 1.35[b]	7.84 ± 0.94[a]	7.60 ± 1.14[a]	5.64 ± 0.87[c]	2.72 ± 1.12[d]
Overall acceptability	6.56 ± 1.03[b]	7.52 ± 0.93[a]	6.70 ± 1.23[b]	5.44 ± 0.83[c]	2.50 ± 1.01[d]

Values are means ± standard deviations. Means with different lowercase superscripts within similar row are significantly different ($p \leq 0.05$). Control: KPP with 100% rice flour; RBF25, RBF50, RBF75, and RBF100: KPP with 25, 50, 75, and 100% Riceberry rice flour, respectively; HNF25, HNF50, HNF75, and HNF100: KPP with 25, 50, 75, and 100% Hom Nil rice flour, respectively.

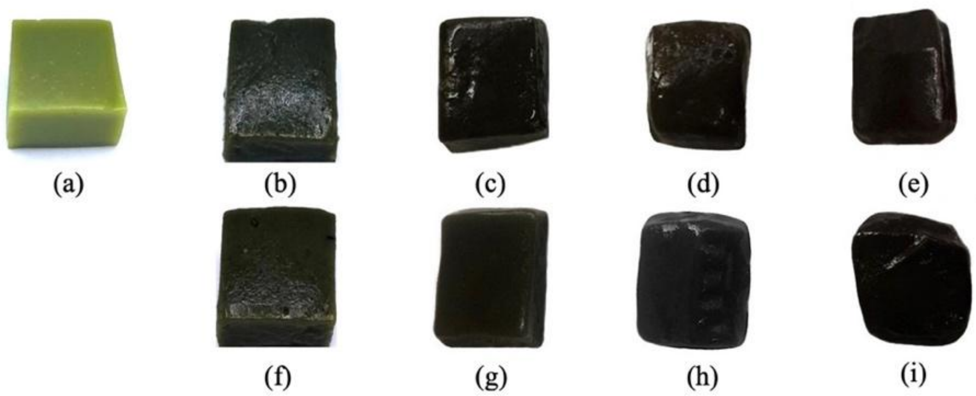


Figure 2. *Kanom piak poon* (KPP): **(a)** Control (100% rice flour); **(b) - (e)** with 25, 50, 75, and 100% Riceberry rice flour, respectively; and **(f) - (i)** with 25, 50, 75, and 100% Hom Nil rice flour, respectively.

ratio, it resulted in a statistically significant reduction in the overall sensory evaluation acceptance score ($p \leq 0.05$). Furthermore, black rice substitution was studied in chiffon cake products at ratios of 10, 20, 30, 40, 50, 60, 70, 80, 90, and 100 (w/w), and it was found that in terms of overall preference, panellists gave a lower preference rating when the amount of black rice was increased to a higher ratio (Mau *et al.*, 2017). The decreasing trend in acceptance levels with increasing RBF and HNF content can be attributed to changes in several sensory properties. For appearance and colour, the higher amounts of RBF and HNF resulted in darker products due to their natural pigments (Thiranusornkij *et al.*, 2018; Chokchaithanawiwat *et al.*, 2019; Settapramote *et al.*, 2021b), which deviated from the traditional appearance of KPP. Regarding smell and taste, the distinctive aroma and flavour of pigmented rice became more pronounced at higher concentrations, affecting the balance of traditional taste characteristics. The texture acceptance decreased as higher levels of RBF and HNF were incorporated, possibly due to their higher fibre content (Ito and Lacerda, 2019; Das *et al.*, 2023) affecting the product's structure, and resulting in a coarser texture compared to traditional KPP. Based on these results, RBF25 and HNF25 were selected for further nutritional analysis and comparison with the control.

Colour analysis

The results of the colour value analysis, as shown in Table 3, illustrate that the control formula, KPP without substituting with RBF and HNF in the formula, had the highest L* and b* values. When comparing to the control, RBF25, RBF50, RBF75, and RBF100, and comparing to the control, HNF25, HNF50, HNF75, and HNF100, it was found that when adding RBF and HNF in increased ratios, the L* and b* colour values decreased. It was observed that the colour of the KPP became darker when increasing the amounts of RBF and HNF, as shown in Figure 2. Therefore, when replacing rice flour with RBF and HNF in increasing amounts from 0% (Control) to 100% (RBF100), the L* and b* values decreased with statistical significance ($p \leq 0.05$) from 32.72 ± 0.07 to 16.47 ± 0.01 and from 25.35 ± 0.01 to 13.48 ± 0.01, respectively, while in increasing amounts from 0% (Control) to 100% (HNF100), the L* and b* values decreased from 32.72 ± 0.07 to 5.12 ± 0.02 and from 25.35 ± 0.01 to 3.32 ± 0.03, respectively. This was consistent with and in the same direction as the results of Khumkhom (2020), who reported that steamed bun products with increasing quantities of RBF that replaced wheat flour resulted in decreased L* and b* colour values with statistical significance ($p \leq 0.05$). Furthermore, this finding was consistent with the results reported by Mau *et al*. (2017), who indicated that an increase in the quantity of black rice resulted in a statistically significant decrease ($p \leq 0.05$) in the L* and b* values of the sample of baked black rice chiffon cakes as a consequence of variations in the pigmentation of the cake's black rice and the oxidation of polyphenolic compounds, which could potentially account for its hue. These findings were also consistent with previous research that reported a significant decrease in L* and b* values of cakes when wheat flour was replaced with increasing proportions of black glutinous rice flour (Itthivadhanapong and Sangnark, 2016). In addition, both RBF and HNF contain high amounts of anthocyanins, which are pigments responsible for purple, red, and blue colours. These pigments are found in the seed coat of pigmented rice varieties. Both RBF and HNF exhibit purple-black coloration, characteristic of Thai pigmented rice varieties (Shao *et al*., 2018; Thiranusornkij *et al*., 2018; Melini *et al*., 2019; Ratseewo *et al*., 2019; Settapramote *et al*., 2021b). According to previous studies, the pigmentation of coloured rice is attributed to the presence of anthocyanins and proanthocyanidins in the aleurone layer of the rice grain. The specific type and concentration of these pigment compounds determine the colour of the rice, which can range from black to purple to red (Min *et al*., 2011; Pereira-Caro *et al*., 2013; Thitipramote *et al*., 2016). The a* value represents the red-green colour. When RBF and HNF were added in increased ratios, statistically significant increases in a* ($p \leq 0.05$) were observed, respectively. This indicated that the addition of more RBF and HNF to KPP also increased the redness.

Table 3. Colour properties of *kanom piak poon* (KPP) rice flour substituted with Riceberry rice flour and Hom Nil rice flour in different ratios.

Parameter	Control	RBF25	RBF50	RBF75	RBF100
L*	32.72 ± 0.07[a]	25.91 ± 0.03[b]	19.59 ± 0.05[c]	18.82 ± 0.01[d]	16.47 ± 0.01[e]
a*	0.52 ± 0.04[e]	0.69 ± 0.03[d]	1.37 ± 0.03[c]	1.65 ± 0.01[b]	2.49 ± 0.01[a]
b*	25.35 ± 0.01[a]	20.98 ± 0.08[b]	17.82 ± 0.06[c]	15.02 ± 0.11[d]	13.48 ± 0.01[e]
Parameter	**Control**	**HNF25**	**HNF50**	**HNF75**	**HNF100**
L*	32.72 ± 0.07[a]	19.32 ± 0.01[b]	12.50 ± 0.01[c]	7.90 ± 0.05[d]	5.12 ± 0.02[e]
a*	0.52 ± 0.04[d]	0.73 ± 0.01[c]	1.96 ± 0.02[b]	2.81 ± 0.01[a]	2.84 ± 0.02[a]
b*	25.35 ± 0.01[a]	11.11 ± 0.01[b]	7.20 ± 0.06[c]	4.30 ± 0.03[d]	3.32 ± 0.03[e]

Values are means ± standard deviations. Means with different lowercase superscripts within similar row are significantly different ($p \leq 0.05$). Control: KPP with 100% rice flour; RBF25, RBF50, RBF75, and RBF100: KPP with 25, 50, 75, and 100% Riceberry rice flour, respectively; HNF25, HNF50, HNF75, and HNF100: KPP with 25, 50, 75, and 100% Hom Nil rice flour, respectively.

Texture analysis

Texture is a very important factor used to indicate the quality of KPP. The results showing the effects of the RBF and HNF substitutions of rice flour on the texture quality of KPP are shown in Figure 3. It was found that substituting rice flour with RBF and HNF in KPP had an effect on hardness and springiness. When replacing rice flour with RBF in increasing amounts from 0% (Control) to 25% (RBF25), 50% (RBF50), 75% (RBF75), and 100% (RBF100), the hardness value ranged from 0.026 ± 0.01 to 0.186 ± 0.06 N, and the springiness value ranged from 4.978 ± 0.63 to 7.161 ± 0.72 mm. Similarly, when replacing rice flour with HNF in increasing amounts from 0% (Control) to 25% (HNF25), 50% (HNF50), 75% (HNF75), and 100% (HNF100), the hardness value ranged from 0.039 ± 0.01 to 0.186 ± 0.06 N, and the springiness value ranged from 6.067 ± 0.20 to 7.161 ± 0.72 mm. These results showed that the hardness and springiness values of the KPP had a significant decreasing trend ($p \leq 0.05$) when increasing the amount of RBF and HNF. However, the control KPP had the highest hardness (0.186 ± 0.06) and springiness values (7.161 ± 0.72). Since native rice flour contains higher amylose content compared to RBF and HNF, when the flour cools down, the amylose molecules tend to reassociate and precipitate more extensively, leading to a process called retrogradation. This explains why the control sample with higher amylose content showed greater hardness compared to samples containing RBF and HNF (Ratanaponat, 2006; Belitz and Grosch, 2013; Fennema *et al*., 2017). In addition, Tao *et al*. (2019) reported that products made from rice with high amylose content had a hard texture after cooking. However, when the ratios of RBF and HNF were increased while the amount of rice flour was decreased, the KPP texture had lower hardness and springiness values. According to Kraithong *et al*. (2018) and Thiranusornkij *et al*. (2018), RBF and

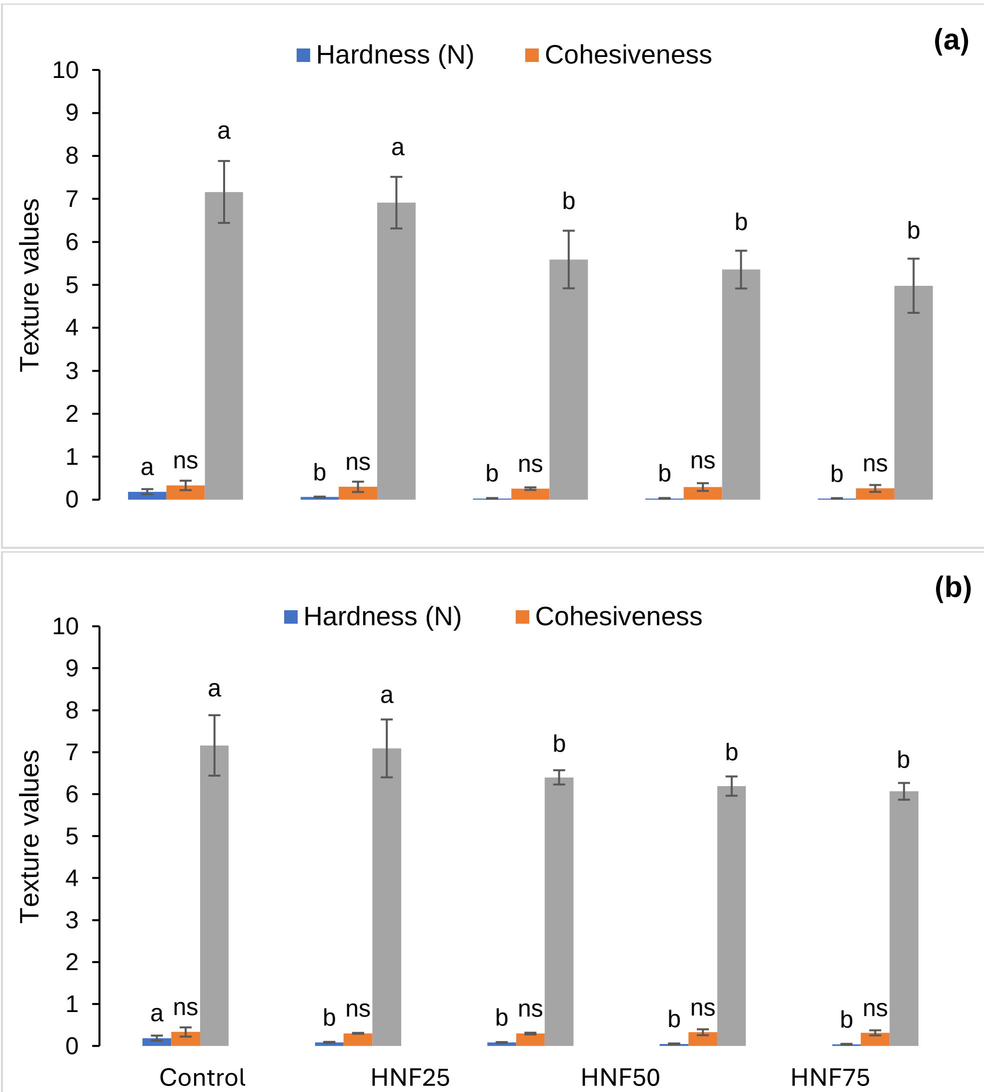


Figure 3. Texture profile analysis of *kanom piak poon* (KPP): **(a)** Control (100% rice flour) and with 25, 50, 75, and 100% Riceberry rice flour; and **(b)** Control (100% rice flour) and with 25, 50, 75, and 100% Hom Nil rice flour. Different lowercase letters within similar parameter indicate significant differences at ($p \leq 0.05$); ns: non-significant difference ($p > 0.05$).

HNF contain lower amylose content (16 - 18%) compared to white rice flour (25 - 30%). Additionally, these pigmented rice varieties have higher dietary fibre content (RBF: 4.2%, HNF: 3.3%) compared to white rice (0.2%) (Bureau of Nutrition, 2018). These compositional differences significantly affect water binding capacity and gel formation. Rice flour with higher amylose content forms stronger and more viscous gels upon cooling due to extensive retrogradation, resulting in higher hardness values (Ratanaponat, 2006; Fennema *et al*., 2017). Furthermore, the presence of dietary fibre in RBF and HNF interferes with gel network formation, leading to reduced hardness and springiness in the final product (Das *et al*., 2023). This explains why the control sample, with its higher amylose content, exhibited higher hardness and springiness values compared to samples containing RBF and HNF. As a result, the cohesiveness values of all KPP samples were not significantly different ($p > 0.05$). This can be explained by the similar gelatinisation behaviour of the starch granules in all formulations. According to Belitz and Grosch (2013), cohesiveness is primarily influenced by the degree of starch gelatinisation and the formation of a continuous gel network. While the three types of flour differed in their amylose content and fibre composition, they all contained similar proportions of total starch (approximately 70 - 75%). Additionally, the presence of palm sugar and clear lime water in equal amounts across all formulations helped maintain consistent gel network formation through sugar-starch interactions and calcium-mediated cross-linking (Fennema *et al*., 2017). These factors contributed to the comparable cohesiveness values observed across all samples, despite differences in other textural properties.

Nutritional value

The comparison of the nutritional values (proximate) of KPP Control, RBF25, and HNF25 is shown in Table 4. HNF25 had the highest fat content (15.77 ± 0.55%), significantly higher than RBF25 (14.05 ± 0.45%) and the control (13.39 ± 0.32%) ($p \leq 0.05$). Conversely, the control had the highest carbohydrate content (13.77 ± 0.52%) compared to RBF25 (10.21 ± 0.20%) and HNF25 (8.33 ± 0.24%) ($p \leq 0.05$). This finding was consistent with the Food Composition Table of Thai Foods, which indicates that 100 g of raw rice has more carbohydrates than raw Riceberry rice and raw Hom Nil rice, with quantities equal to 79.90, 68.59, and 71.79, respectively (Bureau of Nutrition, 2018). The control had the highest protein content (0.60 ± 0.02%), followed by HNF25 (0.43 ± 0.03%) and RBF25 (0.08 ± 0.01%) ($p \leq 0.05$). This result agreed with Ratseewo *et al*. (2019), who reported that as the amount of RBF increased, the protein content decreased accordingly. In contrast, HNF25 had the highest dietary fibre content (10.00 ± 0.14%) compared to RBF25 (9.22 ± 0.18%) and the control (2.25 ± 0.13%) ($p \leq 0.05$). This might have been due to the higher dietary fibre content in RBF and HNF compared to rice flour,

Table 4. Nutritional value analysis results.

Nutrient	Control	RBF25	HNF25
Fat (%)	13.39 ± 0.32^{b}	14.05 ± 0.45^{b}	15.77 ± 0.55^{a}
Carbohydrate (%)	13.77 ± 0.52^{a}	10.21 ± 0.20^{b}	8.33 ± 0.24^{c}
Protein (%)	0.60 ± 0.02^{a}	0.08 ± 0.01^{c}	0.43 ± 0.03^{b}
Dietary fibre (%)	2.25 ± 0.13^{c}	9.22 ± 0.18^{b}	10.00 ± 0.14^{a}
Moisture (%)	69.17 ± 0.39^{a}	65.45 ± 0.59^{b}	64.39 ± 0.64^{b}
Ash (%)	0.81 ± 0.06^{b}	0.98 ± 0.05^{a}	1.07 ± 0.03^{a}
TPC (μg GAE/g dw)	21.78 ± 0.73^{c}	88.56 ± 0.57^{b}	95.24 ± 1.05^{a}
TFC (μg QE/g dw)	10.93 ± 0.82^{c}	65.12 ± 0.65^{b}	68.35 ± 0.69^{a}
DPPH (% inhibition at 0.5 mg/mL)	24.09 ± 0.76^{c}	54.46 ± 0.59^{b}	57.23 ± 0.67^{a}
ABTS (% inhibition at 0.5 mg/mL)	26.44 ± 0.99^{c}	92.71 ± 0.70^{b}	98.04 ± 0.73^{a}

Values are means ± standard deviations. Means with different lowercase superscripts within similar row are significantly different ($p \leq 0.05$). Control: KPP with 100% rice flour; RBF25, RBF50, RBF75, and RBF100: KPP with 25, 50, 75, and 100% Riceberry rice flour, respectively; HNF25, HNF50, HNF75, and HNF100: KPP with 25, 50, 75, and 100% Hom Nil rice flour, respectively. TPC: total phenolic content (μg gallic acid equivalent/g dry weight); TFC: total flavonoid content (μg quercetin equivalent/g dry weight); DPPH and ABTS assays: % inhibition at 0.5 mg/mL.

which was consistent with the Bureau of Nutrition (2018), stating that 100 g of raw Riceberry rice, Hom Nil rice, and raw rice contain 4.2, 3.3, and 0.2 g of dietary fibre, respectively. This finding agreed with Sirichokworrakit *et al*. (2015), who found that noodle products made from RBF at ratios of 0, 10, 20, 30, and 40% had a significant increase in dietary fibre content with increasing RBF ($p \leq 0.05$). It also corroborated the findings of Rodmui (2010), who reported a significant increase in dietary fibre content when increasing the amount of HNF in the development of wide noodle products by substituting rice flour with HNF ($p \leq 0.05$). The control had the highest moisture content (69.17 ± 0.39%), significantly higher than RBF25 (65.45 ± 0.59%) and HNF25 (64.39 ± 0.64%) ($p \leq 0.05$). HNF25 (1.07 ± 0.03%) and RBF25 (0.98 ± 0.05%) had significantly higher ash content than the control (0.81 ± 0.06%) ($p \leq 0.05$).

The nutritional value analysis results of the KPP samples are presented in Table 4. TPC of HNF25 (95.24 ± 1.05 µg GAE/g dw) was significantly higher ($p \leq 0.05$) than that of RBF25 (88.56 ± 0.57 µg GAE/g dw) and the control (21.78 ± 0.73 µg GAE/g dw). Similarly, TFC of HNF25 (68.35 ± 0.69 µg QE/g dw) was significantly higher ($p \leq 0.05$) than that of RBF25 (65.12 ± 0.65 µg QE/g dw) and the control (10.93 ± 0.82 µg QE/g dw). This demonstrated that the incorporation of HNF and RBF into KPP significantly increased the TPC and TFC. HNF exhibited the best results, followed by RBF. On the other hand, the control without the addition of pigmented rice flours had the lowest amount of antioxidant compounds. The high content of TPC and TFC, which are bioactive compounds, in pigmented rice such as Hom Nil rice and Riceberry rice, might have contributed to these results (Thitipramote *et al*., 2016). Furthermore, these rice varieties also contain a significant amount of anthocyanins (Sivamaruthi *et al*., 2018), a subclass of flavonoids, and the most significant water-soluble pigments responsible for the diverse colours found in various plant tissues (Cortez *et al*., 2017; Sivamaruthi *et al*., 2018). This agreed with a previous study that reported significantly higher TPC in HNF compared to Hom Mali 105 rice flour, a white rice cultivar (Thiranusornkij *et al*., 2018). Additionally, recent research has shown that RBF contained higher levels of TPC and TFC than regular white rice flour, and can be used as a substitute in noodle products to enhance their nutritional value (Thongkaew and Singthong, 2020). These results also agreed with earlier studies that have reported higher levels of TPC and TFC in fermented black glutinous rice compared to various white glutinous rice cultivars (Li *et al*., 2020). The experimental results demonstrated that Thai pigmented rice had more effective bioactive compounds than non-pigmented rice (Waewkum and Singthong, 2021).

The antioxidant activities of the KPP samples were evaluated using DPPH and ABTS assays. The DPPH inhibition percentage at 0.5 mg/mL was significantly higher ($p \leq 0.05$) in HNF25 (57.23 ± 0.67%) compared to RBF25 (54.46 ± 0.59%) and the control (24.09 ± 0.76%). Similarly, the ABTS inhibition percentage at 0.5 mg/mL was significantly higher ($p \leq 0.05$) in HNF25 (98.04 ± 0.73%) compared to RBF25 (92.71 ± 0.70%) and the control (26.44 ± 0.99%). The higher antioxidant activity observed in HNF25 and RBF25 compared to the control could have been due to the presence of bioactive compounds, such as phenolics and flavonoids, in the pigmented rice flours. These results agreed with previous studies that reported a positive correlation between the content of bioactive compounds and the antioxidant activity in pigmented rice (Shen *et al*., 2009; Goufo and Trindade, 2014; Thitipramote *et al*., 2016). These results also agreed with reports suggesting that increased antioxidant activity may be due to higher TPC (Sadh *et al*., 2017). The difference in antioxidant activity between HNF25 and RBF25 could have been due to the variations in the type and quantity of bioactive compounds present in these pigmented rice varieties. Hom Nil rice is known to contain a higher amount of anthocyanins, particularly cyanidin-3-glucoside and peonidin-3-glucoside, compared to Riceberry rice (Sivamaruthi *et al*., 2018). In conclusion, the incorporation of pigmented rice flours, particularly HNF, into KPP could significantly enhance its antioxidant activity. This finding highlighted the potential of using pigmented rice as a functional ingredient to develop healthier and more nutritious food products.

Consumer acceptance

In the sensory test of the final products of RBF25 and HNF25, as shown in Figure 4, it was

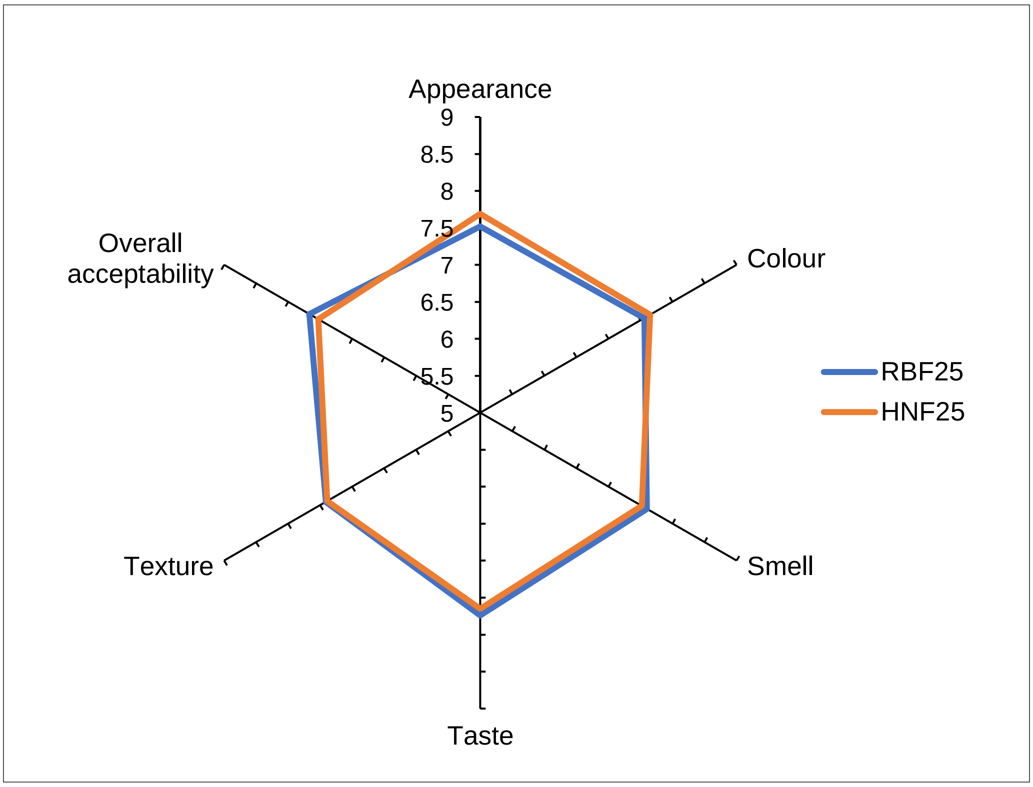


Figure 4. Sensory evaluation of final products: *kanom piak poon* (KPP) with 25% Riceberry rice flour (RBF25) and 25% Hom Nil rice flour (HNF25).

found that for both formulas, the panellists rated their liking at a high level for all characteristics, which were appearance, colour, smell, taste, texture, and overall acceptability. RBF25 had an average score of 7.41 - 7.74, while HNF25 had an average score of 7.39 - 7.69, which fell into the "very good" category, indicating a high level of consumer acceptance for these KPP formulations. The high sensory acceptance scores for RBF25 and HNF25 were consistent with the findings of previous studies that investigated the incorporation of pigmented rice flours in various food products. For example, Sirichokworrakit *et al*. (2015) reported that noodles containing up to 40% RBF received high sensory scores, while Mau *et al*. (2017) found that chiffon cakes with black rice flour substitution up to 20% were well-accepted by consumers. These results might have been due to the 25% substitution level of rice flour with RBF and HNF, which could be optimal in terms of maintaining the desirable sensory properties of KPP while enhancing its nutritional value. Moreover, the attractive purple colour imparted by the anthocyanins in these pigmented rice flours might have positively influenced the panellists' perception of the product's appearance and overall acceptability (Pratiwi and Purwestri, 2017).

From consumers' attitudes towards KPP, as shown in Figure 5, it was found that 100 consumers (95% of participants) expressed the attitude that the use of Thai rice as an ingredient in KPP was unique, which was the statement that consumers agreed with the most. However, it can be seen that while consumers agreed that the application of Thai rice in Thai desserts made them unique, KPP also preserved Thai knowledge on the art of making Thai desserts. Furthermore, consumers were also interested in new products emerging in the market from the application of Thai rice in new types of Thai desserts. They were also interested in the benefits of Thai desserts that affect the health of consumers, and felt that it also supported Thai rice farmers, both directly and indirectly. This was in line with past research on another type of Thai food, namely *som tam*, stating that it is recognised as the national food of Thailand, and has its uniqueness. It has a history, a culture, and benefits for the body in terms of promoting health. It contributes to Thailand's food security, and also creates economic value as a product that promotes the tourism industry in Thailand (Nugroho *et al*., 2023).

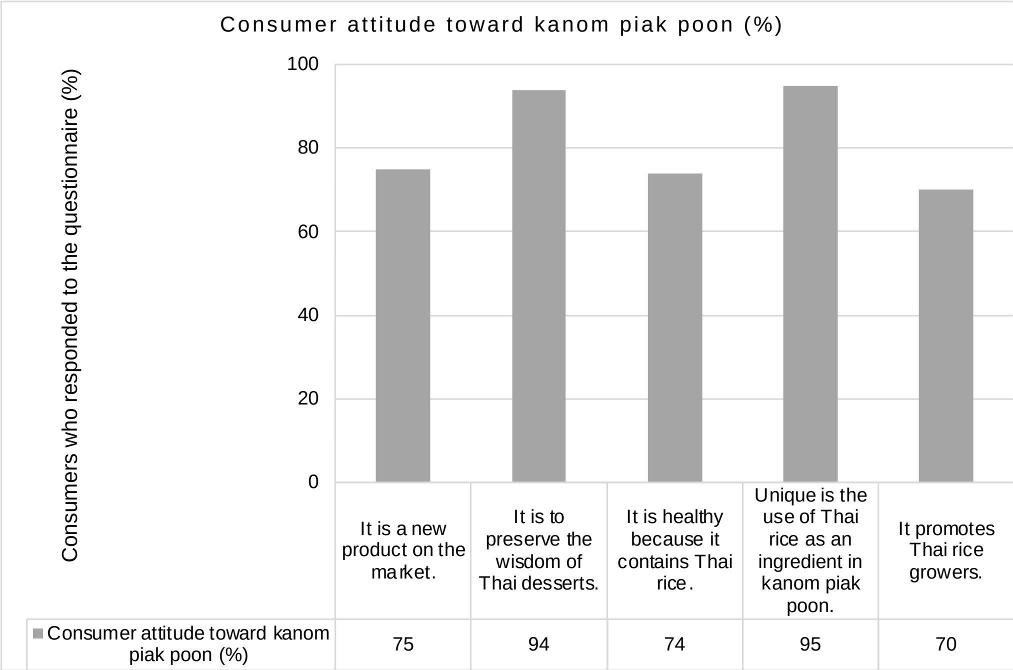


Figure 5. Consumer attitudes toward *kanom piak poon* (KPP).

Conclusion

The present work demonstrated that Riceberry rice flour (RBF) and Hom Nil rice flour (HNF), both derived from Thai pigmented rice varieties, could successfully replace up to 25% of rice flour in *kanom piak poon* (KPP), a traditional Thai dessert, while maintaining desirable characteristics and improving nutritional value. Incorporating 25% RBF (RBF25) and 25% HNF (HNF25) into KPP significantly increased the dietary fibre content, bioactive compounds, and antioxidant activity compared to the control formula. Consumer acceptance tests revealed high approval ratings for RBF25 and HNF25, with consumers expressing that the use of Thai rice varieties as ingredients in Thai desserts added uniqueness to KPP, and helped preserve the knowledge of Thai dessert making. Furthermore, the present work promoted the utilisation of Thai pigmented rice flour in the Thai dessert industry, supporting Thai rice farmers and the cultivation of these nutritious rice varieties. The findings of the present work highlighted the potential of RBF and HNF in enhancing the nutritional profile and consumer appeal of traditional Thai desserts, contributing to the development of healthier and culturally significant food products. Future research could explore the application of Thai pigmented rice flour in other Thai desserts and traditional foods, such as steamed layer cakes (*khanom chan*), rice ball cakes (*khanom khao tu*), rice balls in coconut milk (*khanom bua loi*), and stuffed dough balls in coconut milk (*khanom tom*). These desserts typically use rice flour as their main ingredient, and could benefit from the enhanced nutritional value of pigmented rice flour. Beyond traditional desserts, the application could be extended to modern Thai fusion desserts, bakery products, and rice-based snacks to create healthier alternatives that appeal to contemporary consumers while preserving traditional flavours. Additionally, investigating the impact of different processing methods on the retention of bioactive compounds and antioxidant activity in pigmented rice flour-based products would be valuable for optimising their nutritional benefits.

Acknowledgement

The present work was financially supported by the Faculty of Home Economics Technology, Rajamangala University of Technology Thanyaburi, Pathum Thani, Thailand (grant no.: 2641). The authors would like to thank the Department of Food and Nutrition, Faculty of Home Economics Technology, Rajamangala University of Technology Thanyaburi for providing the research facilities. Thanks to all panellists and consumers for tasting the product.

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