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CHANGES IN THE PHYSICAL, CHEMICAL AND SENSORY PROPERTIES OF PASTA MADE BY PARTIALLY SUBSTITUTING WHEAT FLOUR WITH BLACK GLUTINOUS RICE FLOUR

Subanmanee N[1], Sarasuk C[2]*, Wongtom R[2] and W Khampaen[1]

Natthaporn Subanmanee

*Corresponding author email: chanon.s@rmutk.ac.th
ORCID: https://orcid.org/0009-0006-5742-0411

[1]Division of Food and Nutrition, Faculty of Home Economics Technology, Rajamangala University of Technology Krungthep, Bangkok, Thailand

[2]Division of Food and Product Development, Faculty of Home Economics Technology, Rajamangala University of Technology Krungthep, Bangkok, Thailand

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ABSTRACT

Black glutinous rice flour (BGRF) had the potential to be used as a wheat substitute to increase the health-promoting nutritional value of pasta products. The purpose of this study was to investigate the possibility of using BGRF as an alternative to wheat flour in the production of pasta to improve its nutritional value. The research explored the physical, chemical, sensory properties, and consumer acceptance of pasta formulations with 0%, 20%, 40%, and 60% BGRF substitution. The findings revealed that pigmentation of BGRF contributed to increased phenolic compounds and antioxidant properties, which impacted physical and chemical properties of the pasta. The results indicated that a 40% substitution of BGRF was well-liked by consumers, while a 60% substitution led to decreased acceptance. The physical properties of uncooked pasta (UC-PAS) and cooked pasta (CK-PAS), such as moisture content and color values, were significantly influenced by the percentage of BGRF substitution. Specifically, the moisture content of UC-PAS decreased with higher BGRF substitution, resulting in changes in color values. These changes included an increase in redness, as well as a decrease in lightness and yellowness. Additionally, the pigmentation of BGRF contributed to increased phenolic compounds and antioxidant properties, which affected physical and chemical properties of the pasta. The pasta’s cooking quality, including cooking time (CKT), cooking loss (CKL), and cooking yield (CKY), also showed significant differences with varying percentages of BGRF substitution. Furthermore, the proximate composition indicated that the percentages of ash, protein, fat, and fiber increased as the proportion of BGRF increased, with pasta containing 60% BGRF demonstrating the highest values for these properties. All these findings provide evidence that BGRF substitution had a significant positive impact on the physical, chemical, and sensory properties of pasta. For example, the pasta had better antioxidant properties and was well-accepted by consumers. The potential for enhancing the nutritional profile of pasta products by substituting wheat flour with BGRF is noteworthy.

Key words: black glutinous rice, wheat, rice flour, pasta, antioxidant, bioactive compounds

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INTRODUCTION

Pasta is one of the staple foods worldwide, because it is simple to produce and cook. Pasta is made from wheat flour (semolina), eggs, water and salt. Therefore, it lacks some of the essential nutrients such as fiber and vitamins that are lost during wheat processing. Nowadays, consumers are becoming increasingly health-conscious and demanding more nutritious foods. As a result, global expansion of the market for pasta products around the world is demanding more nutritious pasta products. Even though the pasta may be rich in some nutrients such as carbohydrates and proteins, it lacks other health-promoting nutrients, such as fiber and antioxidants. In addition, pasta products are identified as “refined foods”, rendering them less nutritious [1]. For this reason, many researchers’ interests in enhancing the nutritional value of pasta products have increased [2]. However, no study has shown the potential of black glutinous rice (BGR), which is rich in health-promoting nutrients, as a wheat substitute in pasta.

Rice has emerged as an appealing raw material to produce pasta. Among the rice and pigmented-rice varieties, black rice has gained an increasing appeal due to its sensory qualities, high nutritive value and health-promoting properties. Black glutinous rice (BGR) (*Oryza sativa* L.) is one of the most grown cash crop rice cultivars in the northern and northeastern regions of Thailand [3]. When compared to regular white glutinous rice, BGR provides more beneficial nutrients [4]. This is because the bran layers and embryo contain numerous nutritional and bioactive components, such as essential amino acids, functional lipids, dietary fiber, vitamins, certain minerals and anthocyanins [5,6].

In wheat-based foods such as pastas, gluten is responsible for imparting springy and elastic textures. When substituting wheat flour with another type of flour that lacks gluten, the absence of primary structure-forming proteins such as gluten may result in technological and quality challenges [7]. To solve this difficulty, rice is one of the suitable substitute ingredients that could be used to make pasta, as shown in these studies [8,9]. Similar to other types of rice, glutinous rice is low in protein and lacks technological properties for interacting and forming a cohesive network. Nonetheless, the high amylopectin content of glutinous rice may interact with the gluten proteins in wheat flour to form a more stable gel network structure [10,11]. This is because the kernels of the cooked rice are sticky and adhere together. These qualities of glutinous rice could make it useful for stable food structures [12].

This study aimed to investigate the potential of using BGRF as a wheat substitute in pasta production to increase health-promoting nutritional value. Additionally, it examined the changes in physical, chemical, and sensory properties, as well as consumer acceptance, when partially substituting wheat flour with BGRF.

Furthermore, the substitution of wheat flour with BGRF has the potential to decrease the expenses associated with pasta manufacturing in certain developing countries. Due to the prevalence of tropical climates in most of these countries, which are unsuitable for wheat cultivation, pasta is regarded as a costly food item within these regions. Consequently, using BGRF as a substitute could make pasta more affordable and accessible to consumers in these areas, and also lower the cost of production.

MATERIALS AND METHODS

Raw materials

All the BGR grains (*Oryza sativa* L.; in Thai, Khao Niaw Dam Luem Pua) used in this study were purchased once directly from a supplier in Phetchabun province, Thailand. Rice grains were kept in a vacuum-sealed plastic bag and stored at 4 °C for later use. The milling process was performed using a Cross Beater Mill SK 300 (Retsch, Haan, Germany). Then, the ground material was sieved using the AS 200 control B (Retsch, Haan, Germany) with a 35-mesh sieve to obtain fine flour. Other ingredients (such as semolina flour, eggs, and salt) used for pasta production were purchased from local hypermarkets.

Pasta production

The base pasta formulation (0% BGRF) comprised semolina flour, water, eggs, and salt, as illustrated in Figure 1. Semolina was then substituted with BGRF at three different levels: 20%, 40%, and 60%. For pasta making, salt was mixed with all the semolina flour, sifted well, and put in a mixing bowl. A well was made in the center, and the liquid mixture was poured into the flour. The mixture was then mixed well and kneaded until the dough was smooth for 3 min. It was left to rest for 10 min, then divided into four pieces of 110 g each. The divided dough was rolled out with a pasta roller from numbers 0-4 accordingly. After the dough reached its final thickness, it was rolled into strips. For pasta cooking, UC-PAS was put in boiling water until cooked. The pasta was then soaked in cold water for 1 minute and left to drain for 2 min. Finally, the pasta was placed in a plastic container with a lid for further use.

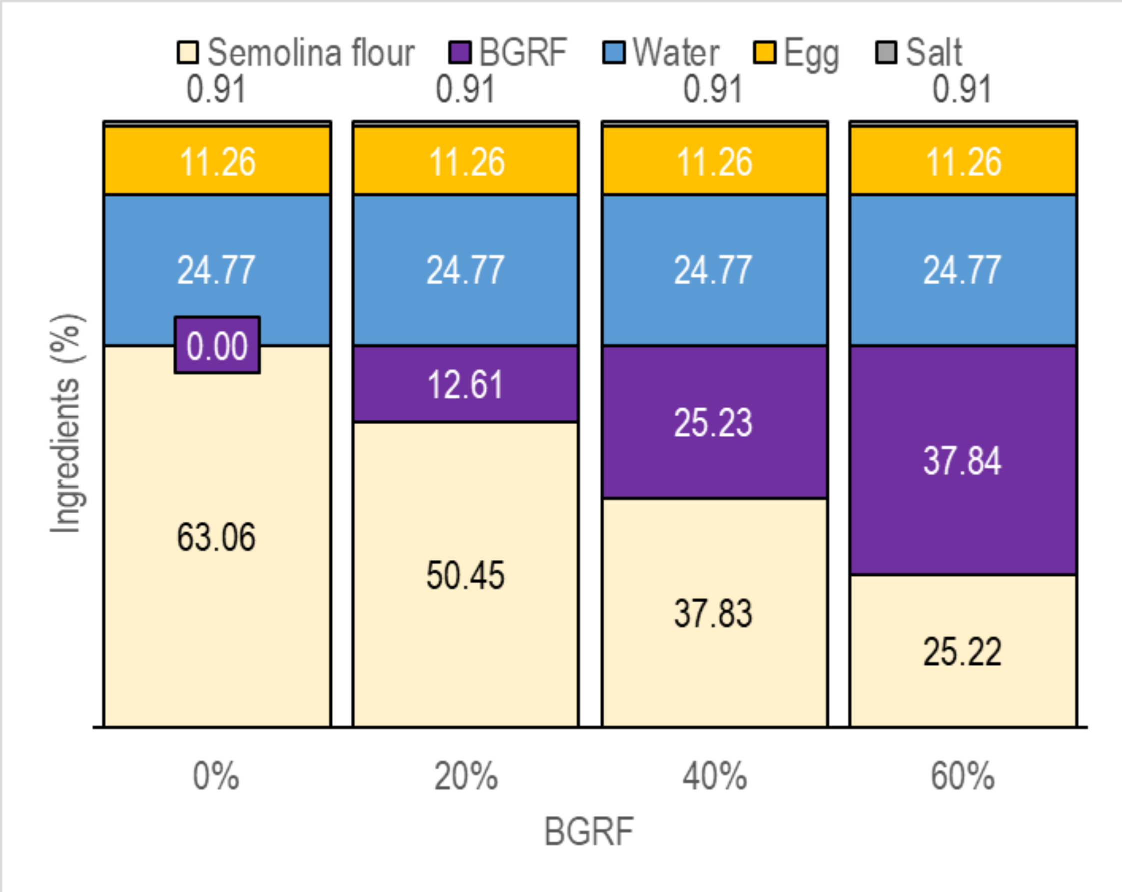

Figure 1: All pasta formulations and percentages of each ingredient

Pasta quality evaluation

The CKT and CKL for the pasta samples were determined by the method described by AACC (2000) [13]. The percentage of increased weight was calculated as CKY using equation (1)

CKY = (Weight of cooked pasta/Weight of uncooked pasta) ×100…Equation (1)

Pasting Properties

Pasting properties were investigated using a Rapid Visco Analyzer (RVA-4, Newport Scientific Pty. Ltd, Warriewood, NSW, Australia). The assessment followed AACC (2000) (No. 61-02) and RACI (No. 06-05). The software integrated with RVA was used to determine these pasting properties in Centipoise (cP): Peak viscosity (PV), Trough viscosity (TV), Breakdown viscosity (BV), Final viscosity (FV), and Setback viscosity (SV). Moreover, Peak time (PkT, min) and Pasting temperature (PsT, °C) were also investigated. All measurements were done in triplicate.

Antioxidant properties

The extraction method had slight modifications from Gull [14]. Briefly, 2 g of raw and 5 g of boiled pasta were extracted for 2 h with 10 ml of 80% methanol at 150 rpm on an orbital agitator. The mixture was centrifuged for 20 min at 1400 rpm, and the supernatant decanted. The sediment was extracted again under the same conditions. The supernatants were combined and used for the determination of antioxidant activity (ATO) and total phenolic compounds (TPC).

The ATO was determined using a DPPH radical scavenging activity assay with a slight modification from Benjakul [15]. The sample (1.0 ml) was added to 1.0 ml of 95% ethanol containing 0.15 mM 2,2-diphenyl-1-picrylhydrazyl (DPPH). The mixture was stirred vigorously and allowed to rest for 30 min at room temperature and in the dark. Using a spectrophotometer, the absorbance of the resulting solution was measured at 517 nm. These respective solvents were used in place of the DPPH solution when preparing the sample blank. Using the equation (2), the DPPH assay method was reported as "DPPH radical scavenging activity (%DPPH-RSA)."

%DPPH-RSA =
(Abs 517 of control-Abs 517 of sample/Abs 517 of control) ×100…….Equation (2)

The TPC was determined in the preparations using the Folin-Ciocalteu reagent according to Benjakul with slight modifications [15]. Appropriately, 1 ml of the diluted solution was thoroughly mixed with 0.2 ml of a 2-fold diluted Folin-Ciocalteu reagent. After 3 min, 3 ml of a 2% (w/v) sodium carbonate solution was added. A UV spectrophotometer was used to measure the absorbance of the solution at 760 nm after 30 min at room temperature. The concentration of total phenolic compounds was determined using a standard curve of gallic acid with a concentration range of 0-0.05 mg/ml and expressed as mg gallic acid equivalent (GAE)/100 g extract. Additionally, the anthocyanin content (ATC) was determined following the protocol from Giusti [16].

Color measurement

The color of UC-PAS and CK-PAS samples was measured using a HunterLab UltraScan VIS (Virginia, USA) in reflectance mode, with illuminant D65 and a standard observer position of 10°. Each sample's lightness (L*), redness-greenness (a*), and yellowness-blueness (b*) values were measured using the CIE-LAB color system. Each measurement was repeated 5 times in triplicate, and the average of the results was used for reporting.

Cutting force and Tensile strength

Texture properties were determined using a texture analyzer (Model TA. XT Plus, Stable Microsystem, Surrey, UK) equipped with spaghetti tensile grips (A/SPR) for tensile strength and a light knife blade (A/LKB) for cutting force. To determine tensile strength, 50 g of pasta with a length of 30 cm were boiled in 2000 ml of boiling distilled water, utilizing the cooking process established in the previous step. One piece of pasta at a time was measured by wrapping a probe at the top and bottom 3 times on each side. The test was performed using these conditions: pre-test speed of 3.0 mm/s, test speed of 3.0 mm/s, post-test speed of 5.0 mm/s, and a distance of 50 mm. To determine the cutting force, 10 cm of pasta were used instead of 30 cm. The rest of the procedure was the same as described for the tensile strength measurement. Five pieces of pasta were placed together under the center of the blade. The test was performed using these conditions: pre-test speed of 10.0 mm/s, test speed of 10.0 mm/s, post-test speed of 10.0 mm/s, and a distance of 90%.

Proximate analysis and water activity

The protein content, ash content, moisture content, and total fat were determined using the AOAC (2000) methods 960.52, 923.03, 934.01, and 963.15, respectively [17]. The AACC (2000) method 32–05.01 was used for determining the total dietary fiber content [13]. Total carbohydrate content estimation was obtained through calculation [17]. The measurement of water activity (a_w) was conducted at 25 °C using a LabMaster-aw meter (Novasina AG, Lachen, Switzerland).

Sensory evaluation

This study was conducted with 100 respondents in the age range of 20-60 years. The respondents were randomly selected from the public and then assisted to the testing area. Only respondents who had consumed any kind of pasta in the previous month were recruited. Eighty g samples were presented in white plastic cups with lids, tagged with a random 3-digit code in a monadic sequence. Samples were rated for consistency of color (COC), overall odor (OOR), rice odor (ROD), tenderness (TDN), toughness (TGN), overall taste (OVT), and overall liking (OVL) on a 9-point hedonic scale. Moreover, the sensory attributes, without overall, were also used in the 3-point just-about-right tests (JAR) (too little: TL, just about right: JAR, and too much: TM). Lastly, a binomial scale of “accept” or “not accept” was used to evaluate the pasta's acceptance.

Statistical analysis

This study was conducted with a completely randomized design for physical-chemical properties and a randomized complete block design for hedonic testing. All data analyses were performed in the R environment using R Version 4.3.2. The R base was used for analysis of variance, and the agricolae R package was used

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for post hoc tests with Duncan's new multiple range test. The SensoMineR R package was used to perform penalty analysis (PA). A t-test was used to compare the antioxidant properties of UC-PAS and CK-PAS. All mean differences were considered statistically significant at a 95% confidence level ($p \leq 0.05$).

RESULTS AND DISCUSSION

Pasta cooking quality

Pasta's qualities are shown in Table 1. The CKT, CKL, and CKY were found to be significantly different ($p \leq 0.05$). The CKT was reduced by substituting more BGRF. On the contrary, an increased substitution of BGRF resulted in a higher CKL. There was no statistically significant disparity observed in terms of CKL and CKY between the 0% and 20% BGRF. In contrast, the substitution of 40% and 60% led to notable CKL. Moisture content had a positive influence on CKT; the greater the moisture content, the shorter the CKT [10]. This explained why CKT decreased as BGRF increased.

The temperature and duration of pasta cooking affected polymer breakdown and solubilization. The solid pasta components disintegrated and dispersed in the water during cooking. Cooking at high temperatures and for longer periods depleted tough solids, and the longer cooking time increased cooking loss in pasta. The absence of a gluten network in BGRF pasta also led to reduced entrapment of starch polymers within the pasta structure [8]. The structural degradation of the BGRF pasta resulted in the dissolution of soluble solids from the pasta, leading to their migration into the cooking water [18]. Therefore, the increased BGRF exhibited a significantly higher CKL compared to the 0% BGRF. Moreover, a high CKL had a lower tolerance for overcooking and could result in a sticky texture [19].

Pasting Properties

Table 2 shows the pasting properties of pastas. The differences in pasting properties of flour were a result of several factors, such as the length of amylose and the size and structure of amylopectin [20]. There were no statistically significant differences in PV among 0%-40% BGRF. This means up to 40% BGRF could be substituted without differences in PV. However, the PV dropped statistically significantly when it reached 60% BGRF. The BV and PsT followed the same trend. There were no statistically significant differences in BV and PsT between 0% and 20% BGRF. Then, the BV and PsT dropped by statistically significant differences when the %BGRF increased. This is because wheat flour has a high viscosity when heated compared to other types of flour. The depletion of gluten may cause starch granule collapse during heating. This explains why substituting wheat flour with less-protein flour would decrease the PV, BV, and PsT [21]. Amylose is a crucial cooking and pasting quality factor in rice. Low-amylose black rice is moist and sticky after cooking. Intermediate-amylose black rice is dry and fluffy and retains its soft texture after cooling. On the contrary, high-amylose black rice is dry and fluffy but hardens when cooled due to retrogradation. Black rice with a higher amylose content has a lower peak viscosity and a higher setback viscosity, while lower amylose-content ones retrograde less and have higher swelling power [22].

Physical properties

The physical properties of pasta are shown in Table 3. The color values of UC-PAS show statistically significant increases ($p \leq 0.05$) with the increase of BGRF. The color properties of CK-PAS displayed distinct changes when BGRF was added. Specifically, the a* value increased, while the L* and b* values decreased. These alterations in color values were determined to be statistically significant ($p \leq 0.05$) as the percentage of BGRF increased. The higher substitution of BGRF had a discernible impact on the brightness, yellowness, and redness attributes of both UC-PAS and CK-PAS. The increased redness in BGRF pasta may be attributed to the presence of color compounds within the flour. Rice bran, particularly varieties with pigmentation such as purple rice bran, contained a notable concentration of anthocyanins. These bioactive compounds are known to enhance sensory attributes, promote health, prevent diseases, and enhance nutritional value through the augmentation of bioactive substances [23].

The cutting force, which serves as a measurement of the strength of the CK-PAS, increased ($p \leq 0.05$) when the percentage of BGRF increased. In contrast, there was a notable decrease in tensile strength ($p \leq 0.05$). The 60% BGRF demonstrated the highest cutting strength and the lowest tensile strength. This finding suggests that increasing the BGRF by 60% led to pasta with enhanced cutting strength while concurrently exhibiting diminished elasticity. Nevertheless, the adhesive quality of the pasta remained comparable to that of the 40% BGRF. Based on these results, it can be observed that rice flour-substituted pasta exhibited reduced hardness and increased stickiness compared to the control. The pigmentation of BGRF contributed to a general increase in phenolic compounds and antioxidant properties. The formation of a complex network in colored wheat flour, which is attributed to the presence of polyphenols, depended on the gluten proteins. This interaction between polyphenols and gluten proteins played a crucial role in determining the structure and functionality of the flour. The potential reduction in the extensibility of gluten proteins within the flour may have impeded the expansion of pasta during the cooking process, stemming from alterations in the protein network [23]. The composition of starch, protein, and fiber in BGRF had the potential to influence the density and adhesive properties of pasta. When long-chain polysaccharides in dietary fiber broke down, the density between the fiber

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molecules dropped. This is called depolymerization, and it led to the fibers dissolving. The behavior observed arose from the disintegration of the surface composition of pasta when exposed to elevated temperatures, as well as its subsequent removal during the boiling process. Consequently, these factors contributed to an increase in pasta density and a reduction in its adhesive properties.

Proximate composition
The proximate composition of UC-PAS is presented in Table 4. The moisture content of UC-PAS showed significant differences due to the increase in BGRF. The 0% BGRF had the highest moisture content. As the percentage of BGRF increased, the moisture content remained unchanged. The percentages of ash, protein, fat, and fiber exhibited an increase as the proportion of BGRF increased. Notably, 60% BGRF demonstrated the highest values for these properties. The observed increase in certain proximate properties, specifically when substituted with black rice flour, was not unforeseen, as evidenced by some studies [24]. This study elucidated the potential correlation between the high proximate content of black rice by comparing the physicochemical and antioxidant properties of various black and red rice varieties from Thailand, Sri Lanka, and China [6]. The proximate composition analysis revealed that Thai black rice had elevated levels of ash, fat, protein, and fiber [6]. Notably, Sompong's study found that the total carbohydrate content in all colored rice samples exceeded 70% [6], suggesting that these rice types are commendable carbohydrate sources. However, the substitution of wheat flour with BGRF in pasta led to an increase in fiber content due to BGRF's naturally higher fiber levels. Simultaneously, the reduction in starch, the primary carbohydrate component in wheat flour, along with the increase in fiber content, resulted in a decrease in total carbohydrate content. This shift in nutritional composition enhanced the health-promoting properties of the pasta, making it a more nutritious option.

Antioxidants properties
The ATO, TPC, and ATC of pasta are shown in Table 5. The results showed that ATO, TPC, and ATC increased with the increasing BGRF, while the ATC of 0% BGRF was not detected. This is because colored rice has been reported as a potent antioxidant source [1]. This type of rice has been encouraged as a viable antioxidant source for functional foods, particularly black rice, which has several nutritional advantages over white rice. However, when the pasta was cooked, all the antioxidant properties decreased statistically significantly. A decrease in antioxidant properties when exposed to heat treatment has been observed in some studies [25]. The diminished levels of TPC observed in CK-PAS were similarly reflected in the reduced content of ATO and ATC. The observed decline

in TPC of CK-PAS can be attributed to the degradation that occurs due to exposure to high temperatures, causing water-soluble polyphenols to leach into the cooking water [26].

Even though cooked rice had fewer phenolic compounds and antioxidant activity, it was as anti-inflammatory as raw rice. Thus, compounds reduced during cooking may still act as inflammatory mediators, potentially offering protective effects against diseases associated with inflammation. The temperature during cooking could result in a decrease in the content and stability of anthocyanins. The breakdown of anthocyanins generated protocatechuic acid, which is a cyanidin fragment. Anthocyanins underwent the same process during deglycosylation. An increase in the concentration of protocatechuic acid, which degrades anthocyanins, occurred during cooking [27].

It is postulated that the rapid degradation of anthocyanin at elevated temperatures may be attributed to hydrolysis of the 3-glycoside structure, which conferred a stabilizing influence on labile anthocyanin content. Another hypothesis posits that hydrolysis of the pyrylium ring led to the formation of chalcone, a compound responsible for the formation of brown-colored foods containing anthocyanin [16]. Furthermore, the impact of temperature on the stability of anthocyanin was investigated by Palamidis [28]. The results indicated that higher storage temperatures led to a progressive acceleration in the degradation of pigments. This data shows that the cooking process clearly influenced the amount of TAC because its depressed TAC in purple rice, reducing some antioxidant capacity [29]. The application of low temperatures during the cooking process of black rice led to a higher preservation of TAC compared to the utilization of high temperatures [27]. This implies that the degradation of anthocyanins was caused by the thermal processes and CKT to which they were treated. While it is known that anthocyanins can degrade when exposed to temperatures over 25°C, it has been observed that the anthocyanins present in black rice pasta exhibited stability even when subjected to the cooking temperature required for pasta preparation.

Sensory evaluation

In Table 6, the 40% BGRF consistently had the highest liking score across all sensory attributes. In contrast, the 60% BGRF exhibited the lowest liking score. Surprisingly, the base formula exhibited a relatively lower level of preference compared to the formulations containing 20% and 40% BGRF. However, it still received a higher liking score than the 60% BGRF. Respondents demonstrated a willingness to accept pasta substituted with BGRF, even when compared to traditional pasta. The liking score significantly decreased at 60% BGRF, implying that the maximum acceptable level of BGRF is 40%. Moreover, the evaluation of the acceptance test depicted in Figure 2 exhibited a similar pattern to the

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preferences of the participants as presented in Table 6. The acceptance rate displayed an uptrend with the increase in BGRF. Once it reached 60% BGRF, a significant decrease was observed in the acceptance rate.

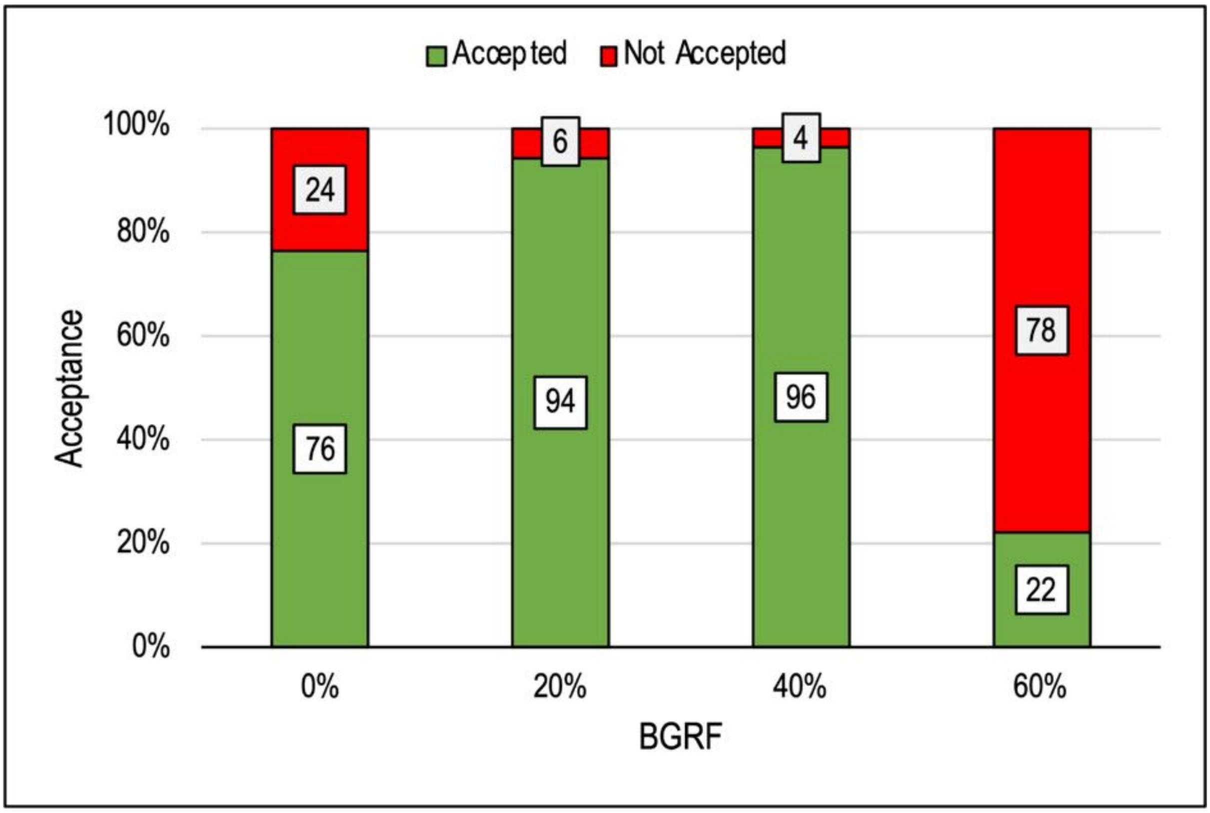

Figure 2: Product's acceptance of CK-PAS

Figure 3 showed a penalty plot (mean drop) against the frequency for each non-JAR attribute. The 20% and 1.0 mean drop value cutoffs were generally used when performing PA. All the pasta, except for 40% BGRF, had several non-JAR attributes in the top right quadrant. This meant most sensory attributes didn't meet the consumers' preferences. The 60% BGRF had the most non-JAR attributes in the critical quadrant, specifically the texture-related, rice odor, and color attributes. These results are related to the hedonic testing in Table 5, where 60% BGRF was the worst compared to others. In contrast, 40% BGRF had the highest liking score, even higher than the control. It was intriguing that consumers preferred pasta containing 40% BGRF over the control. This could imply that consumers were willing to accept pasta made with alternative types of flour, even if the flour had a significantly different color than the traditional one. In addition, the absence of wheat flour at a particular point had no impact on consumer preferences, particularly regarding texture. Notwithstanding, the high amylopectin content of glutinous rice may have interacted with gluten proteins in wheat flour to form a more stable gel network structure [10,11].

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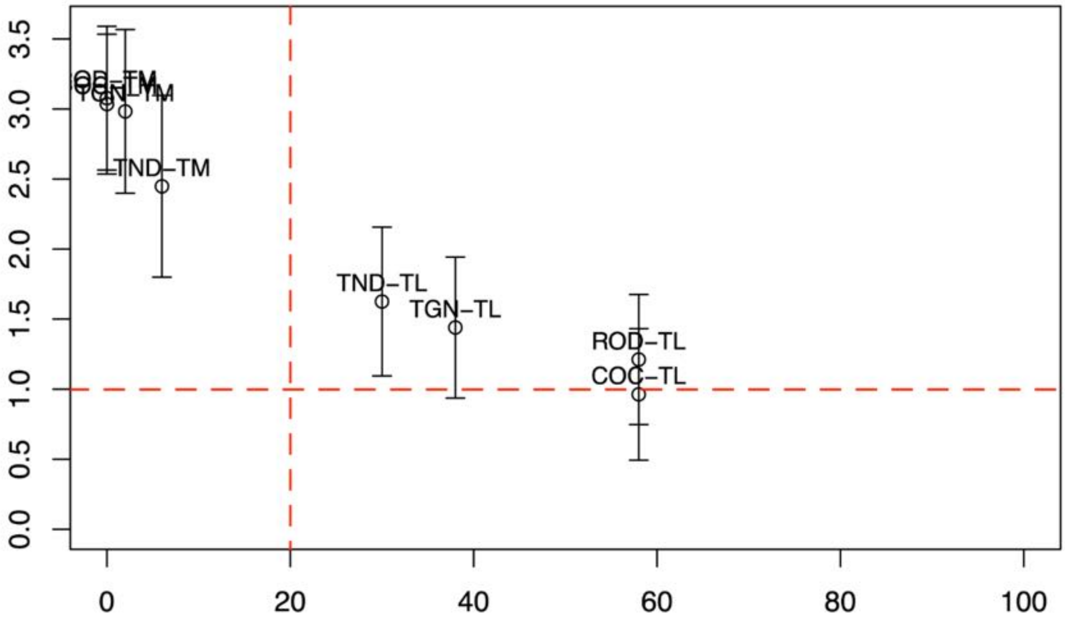
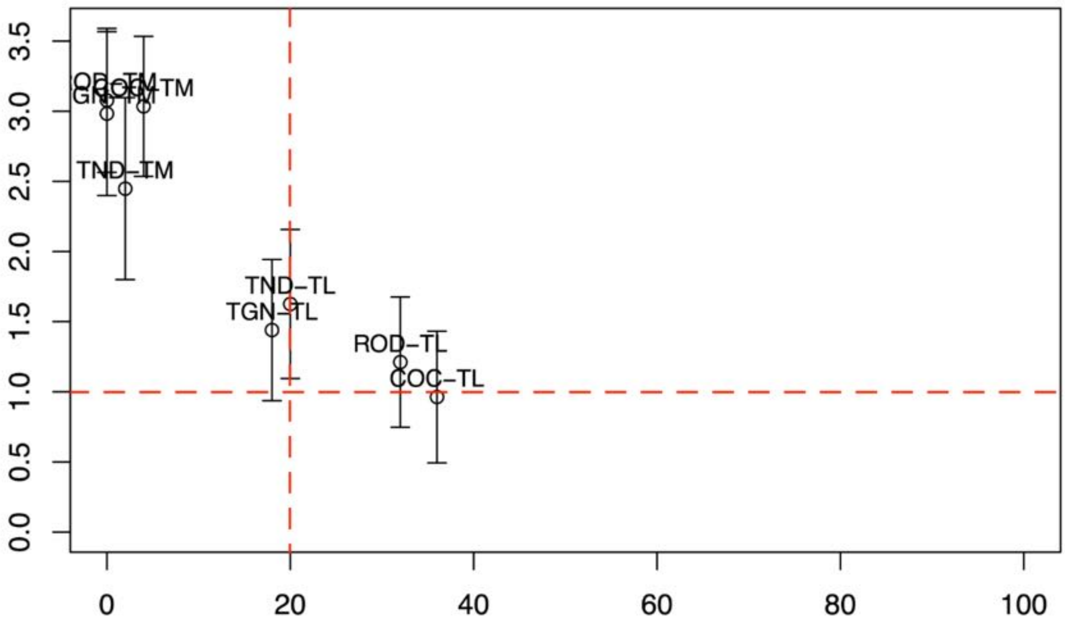


(A) 0% BGRF



(B) 20% BGRF

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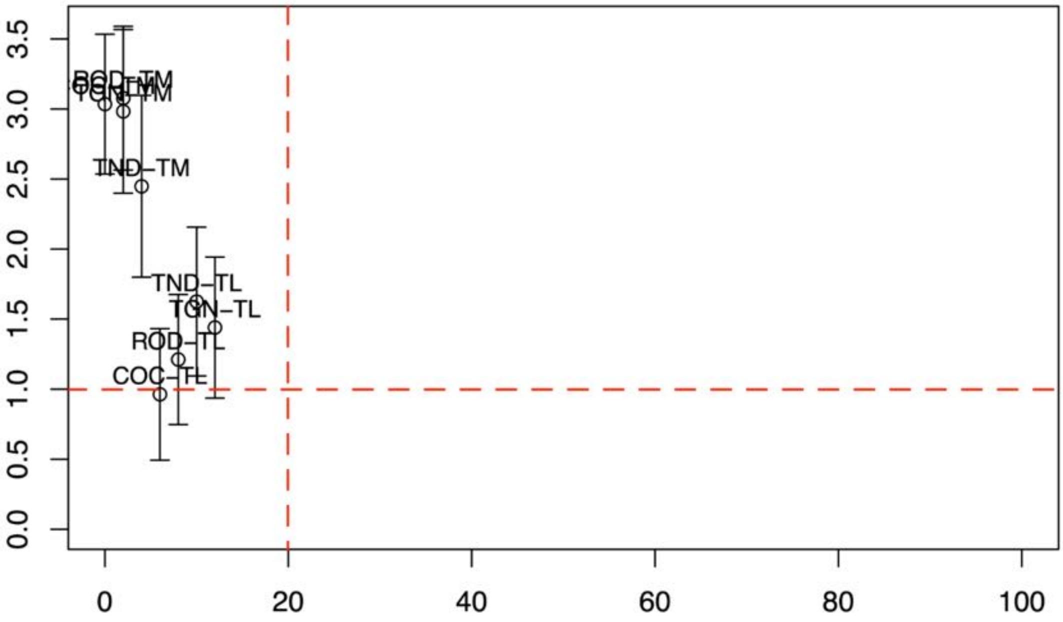
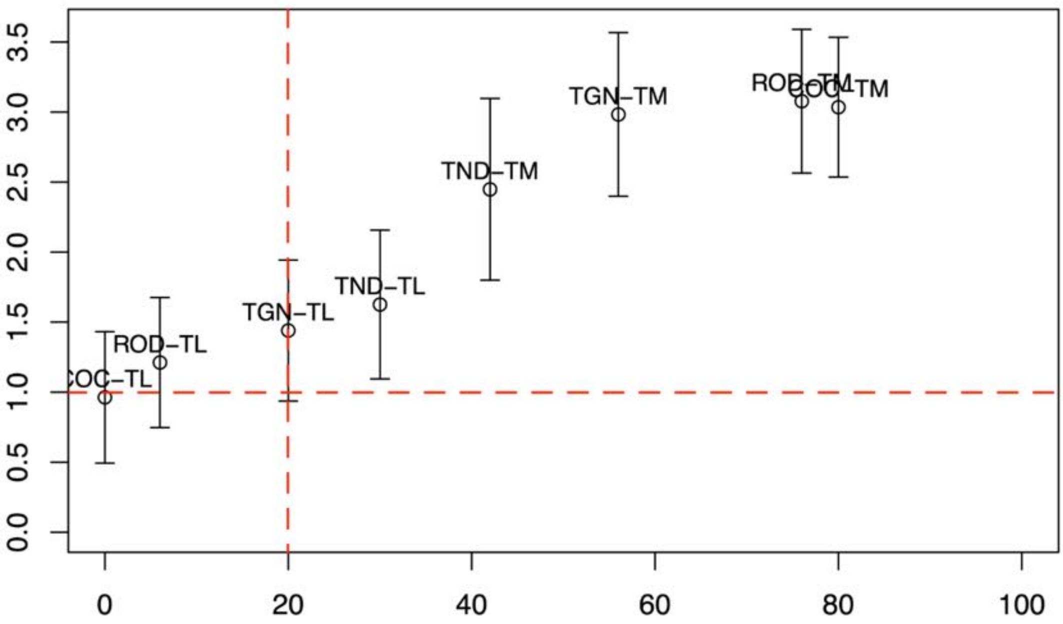


(C) 40% BGRF



(D) 60% BGRF

Figure 3: Penalty score for each sensory attribute: (A) Control pasta without BGRF; (B)-(D) Pasta with 20%, 40% and 60% of black glutinous rice flour (BGRF), respectively

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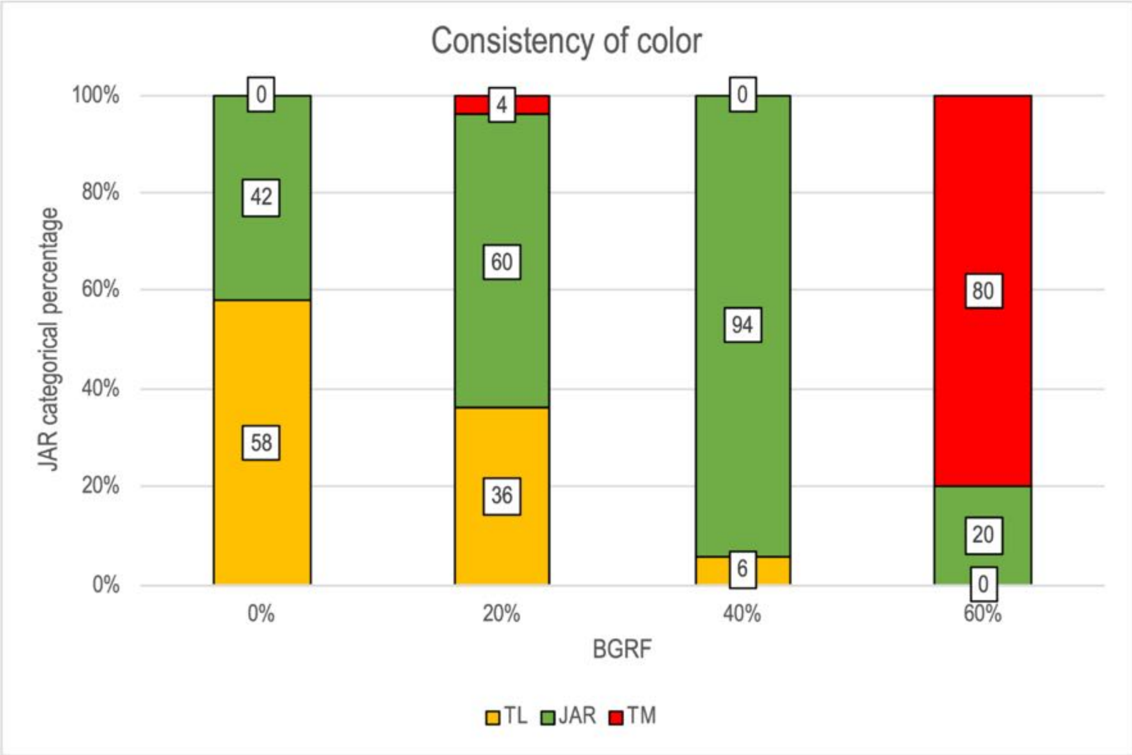
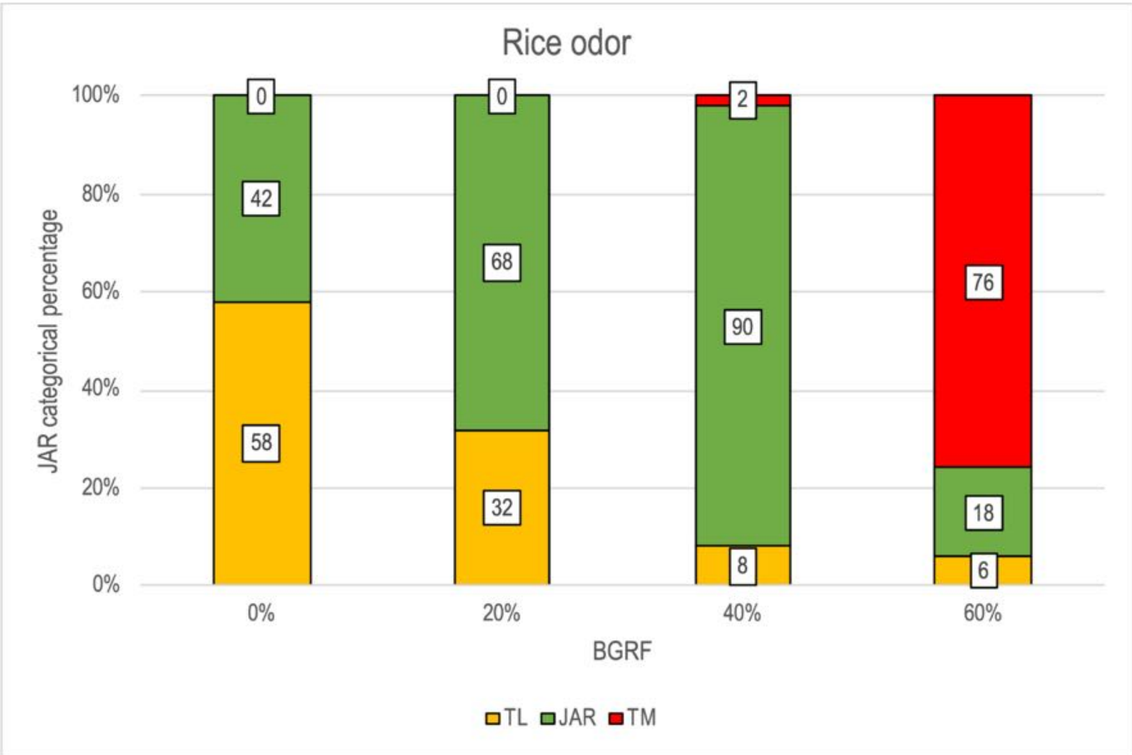


(A)



(B)

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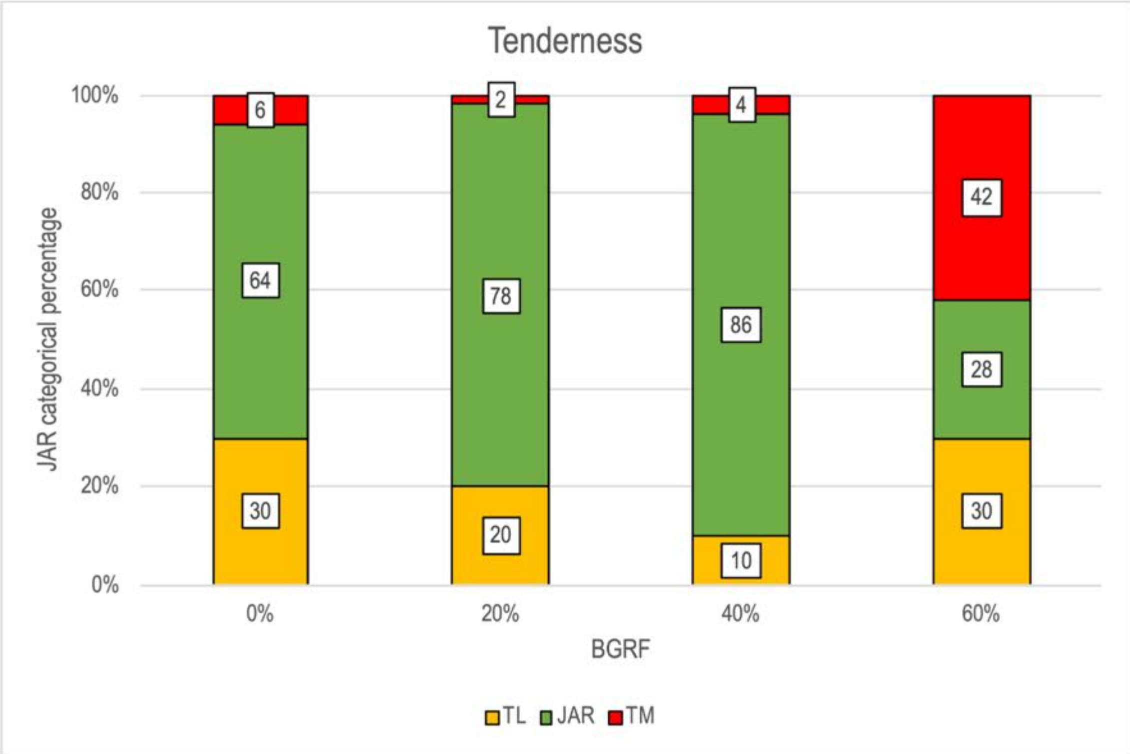
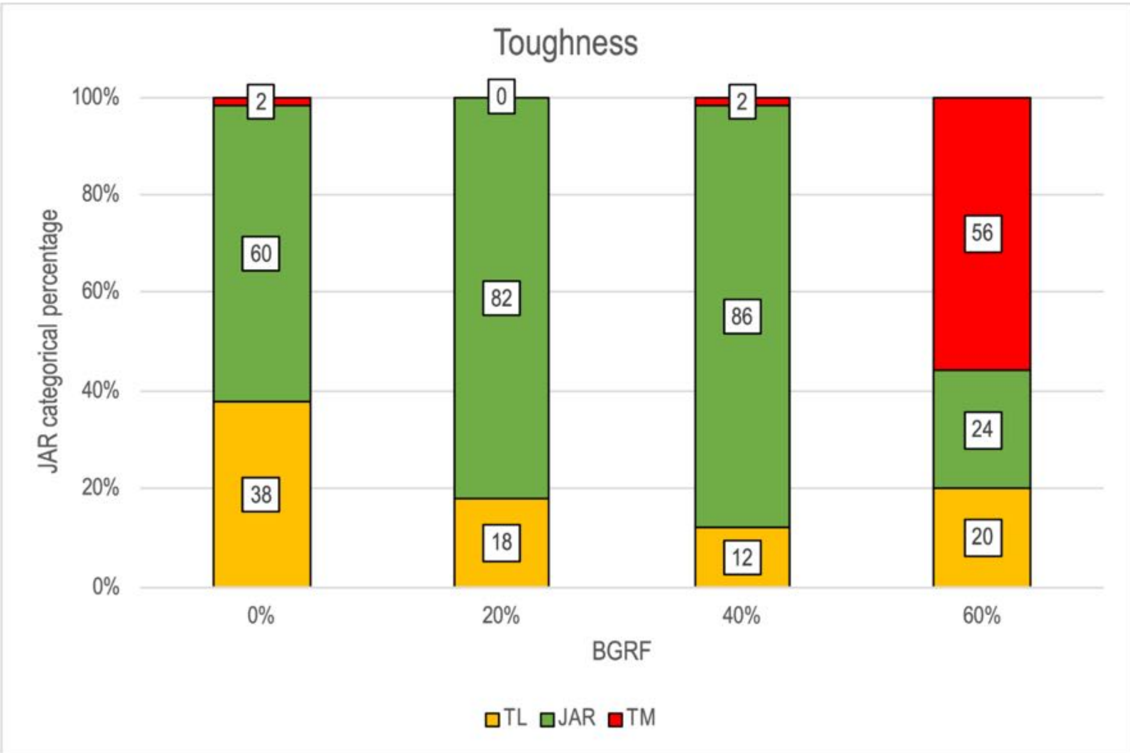


(C)



(D)

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Figure 4: Just-about-right (JAR) categorical percentages for each sensory attributes of all samples; (A) Consistency of color, (B) Rice odor, (C) Tenderness and (D) Toughness

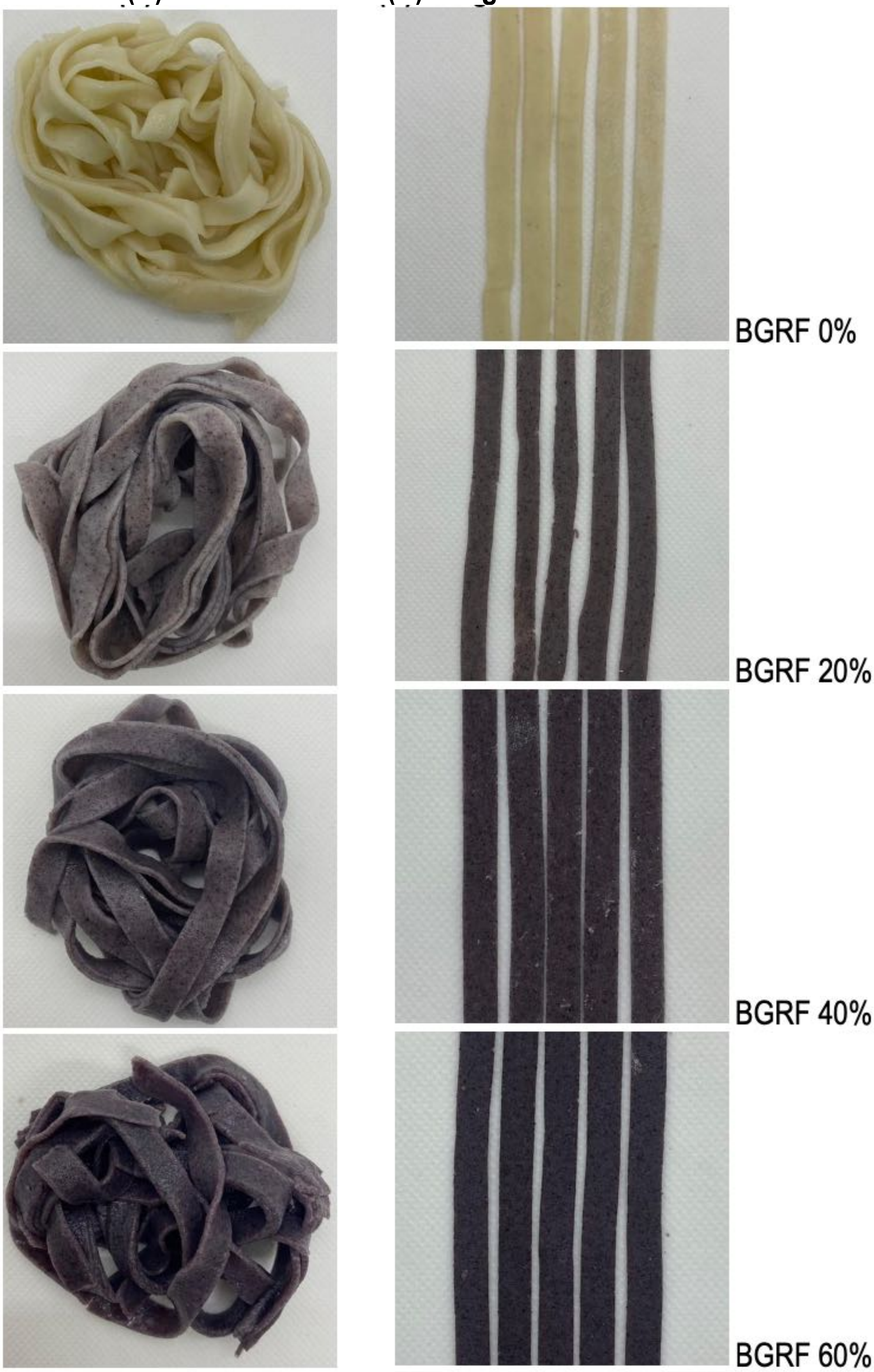

Figure 5: Images of pasta, rolled into balls and stretched

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Consumer acceptance is critical for new food products [24]. The propensity to embrace unconventional BGRF pasta exhibits parallels with certain research investigations [30]. In this study, consumers exhibited a positive reception towards black rice pasta. Typically, consumers are accustomed to pasta that is white or slightly yellow. Consequently, it was anticipated that their level of acceptance would be diminished because of the atypical purple hue, which engenders a sense of skepticism. However, this study showed a considerable level of acceptance by consumers of black rice pasta. This well-accepted reception indicates the potential for this novel product to be embraced and incorporated into dietary patterns, as shown in this study [30].

CONCLUSION AND RECOMMENDATIONS FOR DEVELOPMENT

The results showed that the percentage of BGRF had a major effect on the physical properties of both UC-PAS and CK-PAS. Furthermore, the proximate composition showed that the percentages of ash, protein, fat, and fiber increased as the level of BGRF increased. Additionally, BGRF substitution had a significant impact on the cooking quality of pasta, including CKT, CKL, and CKY, with an increased substitution of BGRF resulting in a higher CKL. The antioxidant properties of UC-PAS and CK-PAS were shown to increase with the increasing percentage of BGRF, while the antioxidant properties decreased when the pasta was cooked, indicating the impact of the cooking process on the stability of anthocyanins and other bioactive compounds. To address the observed increase in CKL with higher BGRF substitution, it is recommended to explore different processing techniques, such as adjusting extrusion conditions and employing specific drying methods. These adjustments could help maintain the cooking quality of pasta formulations with increased percentages of BGRF.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest in this study.

ETHICS STATEMENTS

This study was approved by the Naresuan University-Network of Research Ethics Committee (NU-NREC) (COE No. 0001/2023, NREC No. 0008/2566).

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Table 1: Pasta's quality at different percentages of black glutinous rice flour (BGRF)

Qualities	BGRF			
	0%	20%	40%	60%
CKT (min)	2.50 ± 0.00 a	2.30 ± 0.00 b	2.30 ± 0.00 b	2.20 ± 0.00 c
CKL (g)	0.43 ± 0.04 c	0.47 ± 0.01 c	2.69 ± 0.08 b	2.80 ± 0.12 a
CKY (g)	155.54 ± 3.43 a	153.14 ± 1.80 a	146.90 ± 1.53 b	145.61 ± 2.73 b

Different superscripts of Mean±SD in the same row mean statistically significant differences ($p \leq 0.05$). CKT: Cooking Time, CKL: Cooking Loss, CKY: Cooking Yield

Table 2: Pasting properties of pasta at different percentages of black glutinous rice flour (BGRF) by RVA analysis

Properties	BGRF			
	0%	20%	40%	60%
PV (cP)	1770.00 ± 52.11 a	1740.00 ± 88.10 a	1713.00 ± 59.51 a	1425.00 ± 52.11 b
TV (cP)	1117.33 ± 30.90 ns	1081.33 ± 39.58 ns	1140.00 ± 28.48 ns	1105.33 ± 29.02 ns
BV (cP)	652.67 ± 23.07 a	659.00 ± 49.43 a	573.00 ± 31.80 b	320.33 ± 10.70 c
FV (cP)	2014.67 ± 47.51 c	2278.00 ± 61.59 b	2614.67 ± 56.45 a	2108.61 ± 39.80 c
SV (cP)	244.67 ± 33.25 d	537.67 ± 28.50 c	901.67 ± 12.66 a	683.00 ± 2.64 b
PkT (min)	6.02 ± 0.04 c	5.91 ± 0.03 d	6.11 ± 0.03 b	6.22 ± 0.04 a
PsT (°C)	89.33 ± 0.58 a	88.48 ± 0.45 a	85.83 ± 1.46 b	75.53 ± 0.77 c

Different superscripts in the same row mean statistically significant differences ($p \leq 0.05$). Lower-case "ns" superscripts mean no significant differences ($p > 0.05$). cP (Centipoise), PV (Peak viscosity), TV (Trough viscosity), BV (Breakdown viscosity), FV (Final viscosity), SV (Setback viscosity), PkT (Peak time) and PsT (Pasting temperature)

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Table 3: Physical properties of uncooked and cooked pasta at different percentages of black glutinous rice flour (BGRF)

Properties	**BGRF**							
	0%		**20%**		**40%**		**60%**	
Uncooked pasta:								
a_W	0.93	±0.00 d	0.94	±0.00 c	0.95	±0.00 b	0.96	±0.00 a
L*	77.50	±0.23 a	47.42	±0.05 b	37.81	±0.04 c	33.57	±0.03 d
a*	3.12	±0.04 d	3.58	±0.04 c	3.75	±0.02 b	3.82	±0.06 a
b*	21.10	±0.04 a	2.08	±0.02 b	-1.07	±0.01 c	-0.14	±0.02 d
Cooked pasta:								
L*	72.57	±0.31 a	44.66	±0.01 b	37.27	±0.08 c	36.68	±0.26 d
a*	1.26	±0.09 d	3.74	±0.01 c	3.94	±0.02 b	4.40	±0.04 a
b*	17.23	±0.29 a	1.24	±0.01 b	-0.60	±0.04 c	-0.72	±0.05 c
Cutting force (g)	211.60	±4.68 d	290.73	±23.67 c	365.78	±24.56 b	429.02	±20.88 a
Tensile strength (g)	70.50	±2.11 a	36.01	±3.46 b	23.88	±0.96 c	21.96	±1.25 c

Different superscripts of Mean±SD in the same row mean statistically significant differences (p≤0.05)

Table 4: Proximate composition of uncooked pasta at different percentages of black glutinous rice flour (BGRF)

Properties	**BGRF**							
	0%		**20%**		**40%**		**60%**	
Moisture (%)	61.21	±0.04 a	60.08	±0.10 b	60.07	±0.19 b	60.07	±0.06 b
Ash (%)	5.11	±0.15 c	5.44	±0.11 b	5.48	±0.07 b	6.61	±0.15 a
Protein (%)	12.06	±0.04 c	12.82	±0.32 b	13.06	±0.04 b	14.19	±0.07 a
Fat (%)	1.69	±0.09 b	1.16	±0.01 b	1.34	±0.08 b	4.10	±0.65 a
Fiber (%)	11.24	±0.25 d	12.29	±0.01 c	12.65	±0.10 b	13.37	±0.24 a
Carbohydrate (%)	8.68	±0.23 a	8.20	±0.37 a	7.39	±0.24 b	1.65	±0.55 c

Different superscripts of Mean±SD in the same row mean statistically significant differences (p≤0.05)

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Table 5: Antioxidant activities, total phenolic compounds and anthocyanin content of uncooked and cooked pasta at different percentages of black glutinous rice flour (BGRF)

BGRF	ATO (%DPPH-RSA)		TPC (mg GAE/100 g)		ATC (Cyanidin-3-O-glucoside; mg/g)	
	Uncooked	Cooked	Uncooked	Cooked	Uncooked	Cooked
0%	21.43 ± 0.76 ^{c,A}	13.65 ± 0.63 ^{c,B}	1.93 ± 0.05 ^{d,A}	0.89 ± 0.08 ^{d,B}	ND	ND
20%	38.25 ± 0.94 ^{b,A}	37.02 ± 0.79 ^{b,B}	3.52 ± 0.25 ^{c,A}	1.21 ± 0.04 ^{c,B}	0.03 ± 0.00 ^{c,A}	0.02 ± 0.00 ^{c,B}
40%	57.51 ± 0.61 ^{a,A}	47.69 ± 0.62 ^{a,B}	5.28 ± 0.15 ^{b,A}	1.44 ± 0.02 ^{b,B}	0.08 ± 0.00 ^{b,A}	0.04 ± 0.00 ^{b,B}
60%	56.43 ± 0.16 ^{a,A}	47.63 ± 0.92 ^{a,B}	7.06 ± 0.19 ^{a,A}	1.58 ± 0.07 ^{a,B}	0.13 ± 0.00 ^{a,A}	0.05 ± 0.00 ^{a,B}

Different lower-case superscripts in the same column mean statistically significant differences in different percentages of BGRF ($p \le 0.05$). Different upper-case superscripts mean statistically significant differences between uncooked and cooked pasta at certain percentages of BGRF ($p \le 0.05$). Upper-case “N” superscripts mean no significant differences between uncooked and cooked pasta at certain percentages of BGRF ($p > 0.05$). Upper-case “ND” superscripts mean not detected

Table 6: Sensory attributes and liking score of cooked pasta at different percentages of black glutinous rice flour (BGRF)

Sensory attributes	BGRF			
	0%	20%	40%	60%
Color’s consistency	6.38 ± 0.99 ^{c}	7.26 ± 0.94 ^{b}	8.42 ± 0.97 ^{a}	4.68 ± 0.99 ^{d}
Overall odor	6.00 ± 0.92 ^{c}	7.10 ± 0.79 ^{b}	8.20 ± 0.80 ^{a}	3.90 ± 0.79 ^{d}
Rice odor	6.86 ± 0.95 ^{c}	6.86 ± 0.95 ^{b}	8.08 ± 1.01 ^{a}	4.72 ± 0.90 ^{d}
Tenderness	6.14 ± 0.86 ^{c}	7.07 ± 0.92 ^{b}	7.94 ± 0.96 ^{a}	4.68 ± 0.93 ^{d}
Toughness	6.14 ± 0.95 ^{c}	7.06 ± 1.00 ^{b}	8.08 ± 0.94 ^{a}	4.60 ± 0.75 ^{d}
Overall taste	6.00 ± 0.78 ^{c}	6.84 ± 0.93 ^{b}	8.10 ± 0.97 ^{a}	4.18 ± 0.98 ^{d}
Overall liking	5.50 ± 0.97 ^{c}	6.90 ± 0.97 ^{b}	8.06 ± 0.93 ^{a}	3.88 ± 0.92 ^{d}

Different superscripts of Mean±SD in the same row mean statistically significant differences ($p \le 0.05$)

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