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Improvement of resistant-starch rice for a low glycemic pasta, and determination of its properties

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Abstract

Jasmine rice is the main food consumed in Thailand. However, it is generally medium-to-high glycemic index (GI), resulting in high blood pressure levels. This study was aimed at developing low glycemic index, gluten-free rice pasta by improving its level of resistant starch. Enzymatic, physical modifications and hydrocolloids were carried out, and the resistant starch levels were determined. It was found that 0.1% pullulanase and 4 hrs of incubation produced the highest resistant starch content. Then, pasta was produced, and sensory evaluation was carried out. It was found that gluten-free pasta containing 22% rice resistance starch, 11% pea protein isolate, 17% chickpea flour, 17% lentil flour, 17% mung bean flour, 11% chia seed, 5% spinach powder and 2.5% CMC hydrocolloid had a moderate level of acceptance. The GI of pasta was 52%, indicating a low GI. The pasta quality was evaluated. Pasta with resistant starch reduced cooking time and increased cooking loss. Finally, the nutritional quality of pasta was analyzed. The pasta had high protein and fiber content. In summary, this study has demonstrated that resistant starch rice has high nutritional value and low GI pasta, which are good for health. However, it may have a decreased texture and cooking quality.

1. Introduction

Rice is the main food for Thai people. It has a high carbohydrate content, which provides energy. In Thailand, Jasmin rice 105 is very popular due to its low amylose content when compared to other types of rice. Amylose content has been classified as waxy (0-5%), very low (3-9%), low (10-19%), intermediate (20-25%), and high (>25%) (Li and Gilbert, 2018). Low amylose content results in an elastic soft texture after steam-cooking and a low degree of retrogradation, while cooked rice with high amylose is dry and hard (Tao *et al*., 2019). However, several evidence have indicated that rice flour has a medium-to-high GI. It has been reported that the GIs of rice range from 54 to 121 (Shobana *et al*., 2012). Glycemic index (GI) is a rating system that measures how quickly a carbohydrate increases blood sugar (glucose) level after consumption. It is classified into three categories based on GI values, viz: high-GI foods (> 70), intermediate-GI foods (>55 – < 70), and low-GI foods (< 55) (Dona *et al*., 2010). In addition, GI level is related to glycemic load (GL), which refers to the carbohydrate content per serving of food and its GI. Low GI is not only dependent on the low GI of each food, but also on the amount of food consumed. For example, eating large amounts of low-GI foods results in high blood sugar levels. Therefore, it is advisable that people should eat foods that are low GI and in the right amounts per day. Both low-GI and low-GL diets are associated with a lower risk of type 2 diabetes and cardiovascular disease (Ramdath, 2016). Nowadays, GI value plays an important role for the consumer as a useful tool in planning diets for diabetic patients, and it is vital in the prevention and management of diabetes and other diseases (Omoregie and Osagie, 2008).

Resistant starch (RS) is described as starch that is not susceptible to digestion in the small intestine (Pongjanta *et al*., 2008). It can be found in various sources in nature. The amount of RS depends on the botanical source and the granular structure of starch (resistant starch types I and II). In addition, resistant starch type III (RS III) can be produced from the retrogradation of gelatinized starch. Studies have shown that starch retrogradation could result in a reduction in GI value due to increased starch resistance to digestive enzymes (Willet *et al*., 2002). A low-GI high-fiber (LGI-HF) rice flour has been developed from two-year-storage amylose rice using pullulanase debranching enzyme and physical modification through freeze-thaw process (Parinya *et al*.,

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2018). The LGI-HF rice flour had 54.67% resistant starch content and an estimated glycemic index of 30.66.

Pasta is one of popular noodles in the world today due to ease of cooking and long shelf life (Mercier *et al*., 2016). In Europe alone, about 5.4 million tons of pasta were purchased in 2017 (Eurostat, 2018). Generally, durum wheat semolina flour is the main ingredient for pasta production (Feillet *et al*.,1996). However, pasta is not nutritionally balanced, due to the low biological value of its protein (Asif *et al*., 2013). Moreover, it is associated with gluten allergy, which is one of the most common food intolerance problems (Gobbetti *et al*., 2018). Therefore, gluten-free pasta is a reasonable alternative for consumers. Many studies have tried to develop rice pasta. A study found that rice pasta enriched with 15% soybean flour was highly ranked in sensory attributes, as well as improved color and reduced cooking time (15.59–15.11 mins), but it had increased cooking loss (7.30–7.49%) (Bolarinwa and Oyesiji, 2021). The addition of waxy starch or tapioca starch resulted in rice pasta with increased hardness and stickiness, whereas the addition of common corn, Hylon V, or Hylon VII resulted in rice pasta with decreased hardness, stickiness, and adhesiveness (Mertz and Wang, 2011). Rice-buckwheat pasta raised the moisture content of the raw materials, increased cooking loss and stickiness, and decreased firmness while increasing barrel temperature, hardness and firmness, but it reduced cooking loss and stickiness (Bouasla and Wójtowicz, 2019).

Gluten-free pasta production requires the use of a variety of grains and plant fibers to improve nutrient content and texture. White or durum wheat has gluten, which helps provide good texture, but other plants do not have this. Moreover, the selection of plant cereals and legumes plays an important role in lowering the GI values of the pasta products. Pasta containing legume levels such as 60% grass pea flour and 40% chick pea flour had GI of 20, while pastas containing 100% red lentil flour and 100% pea flour had GI values of 22.3 and 23.3, respectively (Pede *et al*., 2021). Rice is generally medium-to-high GI. Thus, a decrease in GI is necessary for consumer health. The aim of this research was to develop low-GI, gluten-free pasta by improving its level of resistant starch. Cereals and legumes were added for nutrient balance, and finally, the pasta quality was evaluated.

2. Materials and methods

2.1 Materials and preparation

Jasmin rice 105 was obtained from Sridonmoon district, Chiang Rai province, Thailand. Chickpea flour was bought from Suanpana. Lentil flour was purchased from KC Maharajah. Pea protein isolate was purchased from Workout Day. Mung bean was bought from Sitthinun Co. Ltd., Chia seed was bought from Healthy Choice Asia Co. Ltd. Spinach powder was purchased from Healthy Vegetable Powder. Xanthan gum, Konjac, Xanthan gum, and Guar gum were purchased from TCS Pacific Co. Ltd. Carboxymethyl cellulose (CMC) was bought from NWC Superstore. Transglutaminase and pullulanase were bought from Kinry Food ingredients Co. Ltd. and Sigma, respectively. Resistant assay kit was purchased from Megazyme (Ireland). Jasmin rice 105 was soaked in water for 4 hrs. It was dried in a tray drier at 50°C for 14 hrs. Then, it was finely ground into powder using a blender. The flour was kept in a plastic bag without oxygen and moisture until analysis.

2.2 Preparation of resistant starch

The method used was a slight modification of the method of Pongjanta *et al*. (2008). A 15% rice flour solution was prepared. Then, it was shaken at room temperature for 1 hr. Thereafter, it was incubated in a water bath at 75°C for 30 mins and cooled down to 55°C. Pullulanase enzyme was added to the slurry at levels of 0.05, 0.10, 0.20 and 0.40%. Hydrocolloids: konjac, xanthan gum, guar gum and CMC at the level of 2% of flour were added and incubated for 4 hrs. This was followed by autoclaving at 121°C for 15 mins. After cooling down in an ice water bath, the samples were kept in the refrigerator at 4°C for 16 hrs, and then kept in the freezer at -10°C for 24 hr, followed by thawing at 30°C. The control (without enzyme) was frozen and refrozen 3 times. Finally, the samples were dried at 50°C overnight until dry.

2.2.1 Analysis of resistant starch and determination of glycemic index

Resistant starch (RS) was determined using a Megazyme Resistant Starch kit (K-RSTAR test kit). Approximately 100 mg of samples were incubated in a shaking water bath with pancreatic α-amylase and amyloglucosidase for 16 hrs at 37°C, to hydrolyze digestible starch to glucose. The reaction was terminated with 4 mL of 99% ethanol, and the RS sediment was recovered by centrifugation at 3000 rpm for 10 mins. The supernatant was decanted and washed twice with 50% ethanol to remove the digested starch (DS). The pellets were solubilized in 2 mL of 2 M KOH in an ice bath and neutralized with 8 mL of 1.2 M sodium acetate (pH 3.8). Then, the RS was hydrolyzed to glucose with 0.1 mL of amyloglucosidase (3300 U/mL) at 50°C for 30 mins. Transfer 0.1 mL of aliquots into the tube, and 3.0 mL of GOPOD reagent was added and incubated at 50°C for 20 mins. The glucose oxidase/peroxidase reaction

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was used to measure glucose released from the digested starch and resistant starch. 0.1 mL D-glucose and 3.0 mL of GOPOD reagent were used as standard. Absorbance was read at 510 nm, and RS was calculated using the formula below (Equation 1):

$$RS = \Delta E \times (\frac{F}{W} \times 0.9) \quad (1)$$

where ΔE is the absorbance of the sample, F is [absorbance of sample/absorbance glucose standard (100 μg/mL) × 100]; and W is the weight of the sample (g).

In vitro starch hydrolysis and GI were determined according to the method of Gõni *et al*. (1997). The kinetics of starch hydrolysis were consistent with the equation

$$C = C_\infty (1-e^{-kt}) \quad (2)$$

where C, C_∞ and k are the concentration at time t, the equilibrium concentration, and the kinetic constant, respectively. Using the hydrolysis curve (0-180 mins), the hydrolysis index (HI) was calculated as the percentage of total glucose released from the samples, relative to that released from white bread.

The GI of the samples was estimated according to the equation:

$$GI = (39.71 + 0.549) \times HI \quad (3)$$

Before analysis, the samples were cooked, after which each sample was adjusted to a chewable texture.

2.2.2 Analysis of flour structure

The microstructure of each rice flour was analyzed using scanning electron microscopy (SEM). Samples of powder were placed on aluminum stubs containing carbon tape. The samples were analyzed with SEM (Quanta250, FEI) in high vacuum mode using a secondary electron detector (SED). The SEM was set at an ETV target of about 10-15 keV, the spot size of about 2-4, and a working distance of about 5-10 mm, with magnifications of 300×, 2000× and 6000×.

2.3 Pasta production

2.3.1 Pasta formulation

All materials. i.e., rice flour, pea protein isolate, chickpea flour, lentil flour, mung bean flour, chia seed and spinach powder were prepared as basic pasta recipes. All flours were weighed as shown in Table 1. The compositions of formulations 1, 2 and 3 were the same as those of formulations 4, 5 and 6, but they differed in the type of hydrocolloid used.

Transglutaminase (0.5%) was added to improve texture, and 0.3% salt was used to improve flavor. Then, water was added to each formulation to achieve a moisture content of about 25%. The ingredients were kneaded to form a dough. Thereafter, the dough was covered with plastic wrap and kept at room temperature for about 1 hr before extrusion. The barrel 1, 2, 3 and die condition of extruder were set at 90°C, 90°C,90°C and 70°C, respectively, and screw speed was set at 80 rpm.

Table 1. Levels (%) of ingredients used in formulations of pasta.

Ingredients	F1	F2	F3	F4	F5	F6	*1	*2
Rice flour	20	30	40	20	30	40	22	-
Mung bean flour	25	25	25	25	25	25	17	17
Pea protein isolate	5	5	5	5	5	5	11	11
Chickpea flour	20	15	10	20	15	10	17	17
Lentil flour	20	15	10	20	15	10	17	17
Chia seed	5	5	5	5	5	5	11	11
Spinach powder	5	5	5	5	5	5	5	5
Xanthan gum	2.5	2.5	2.5	-	-	-	-	-
CMC	-	-	-	2.5	2.5	2.5	2.5	2.5
Rice resistance	-	-	-	-	-	-	-	22

*Hydrocolloids (xanthan gum and CMC) were added 2.5% to 100 g of ingredients.

2.3.2 Analysis of chemical composition

The protein and dietary fiber contents of the raw materials were determined according to the method of AOAC Official Method 991.20 (2019) and AOAC Official Method 985.29 (2019), respectively. Nitrogen content was determined using the Kjeldahl digestion method, while fiber contents were analyzed using fiber tech. The pasta was analyzed with respect to levels of protein - AOAC Official Method 991.20, fat - AOAC Official Method 922.06, dietary fiber - AOAC Official Method 985.29, and ash - AOAC Official Method 920.153.

2.4 Pasta quality

2.4.1 Texture analysis

Each pasta was cut to a width and height of about 3 and 10 mm, respectively. The trigger was 2 g, the deformation was 3 mm, and the test speed was 0.5 mm/s. A cylinder probe was used. Texture analysis was done with a Texture Analyzer (Brookfield Ametek, CTX). The following parameters were determined: hardness (g) and adhesiveness (mJ). The tensile strength (g) of pasta was measured. The length of each of the samples prepared was about 15 cm. A Tensile probe was used with a trigger of 5 g, a test speed of 1 m/s, and a deformation of 50 mm. The peak load was read.

2.4.2 Color

The CIE color coordinates, L* (light or dark, 0-100); a* (-redness to greenness) and b* (-yellowness to blueness) were determined using a colorimeter

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(Reflection Spectrometer Avantes).

2.4.3 Cooking yield and cooking loss

The method of the American Association of Cereal Chemists (2000) (Method 66-50) was followed. Approximately 10 g of each pasta was weighed and cooked in 300 mL of water for 10 mins. Then, the pasta was drained of water and weighed. The cooking yield was calculated using equation 4:

$$CY\ (\%) = W1/W2 \times 100 \quad (4)$$

where W1 is the weight of pasta before cooking, and W2 is the weight of pasta after cooking.

After cooking, the beaker was placed in an oven at 105°C to evaporate the water completely. Then, the beaker and remaining material were weighed to determine the cooking loss (CL) using the following formula:

$$CL\ (\%) = W2/W1 \times 100 \quad (5)$$

where W2 is the total mass of pasta residue in the cooking water, and W1 is the weight of the pasta before cooking.

2.4.4 Cooking time

Cooking time was measured according to the method of AACC (2000). Each pasta sample (20 g) was cooked in 300 mL of boiling water, with sampling every 30 s until the white particles of uncooked starch disappeared when compressed with transparent glass. Optimal cooking time was recorded when the core completely disappeared.

2.4.5 Water absorption capacity

Water absorption capacity (WAC) was determined according to the method of Bouasla *et al*. (2016). 10 g of pasta was cooked in 200 mL of boiling water, rinsed with cold water (20°C) and drained for 5 mins. The pasta was weighted and calculated using equation 6:

$$WAC\ (\%) = W2/W1 \times 100 \quad (6)$$

where W2 is Weight of hydrated pasta, and W1 is weight of dry pasta

2.4.6 Sensory evaluation

About 30 g of pasta and 15 g of carbonara sauce were mixed for 1 serving. The characteristics of pure pasta were evaluated first. Then, the characteristics of pasta mixed with sauce were assessed to determine overall preference. Each formulation, which was assigned a three-digit code, was served in random order to a panel of 30 untrained consumers. Acceptance of consumers was assessed using a 5-point hedonic scale, with 1 standing for 'least liked' ,and 5 as 'most liked' , with respect to 5 characteristics, i.e., color, odor, texture, flavor, and overall preference. Thereafter, the best formulation was chosen for the estimation of GI.

2.5 Statistical analysis

Data are reported as mean ± standard deviation (SD). Statistical processing was done using IBM SPSS software, version 24 (IBM Singapore Pte. Ltd., Changi, Singapore). A completely randomized experimental and randomized complete block design was used. Analysis of variance (ANOVA) was used for statistical analyses. Values of $p\leq0.05$ indicated statistically significant differences.

3. Results and discussion

3.1 Resistant starch

The enzymatic, physical modification and hydrocolloids for improvement of resistant starch resulted in RS in the range of 0.05-23.2%, as shown in Table 2. The physical characteristics of the flour sample are shown in Figure 1. The jasmine rice flour without pullulanase enzyme treatment, retrogradation process and hydrocolloids had the lowest RS of about 0.05%, which was significantly different from that of the physical modification value. The physical modifications 1, 2 and 3 were the physically modified rice flour subjected to freeze-thaw treatment 1, 2 and 3 times, respectively, without enzyme. As a result, RS levels of 1, 2 and 3 cycles were similar. Increasing the freeze-thaw durations did not affect the levels of RS. During cooling, a small amount of RS is formed (Skotnicka *et al*, 2015).

Table 2. Resistant contents of different flour.

Sample	Resistant starch (%)
Unprocessed rice flour	0.05 ± 0.01^{a}
Frozen-thawed 1 cycle	0.13 ± 0.01^{b}
Frozen-thawed 2 cycles	0.13 ± 0.01^{b}
Frozen-thawed 3 cycles	0.12 ± 0.01^{b}
0.05% enzyme	4.52 ± 0.02^{e}
0.1% enzyme	23.2 ± 0.05^{i}
0.2% enzyme	1.35 ± 0.03^{d}
0.4% enzyme	1.02 ± 0.02^{c}
2% Konjac	5.32 ± 0.02^{g}
2% Xanthan gum	4.48 ± 0.04^{e}
2% Guar gum	4.60 ± 0.01^{f}
2% CMC	8.10 ± 0.03^{h}

Values are presented as mean±SD. Values with different superscripts within the same column indicate significant differences ($p < 0.05$). 0.05, 0.1, 0.2 and 0.4% enzyme were the levels of pullulanase enzyme per weight of flour. 2% of each hydrocolloid was calculated based on the flour weight.

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This indicates that physical modification may increase starch resistance.

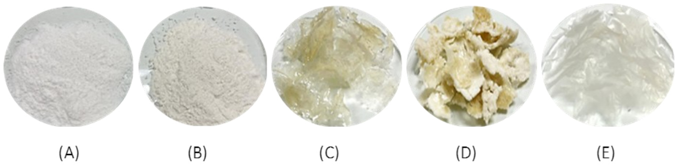

Figure 1. Jasmine rice flour (A). Rice flour with 0.1% pullulanase (B), rice flour with 0.05% pullulanase after drying (C), rice flour with 0.1% pullulanase after drying (D), and rice flour with 2% CMC after drying (E).

Results from pullulanase hydrolysis revealed that the rice flour incubated with 0.1% pullulanase for 4 hrs had the highest level of RS ($p \leq 0.05$). Increasing pullulanase hydrolysis decreased the RS content. It was found that increasing the amount of enzyme led to higher sugar levels due to enzymatic hydrolysis. Pullulanase is a debranching enzyme which rapidly hydrolyzes only α-1,6-glucosidic bonds to produce a linear chain from amylopectin. In addition, retrogradation is often enhanced when starch gels are subjected to freezing and thawing treatments (Tovar *et al*., 2002). The retrogradation process also promotes the formation of types 3 (retrograded starch) and 5 (amylose-lipid complexes) RS (Klostermann *et al*., 2021). Yadav *et al.* (2009) showed that the use of a combination of heating and cooling cycles in starch products increased the RS contents. The use of hydrocolloids had the effect of increasing the amount of RS, especially CMC. Srikaeo and Paphonyanyong (2020) found that hydrocolloid-cooked waxy rice exhibited more retrograded starch than the control and delayed the starch digestion rate.

3.2 Analysis of flour structure

SEM images of the rice samples are shown in Figure 2. The structure of the rice flour (unprocessed) was arranged in the form of crystals. Altered starch structure was observed in the physical modification and enzymatic samples, especially 0.4% pullulanase enzyme. The structure of the rice flour was porous, possibly due to irreversible swelling and fusion of fully starch granules, resulting in the transformation of the crystalline form into an amorphous form.

3.3 Results of pasta analysis

3.3.1 Chemical composition

Before pasta production, the protein and fiber compositions of materials were analyzed. The data are shown in Table 3. The highest protein content was found

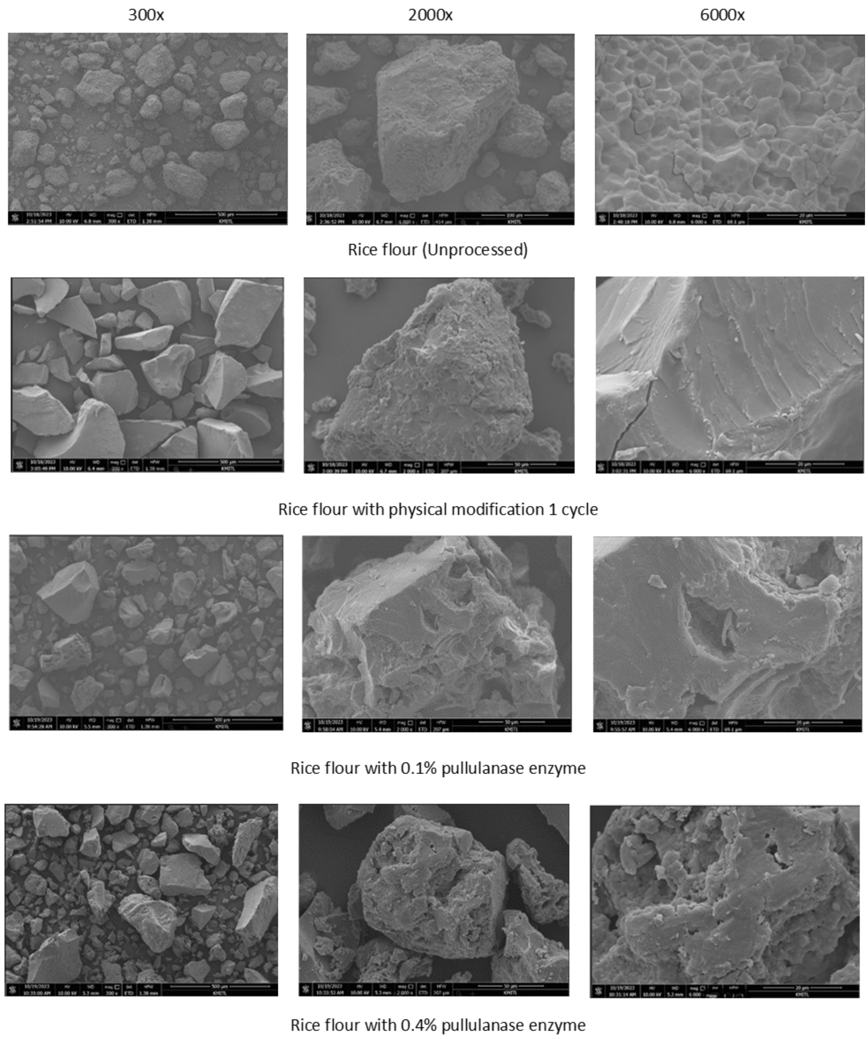

Figure 2. Structures of rice flour as seen using under scanning electron microscope (SEM).

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in pea protein isolate, followed by lentil flour and chia seed flour, with values of 51.4, 19.9 and 18.8%, respectively. Chia seed flour was richer in fiber content than spinach powder (19.78 and 13.82%, respectively). Lentil fortification of spaghetti increased the levels of essential amino acids (Stefano *et al.,* 2021). Chickpea nutrition is rich in fiber, protein, and healthy fat (Reister *et al*, 2020). Chia seeds constitute a complete protein source containing all nine essential amino acids, as well as high levels of fiber and omega-3 fatty acids (Suri *et al.*, 2016). Spinach is high in fiber but low in calories and fat. It is an excellent source of vitamin K, vitamin C, and potassium (United States Department of Agriculture [USDA], 2019). The mung bean is balanced in nutrients such as protein, dietary fiber, minerals, vitamins, and significant amounts of bioactive compounds (Gan *et al*., 2017). The results obtained in analyses of the plant samples showed high nutrient contents. Therefore, the plant samples were suitable for use in the development of pasta products.

Table 3. Protein and fiber contents of all materials.

Material	Protein (%)	Fiber (%)
Jasmine rice flour	8.44±0.02[b]	0.75±0.04[b]
Pea protein isolate	51.4±0.04[g]	0.91±0.01[c]
Chickpea flour	14.6±0.04[d]	1.15±0.01[d]
Lentil flour	19.9±0.02[f]	3.14±0.02[e]
Mung bean flour	5.60±0.02[a]	0.10±0.01[a]
Chia seed	18.8±0.14[e]	19.8±0.04[g]
Spinach powder	10.5±0.02[c]	13.8±0.01[f]

Values are presented as mean±SD. Values with different superscripts within the same column indicate significant differences ($p < 0.05$).

3.3.2 Sensory evaluation

Six formulations of pasta were prepared for the sensory test (Figure 3). Each pasta formulation was cooked and tested with carbonara sauce. The results of the sensory score are presented in Table 4. The pasta containing CMC had a tendency to be a higher score than pasta with xanthan gum, with respect to color, texture and flavor. An increase in level of rice flour resulted in a higher score in texture characteristics, with consumers stating that it led to a softer texture. Similar results were obtained in the analysis of hardness using a texture analyzer (Table 5). Formulations 5 and 6 did not significantly differ in overall preference. Therefore, formulation 5 was chosen for the determination of GI because this recipe tended to have better texture and taste score. The formulation had a GI level of 57.24, which indicated a medium GI level.

Figure 3. Pasta after extrusion (A) and after cooking (B).

Therefore, the composition of the formulation (5) was adjusted to 22% rice flour, 17% mung bean flour, 11% pea protein isolate, 17% chickpea flour, 17% lentil flour, 11% chia seed flour, and 5% spinach powder. It was found that increasing levels of chia (for fiber) and pea (for protein) from 5 to 11% resulted in decreases in GI values. The estimated GI was 55, which was low. The product was still acceptable to consumers, with the high score of overall liking being 4.07. When rice flour was replaced with RS in the recipe, there was a slight decrease in consumer preference. However, the pasta that was produced with RS in the formulation was not sticky in texture, and it was brittle. This formulation may be suitable for children or the elderly. It may be characterized as a high nutritional-value food rich in dietary fiber.

3.3.3 Texture analysis

Table 5 reveals the results of the texture profile analysis of pasta samples with respect to the parameters: hardness, tensile and adhesiveness. Replacement of rice flour with proteins, especially high amounts of chickpea and lentil, resulted in increases in hardness. Reduction of rice flour content using chick pea flour as a substitute caused increased hardness and tensile strength. It has been reported that chickpea has the highest levels of -SH groups and S-S bonds, followed by lentil flour and pea flour (Ladjal-Ettoum *et al*., 2015). The formation of hydrogen bonds increases the strength of starch (Sriroth and Piyajomkwan, 2007). As a result, replacing rice flour with other proteins resulted in a firm texture. Moreover, increased protein content resulted in greater tensile strength. Effect of hydrocolloids on tensile strength, pasta with xanthan gum added had a higher value than CMC. This indicated that it was more flexible than CMC.

The addition of CMC did not result in statistically significant differences in adhesiveness of pasta (a measure of the adhesion strength between the structure of pasta and the contact surface) ($p > 0.05$). In contrast, the addition of RS led to decreases in hardness, tensile strength and adhesiveness. The RS was formed through a retrogradation process, which led to an increase in the crystalline nature of starch molecules, resulting in reduced water solubility and gelling properties. For this reason, pasta with RS was easily ruptured.

Table 4. Acceptance of pastas with different formulations.

Formulation	Color	Odor	Texture	Flavor	Overall acceptance
F1	3.17±0.86[a]	3.60±0.86 [a]	3.30±0.70[a]	3.60 ±0.93[a]	3.47±1.04[a]
F2	3.13±1.04[a]	3.57±0.96[a]	3.33±0.92[a]	3.57±0.86[a]	3.37±0.89[a]
F3	3.20±0.71[a]	3.53±0.73[a]	3.73±0.78[ab]	3.77±0.82[ab]	3.50±1.14[a]
F4	3.60±0.82[b]	3.57±0.86[a]	3.30±0.94[a]	3.50±0.90[a]	3.43±0.99[a]
F5	3.70±0.99[bc]	3.77±1.14[ab]	4.20±0.91[c]	4.11±0.78[b]	4.15±1.12[b]
F6	3.87±1.13[c]	3.73±1.04[ab]	4.00±1.05[b]	4.02±1.01[b]	4.10±1.25[b]
*1	3.88±1.05[c]	3.58±1.00[a]	3.75±0.97[ab]	3.67±1.05[ab]	4.07±0.96[b]
*2	3.90±1.02[a]	3.68±0.87[ab]	3.05±1.02[a]	3.55±0.89[a]	3.10±1.01[a]

Values are presented as mean±SD. Values with different superscripts within the same column indicate significant differences ($p < 0.05$). Formulations 1-3 contained 2.5% xanthan gum and 4-6 adding 2.5% CMC. *1: Adjusted formulation 5 (Table1), *2: Same composition as formulation *1, except that RS was used in place of rice flour.

Table 5. Textures of pastas with different formulations.

Formulation	Hardness (g)	Tensile strength (g)	Adhesiveness (mJ)
F1	4290±91.9[g]	102±11.3[f]	17.69±0.65[bc]
F2	3322±24.8[f]	78±5.66[de]	20.84±0.83[d]
F3	3061±71.4[e]	87±6.36[e]	16.89±0.44[b]
F4	4285±35.4[g]	65±4.95[d]	22.41±0.55[d]
F5	2450±56.6[d]	46±4.24[c]	22.40±0.21[d]
F6	2220±80.6[c]	36±6.36[bc]	20.60±0.57[d]
*1	1932±61.2[b]	28±0.70[ab]	14.88±0.65[b]
*2	1611±17.7[a]	21±0.71[a]	8.05±0.56[a]

Values are presented as mean±SD. Values with different superscripts within the same column indicate significant differences ($p < 0.05$). Formulations 1-3 contained 2.5% xanthan gum and 4-6 adding 2.5% CMC.*1: Adjusted formulation 5 (Table1), *2: Same composition as formulation *1, except that RS was used in place of rice flour.

3.3.4 Cooking quality

The cooking properties of pasta are shown in Table 6. Formulation 2 had the longest cooking time, while formulation 4 had the shortest cooking time. It can be seen that the type of hydrocolloid used affected cooking time. Addition of xanthan gum (formulations 1, 2 and 3) led to longer cooking times than addition of CMC. Moreover, increases in rice flour content did not affect cooking time. These results differ from those reported by Detchewa *et al*. (2022), who found that decreased cooking time of pasta occurred with the replacement of rice flour with rice protein. The differences in the cooking time could be due to differences in the composition of the composite flour used for pasta preparation (Bolarinwa *et al.*, 2021). In a study, it was found that the cooking time of spaghetti depended on the pasting temperature, the degree of gelatinization, and the pasting time of the mixed ingredients (Srirajan *et al.,* 2021).

The highest weight of cooking yield was seen in the formulation with the highest rice flour content. Rice flour at the level of 30 % produced the greatest effect on yield. However, an excessive increase in the amount of rice flour did not maximize yield. This may be due to the effect of the ratio of other ingredients on yield, since the amount of rice flour may not be the only factor that affects yield. It was clear that the higher yield corresponded to higher water absorption of the pasta. Moreover, the hydrocolloid type had no effect on yield and water absorption. Increasing the amount of rice flour

Table 6. Physicochemical properties of pasta with different formulations.

Formulation	Cooking time (min)	Cooking Loss (%)	Cooking yield (%)	Water absorption (%)	L*	a*	b*
F1	18±0.11[d]	6.66±0.06[a]	185.9±5.04[a]	85.94±5.04[a]	33.07±0.02[b]	-3.47±0.01[f]	4.73±0.04[c]
F2	19±0.05d	7.14±0.01[b]	212.7±5.70[bc]	112.7±5.71[c]	34.87±0.69[c]	-3.33±0.03[e]	4.37±0.23[b]
F3	16±0.03[c]	7.68±0.02[c]	198.2±13.4[abc]	101.3±8.95[abc]	36.56±0.56[d]	-3.23±0.01[cd]	3.47±0.02[a]
F4	13±0.14[b]	7.79±0.01[c]	195.0±8.95[ab]	94.96±8.96[ab]	31.68±0.99[a]	-3.15±0.07[c]	5.89±0.034
F5	14±0.02[b]	7.86±0.04[d]	210.3±13.5[abc]	106.4±7.80[bc]	34.71±0.78[c]	-2.94±0.03[b]	5.46±0.01[d]
F6	14±0.09[b]	7.95±0.01[d]	194.0±14.2[ab]	93.85±1.63[ab]	33.45±0.62[b]	-2.87±0.02[b]	4.63±0.02[c]
*1	15±0.04[b]	8.71±0.04[e]	276.5±6.36[d]	170.5±6.33[d]	39.06±0.56[e]	-4.73±0.03[g]	3.51±0.06[a]
*2	11±0.06[a]	11.3±0.08[f]	220.1±9.12[c]	114.0±5.66[c]	42.81±0.13[f]	-2.19±0.02[a]	11.46±0.04[f]

Values are presented as mean±SD. Values with different superscripts within the same column indicate significant differences ($p < 0.05$). Formulations 1-3 contained 2.5% xanthan gum and 4-6 adding 2.5% CMC. *1: Adjusted formulation 5 (Table1), *2: Same composition as formulation *1, except that RS was used in place of rice flour.

resulted in an increased level of solid loss. Substituting rice flour with other proteins reduced cooking loss. In this study, cooking time and cooking loss were in the ranges of 11-19 mins and 6.66 - 11.30%, respectively. Bolarinwa *et al*. (2021) reported that the cooking time and cooking loss of gluten-free rice-soy pasta varied from 15.11 to 15.59 mins and 7.30 to 7.49%, respectively. The color parameters of cooked pasta are shown in Table 6. Higher amounts of rice flour resulted in increases in brightness. The redness (a*) and yellowness (b*) values of pasta tended to increase with increases in the amount of rice flour substituted.

3.3.5 Nutrient compositions and glycemic indexes

The proximate composition of rice flour and the pastas is presented in Table 7. Jasmine rice flour showed low levels of protein and fiber, and high carbohydrate content, while pasta with rice flour and pasta with resistant starch had high nutritional value, with protein, fiber and carbohydrate levels of approximately 19.71-19.76, 4.35-6.47, and 65.93-67.73%, respectively. These results are similar to those of Petitot *et al.* (2010), who reported that the protein, fiber and carbohydrate contents of a formulation containing 65% durum wheat semolina + 35% faba bean flour were 18.8, 4.1 and 66.0%, respectively. Moreover, commercial spaghetti with durum wheat had protein, fiber and carbohydrate levels of 13.3, 2.4 and 77.6%, respectively (Petitot *et al.*, 2010). There were no differences in nutritive value between pasta with rice flour and pasta with resistant starch. Both contained high protein and fiber contents. Dietary fiber assists in decreasing the digestibility of starchy foods and producing lower glycemic responses (Zhang *et al*.,2022). The use of RS in place of rice flour may not change the nutritional profile of the pasta. However, it may slightly reduce carbohydrate intake. The results obtained in GI estimation showed that rice flour had a medium GI (65), while pastas with RF (55) and RS (52) were classified as low-GI foods.

Incorporation of 25% chickpea flour into spaghetti resulted in a significantly lower GI (58.9) than traditional spaghetti (72.8). Chickpea flour, an ingredient in pasta products, results in a food product with a low glycemic response (Goni, 2003). A 20% low glycemic index-high fiber (LGI-HF) rice flour has been produced using enzymatic and physical modification of chocolate chip (Parinya *et al*., 2018). Results from the estimation of GI showed a lower value for the developed cookies (60.63) than the control (72.01) .Guar gum (GG) and CMC, which are soluble fibers incorporated into pasta, were found to significantly reduce the rate of *in vitro* digestion of starch, which is beneficial to health due to low GI (Aravind *et al*., 2012). Moreover, the amount of reducing sugars produced after 300 mins was reduced by 18% after incorporation of 1.5% CMC, and by 24% after incorporation of 20% GG (Aravind *et al*., 2012). Food formulation and processing technologies have been recognized as the most important factors that affect the GI of food products (Bahado-Singh *et al.,* 2020).

4. Conclusion

The combination of physicochemical, enzymatic processes and hydrocolloids increased the level of resistant starch in rice. The use of 0.1% pullulanase for 4 hrs and one cycle of rice retrogradation (heat/freeze-thaw) process produced the highest resistant starch level. The addition of legume and cereal flours improved the nutritional value of the pasta products. However, too much legume or cereal flour affected the quality of the pasta by increasing its firmness. Moreover, pasta with RS had a low GI (52), which classifies it as a low GI food. In addition, the pasta contained high contents of protein and fiber. An alternative way of developing a low GI pasta may be by selecting raw materials with low starch content and high fiber content, or using hydrocolloids which reduce GI. In further studies, it may be necessary to investigate the antioxidant levels and shelf life of the product.

Conflict of interest

The authors declare no conflict of interest.

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Table 7. Nutritional values and predicted glycemic index (pGI) of Jasmine rice flour and pasta.

Sample	Moisture (%)	Fat (%)	Ash (%)	Fiber (%)	Protein (%)	Carbohydrate (%)	Energy (kcal/100 g)	pGI
JRF	13.55±0.01[c]	0.47±0.01[a]	0.37±0.01[c]	0.76±0.01[a]	8.45±0.01[a]	77.10±0.02[c]	347.15±0.02[a]	65.57±0.07[c]
PRF	8.63±0.03[a]	3.61±0.02[b]	0.31±0.00[b]	6.47±0.00[c]	19.71±0.04[b]	67.73±0.02[b]	383.85±0.05[b]	55.27±0.41[b]
PRS	9.56±0.01[b]	4.55±0.01[c]	0.18±0.00[a]	4.35±0.01[b]	19.76±0.03[b]	65.93±0.05[a]	382.34±0.10[b]	52.65±0.25[a]

Values are presented as mean±SD. Values with different superscripts within the same column indicate significant differences ($p < 0.05$). JRF: jasmine rice flour, PRF: pasta with jasmine rice flour, PRS: pasta with rice resistant starch.

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