Development of low glycemic index instant porridge from taro, sweet corn, and red bean

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ABSTRACT

Taro's dietary fiber content contributes to its potential as a low glycemic index food, although the glycemic index has yet to be established. Sweet corn (glycemic index 37) and red beans (glycemic index 20) are also recognized for their low glycemic index. The present research aims to develop a low glycemic index instant porridge using taro, sweet corn, and red beans as functional ingredients to support blood glucose control. The glycemic index of taro was initially determined before milling taro, sweet corn, and red beans into flour. Three formulas were developed with different proportions of taro, sweet corn, and red bean flour (Formulas 1 to 3): 50:25:25, 25:50:25, and 25:25:50. The instant porridge samples were evaluated for glycemic index, physicochemical properties, and sensory profile using the Rate-All-That-Apply and hedonic methods. The findings showed taro has a moderate glycemic index of 60. Formula 3 was identified as the optimal formula because it contained high levels of total dietary fiber (17.45 g/100 g), high protein (24.21 g/100 g), and resistant starch (4.51 g/100 g), along with sensory acceptance (5.35 out of 7). The results showed significant differences among the formulas (p < 0.05). A higher proportion of red bean in formula 3 positively affected chemical characteristics and sensory acceptance of the instant porridge. Formula 3 also had a low glycemic index (35) and a low glycemic load (9.9).

Contribution/Originality: This study presents a novel approach to improving food matrices that can help regulate postprandial glucose levels. As no previous research has examined the glycemic index of taro, this study highlights its originality. The results will contribute to the literature on developing a new instant porridge made from taro, sweet corn, and red bean, thereby influencing functional food innovation.

1. INTRODUCTION

Type 2 Diabetes Mellitus (DM) is a metabolic disorder characterized by ineffective insulin production, known as insulin resistance. Several studies have shown that a diet rich in low-glycemic index (GI) foods, high in fiber, resistant starch, and protein, can help prevent type 2 DM and manage the condition in diagnosed individuals (Manullang, Rahadiyanti, Pratiwi, & Afifah, 2020). The GI, as noted by Rimbawan and Siagian (2004), is a food score indicating its effect on blood glucose levels, categorized as low (≤55), moderate (55−70), and high (≥70). GI does not describe the magnitude and duration of blood glucose increase after eating. Conversely, glycemic load (GL) more accurately

assesses a food's actual impact on post-meal blood sugar levels (Vlachos, Malisova, Lindberg, & Karaniki, 2020). The GL, as stated by Franz (2012), consists of three groups of food values: low (≤10), moderate (11−19), and high (≥20).

Taro (Colocasia esculenta L. Schott), available in Indonesia's Bogor region, is a rich source of carbohydrates and fiber. For decades, fresh taro and processed products like sponge cake have been produced in Bogor as souvenirs. However, taro has limited uses and a short shelf life, according to a study by Saxby, Li, Lee, and Kim (2019). Taro is considered a high-fiber food, with total dietary fiber reaching 4.1%. Despite its health benefits, there is no prior research on its glycemic index (GI) using the standardized ISO 26642:2010 method.

Recent research indicates that adjusting carbohydrate intake can help prevent blood sugar spikes. The goal is to slow glucose absorption into the bloodstream by using low-GI ingredients, resistant starch, dietary fiber, and innovative food processing techniques. Incorporating soluble dietary fiber, modified starches, proteins, and plant polyphenols into foods like noodles has been shown to significantly lower GI by delaying starch digestion and glucose absorption, thereby aiding better blood glucose management (Cui et al., 2024). According to a recent review by Jeevarathinam et al. (2024), new food processing methods address high-GI primarily in two ways: first, by designing foods with added fiber and protein to slow digestion; second, by controlling thermal processing parameters like heating duration and moisture to chemically and physically modify starch. These developments highlight the significance of carbohydrate modification in managing blood glucose levels.

Sweet corn and red bean, with established GI values of 37 and 20, show potential as ingredients for low-GI food products (Afandi, Wijaya, Faridah, Suyatma, & Jayanegara, 2021; Daniels, 2022). After determining taro's GI, instant porridge was developed using a mixture of taro, sweet corn, and red bean. The porridge was made from low-moisture composite flour of taro, sweet corn, and red bean, processed into pregelatinized flour by steaming and drying. Pregelatinization increases slowly digestible and resistant starches, which can reduce glycemic response and help maintain stable blood glucose levels after meals (Agama-Acevedo, Bello-Perez, Lim, Lee, & Hamaker, 2018).

Moreover, instant porridge has a smooth texture, is easy to consume, and is simple to prepare with hot water. This makes it suitable for individuals, especially children and patients. The product development offers a dietary alternative to help manage and prevent type 2 DM. This research aims to: (1) determine the GI value of taro, (2) evaluate the physicochemical characteristics of flour and instant porridge, and (3) determine the GI value of instant porridge based on the optimal formula from chemical and sensory analysis.

2. MATERIALS AND METHODS

2.1. Materials

Raw materials, including taro (Silk variety), sweet corn (Exotic variety), and red bean (Kidney variety), were sourced from Kemang Market in Bogor, Indonesia. Additional components such as skim milk powder (Nestlé SA Ltd., Switzerland), sucralose (Mitra Tiga Sepakat Ltd., Indonesia), salt (Susanti Megah Ltd., Indonesia), and vanilla powder Koepoe (Gunacipta Ltd., Indonesia) were used.

2.2. Determination of Glycemic Index Value

This part of the method consists of two stages. First, the GI of taro was determined. One kilogram of taro was peeled, washed, chopped into 1 cm cubes, soaked in 1 L of 10% NaCl solution for 60 minutes to reduce calcium oxalate, rinsed, and steamed using a steam blancher ME-50 (Miura Ltd., Japan) at 90−100°C for 15 minutes. GI testing followed the ISO 26642:2010 in vivo protocol with 10 healthy adult participants (fasting glucose <100 mg/dL, no diabetes history, and who had completed the informed consent). Subjects consumed 50 g of available carbohydrates from taro or glucose (reference) after a 10-hour fast. Blood glucose was measured via capillary samples at 15, 30, 45, 60, 90, and 120 minutes using a One Touch Ultra Lifescan glucometer (Johnson & Johnson Ltd., USA). Glycemic response was assessed by calculating the incremental area under the curve (iAUC).

In the second stage, the optimal instant porridge formula was selected based on the highest dietary fiber, protein, and resistant starch content, due to their presumed inverse relationship with GI. Sensory characteristics were also considered for product acceptability. The test portion was calculated from chemical analysis and served freshly by reconstituting powder in hot water (90 ± 2 °C) at a 1:3 (w/v) ratio. GI and glycemic load (GL) were calculated using Equation 1 and Equation 2.

$$GI = \frac{\text{iAUC Average of Test Food}}{\text{iAUC Average of Glucose}} \times 100 \qquad (1)$$

$$GL = \frac{GI \times \text{Amount of Carbohydrates (g) in A Serving Food}}{100} \qquad (2)$$

2.3. Flour Production

Raw materials are processed into flour using a drum drying method, as outlined in previous studies by Wiriyawattana, Suwonsichon, and Suwonsichon (2018). The process involved peeling, cutting, and thorough washing of the raw materials, followed by steaming in a steam blancher ME-50 (Miura Ltd., Japan) at 90-100°C for 15 minutes. The materials were then processed in a double drum dryer (Simon Ltd., UK). Drum dryer parameters included a surface temperature of 110°C, a speed of 3 rpm, a gap of 0.02 cm, and a steam pressure of 4.5 kg/cm². Thin sheets from the drying process were crushed using the Fct-Z500 miller machine (FOMAC Ltd., Indonesia) and sieved through a 250 μm mesh. Pregelatinized flour was stored in low-density polyethylene bags.

2.4. Formulation of Instant Porridge

The formulation of instant porridge powder was based on the proportion of taro flour to sweet corn flour and red bean flour, with three formulas: F1 (50:25:25), F2 (25:50:25), and F3 (25:25:50). The main ingredients included taro, sweet corn, and red bean flour. Supporting ingredients were 14.60% skim milk, 0.01% sucralose, 0.1% salt, and 0.10% vanilla powder. These formulations considered each flour's chemical characteristics, including proximate and dietary fiber content. All ingredients were mixed using a hand mixer HR1559 (Philips Ltd., Netherlands), and the instant porridge was stored in low-density polyethylene bags.

2.5. Chemical Analysis

Both the flours and the three instant porridge formulas were analyzed for proximate composition, including moisture, ash, fat, protein, carbohydrate, and total dietary fiber, following the method of Association of Official Agricultural Chemists (2010). Duplicate measurements were performed for each sample. Moisture content was determined by drying samples in a hot air oven (Memmert model UNE 500, Eagle, WI, USA) at 105 °C until reaching constant weight. Ash content was measured by incineration of organic matter in a muffle furnace (Carbolite model CWF 1100, Hope, UK) at 550 °C. Total fat was extracted using the Soxhlet method (922.06), involving acidic digestion and hexane solvent extraction. Protein content was assessed via the Micro Kjeldahl method (960.52), with digestion and distillation units (BÜCHI Corporation, USA), and calculated using a conversion factor of 6.25. Carbohydrate content was derived by difference. Total dietary fiber was evaluated using the enzyme gravimetric method (985.29). The enzymatic method by Goñi, Garcia-Diz, Mañas, and Saura-Calixto (1996) was used to determine the resistant starch of the samples.

2.6. Sensory Analysis

The hedonic rating method was conducted following standards outlined by the National Standardization Agency. All samples were prepared on the same day and served fresh. Each sample was weighed at five grams in a plastic cup labeled with a three-digit code, then reconstituted with hot water (90 ± 2 °C) at a ratio of 1:3 (w/v). The randomization process adhered to ISO 11136:2014 standards. Cooked porridge samples were cooled for 10 minutes before serving to panelists. A hedonic test involved 70 panelists (n=70), aligning with Indonesia's National

Standardization Agency requirements. Evaluation focused on aroma, color, taste, texture, and overall liking, using a seven-point hedonic scale (1= very unfavorable to 7= very favorable). This methodology ensured standardized sensory analysis, providing reliable data on consumer preferences while maintaining consistency with established standards.

The sensory profile analysis was conducted through focus group discussion (FGD) and the Rate-All-That-Apply (RATA) test. The FGD involved untrained panelists, four males and six females, from the Food Science and Technology program at Bogor Agricultural University. Panelists were familiarized with a sensory lexicon from previous research on millet flour-based instant porridge (Onyeoziri, Torres-Aguilar, Hamaker, Taylor, & de Kock, 2021), which served as a reference for the attributes list. They tasted three samples: two commercial products and one optimal formula from this study. The commercial products included a cereal beverage and instant arrowroot porridge with vanilla flavor. In the RATA test, panelists rated the intensity of perceived attributes on a 5-point scale (1=very weak, 5=very strong), with absent attributes not rated. The discussion aimed to analyze sensory attributes and compare the samples' profiles.

2.7. Physical Analysis

The analysis focused on three instant porridge formulas, examining their physical properties, specifically Water Absorption Index (WAI) and Water Solubility Index (WSI). These measurements followed methods outlined by Mandge, Sharma, and Dar (2014) and Yadav, Chhikara, Anand, Sharma, and Singh (2014). Each sample was tested in duplicate. WAI involved weighing 3 g of dry sample, dispersing it in 30 mL of distilled water in a 50 mL centrifuge tube, and stirring gently at 3000 g for 15 minutes. The supernatant was then poured into an evaporating dish, dried, and weighed until constant. The remaining pellet's weight was used to calculate WAI. WSI was determined by measuring the dried precipitate from the supernatant, expressed as a percentage of the original sample weight. This method provided consistent, reliable data on the physical characteristics of the porridge formulas.

Bulk density was determined by weighing an empty 50 mL measuring beaker, then adding the sample until it reached the calibration mark, and reweighing the beaker. The bulk density value was calculated based on the ratio of the sample weight to the volume of the measuring beaker. Rehydration time was measured by adding boiling water at 100 °C to the sample at a ratio of 1:4 (w/v). The time for the sample to absorb water until the texture became homogeneous was recorded using a stopwatch (Yu, Chen, & Wu, 2011). The samples' color parameters (L*, a*, b*) were determined using a Konica Minolta Chromameter CR-400.

2.8. Statistical Analysis

The results obtained were analyzed using Analysis of Variance, followed by Duncan's Multiple Range Test at a significance level of p-value < 0.05. The analysis results were expressed as mean ± standard deviation. The sensory profile (Rate-All-That-Apply) results were analyzed by Principal Component Analysis (PCA) using XLSTAT software (ver. 2024).

3. RESULTS AND DISCUSSIONS

3.1. Glycemic Index Value of Taro

Table 1 shows the results for each participant's taro GI, which were analyzed. Carbohydrate content, total dietary fiber, and available carbohydrate of steamed taro were measured at 34.83 g ± 0.1 wb, 3.73 g ± 0.1 wb, and 31.10 g, respectively. The available carbohydrate was calculated by subtracting dietary fiber from total carbohydrate. To achieve an intake of 50 g of available carbohydrates, each subject needed to consume 160.77 g of taro, based on the available carbohydrate content. All participants exhibited coefficient of variation values between 8.13% and 19.43% when consuming reference foods. These values comply with ISO 26642:2010, which requires intra-subject variation

to be below 30% for accurate results. Including at least 10 participants, as recommended by Wolever (2013), ensures statistical power (80% at $p \leq 0.05$) and maintains precision.

Ten healthy non-diabetic volunteers, including seven women and three men, participated in this study. Their ages ranged from 21 to 51 years, with an average body mass index of 23.48 kg/m². The glycemic index (GI) of taro was 60 ± 10.4, classifying it as a moderate GI food. This value is lower than the in vitro GI estimate of 63.1 ± 2.5 reported by Simsek and El (2015). Differences between this study and previous literature may result from the in vitro method, which tends to produce higher estimated GI values compared to the in vivo method (Ferrer-Mairal et al., 2012).

Table 1. Glycemic index values of taro from ten participants.

Subjects	Glucose iAUC (mg/dL)	Taro iAUC (mg/dL)	Glycemic Index
1	4313.0	2730.0	63
2	7610.3	4050.9	53
3	5388.7	2605.7	48
4	4960.0	3660.6	74
5	5531.5	2261.6	41
6	6236.2	3615.0	58
7	4685.2	3319.1	71
8	6390.0	3937.5	62
9	12206.2	8317.6	68
10	5372.9	3491.7	65
Mean ± standard deviation			60 ± 10.4

3.2. Chemical Characteristics of Taro, Sweet Corn, and Red Bean Flour

Significant differences were observed among the samples for proximate parameters and total dietary fiber of taro flour, sweet corn flour, and red bean flour (Table 2). Red bean flour exhibited the highest water (9.57%), ash (4.28%), protein (25.33%), and total dietary fiber (25.49%) content, reflecting naturally higher levels in raw Indonesian red beans (14.33%, 3.61%, 25.23%, and 25.75%, respectively) (Ratnawati, Desnilasari, Surahman, & Kumalasari, 2019). The results indicate that all three types of flour used qualify as high-fiber foods, containing more than 6 g of total dietary fiber per 100 g (The European Parliament and The Council of the European Union, 2006). Sweet corn flour exhibited the highest fat content at 15.83%, likely due to the inherent characteristics of sweet corn, which typically contains higher protein and fat content than other cultivars (Budak & Aydemir, 2018). Taro flour exhibited the highest carbohydrate content because carbohydrates are the main component of fresh taro, ranging from 62.43% to 76.08% (Boampong, Aboagye, Nyadanu, Essilfie, & Adu Amoah, 2019).

Table 2. Chemical characteristics (% dry basis) of taro, sweet corn, and red bean flour.

Samples	Water	Ash	Fat	Protein	Carbohydrate	Total dietary fiber
Taro flour	7.16±0.0[c]	3.10±0.0[c]	7.69±0.1[c]	6.25±0.1[c]	81.24±0.0[a]	10.00±0.1[c]
Corn flour	7.85±0.0[b]	3.66±0.0[b]	15.83±0.0[a]	13.16±0.0[b]	67.42±0.1[b]	23.69±0.1[b]
Red bean flour	9.57±0.0[a]	4.28±0.0[a]	8.15±0.1[b]	25.33±0.1[a]	62.18±0.1[c]	25.49±0.2[a]

Note: Means with different letters (a,b,c) in the same column were significantly different at $p < 0.05$.

3.3. Chemical Characteristics of Instant Porridge

The results in Table 3 showed that F3 had the highest values for moisture content (7.89%), ash (4.71%), protein (24.21%), total dietary fiber (17.45%), and resistant starch (4.51%). These results indicate that increasing the proportion of red bean flour used leads to higher values of moisture content, ash, protein, total dietary fiber, and resistant starch in the instant porridge, consistent with the chemical characteristics of red bean flour in this study (Table 3). Higher protein content in food is negatively correlated with GI because protein stimulates insulin secretion, helping control blood glucose levels (Bin Arif, Budiyanto, & Hoerudin, 2013).

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The highest resistant starch content in F3 may be due to the naturally higher level of resistant starch in red bean flour, as reported by Thuy et al. (2022), with a value of 15.54%. In contrast, resistant starch in taro flour (4.13%) and sweet corn flour (1.8%) is lower (Ratnawati et al., 2019). Resistant starch is classified into different categories: low (1-2.5%), medium (2.5-5.0%), high (5.0-15%), and very high (≥15%) (Goñi et al., 1996). It is a critical factor, along with dietary fiber and protein, influencing the quality of instant porridge because it affects the glycemic index (GI). All formulas fall into the moderately resistant starch category (3.05-4.51%). Resistant starch lowers GI by resisting digestion due to its compact molecular structure, preventing blood glucose spikes (Afandi et al., 2021). The highest fat content was found in F2 (9.13%), attributed to the higher fat content of sweet corn flour, consistent with its chemical characteristics.

Table 3. Chemical characteristics (% dry basis) of all instant porridge formulas.

Treatment	Water	Ash	Fat	Protein	Carbohydrate	Total dietary fiber	Resistant starch
F1	7.14±0.0[c]	4.71±0.0[a]	6.26±0.3[b]	15.24±0.3[c]	73.79±0.8[a]	12.94±0.3[c]	3.40±0.0[b]
F2	7.50±0.0[b]	4.72±0.0[a]	9.13±0.6[a]	19.15±0.4[b]	66.99±0.3[b]	14.65±0.5[b]	3.05±0.1[c]
F3	7.89±0.0[a]	4.93±0.0[a]	7.89±0.4[a]	24.21±0.2[a]	62.97±0.1[c]	17.45±0.2[a]	4.51±0.2[a]

Note: Means with different letters (a,b,c) in the same column were significantly different at $p < 0.05$. Proportion of taro flour to sweet corn flour, and red bean flour, F1= 50:25:25, F2= 25:50:25, and F3= 25:25:50.

The total dietary fiber content in all instant porridge formulas (12.94−17.45%) met the criteria for the high-fiber food category, with total dietary fiber exceeding 6 g per 100 g (The European Parliament and The Council of The European Union, 2006). The American Diabetes Association recommends a dietary intake of 25 to 38 g/day for patients with diabetes (McRae, 2018). Consuming 45 g servings of instant porridge, as indicated in this study, can meet up to 31.4% of the dietary intake for patients with diabetes. Dietary fiber reduces the glycemic index by slowing starch digestion and extending intestinal transit, acting as a physical barrier that limits enzyme and substrate interaction in the intestine (Afandi et al., 2021).

3.4. Physical Characteristics of Instant Porridge

The physical characteristics of all instant porridge formulas based on taro, sweet corn, and red bean ratios are shown in Table 4. Bulk density values in this study varied, with F3 having the highest (0.6 g/cm³). A higher bulk density indicates that the same volume of powder is heavier. Powder products generally have bulk densities in the 0.30-0.80 g/cm³ range. Powders with low density tend to maintain consistent volume during storage, which is advantageous for products where volume consistency is crucial (Kumar & Saini, 2016). F1 exhibited the highest WAI (5.70 g/g), likely due to its larger proportion of taro flour. The highest WSI percentages were observed in F2 (19.23%) and F3 (17.63%). Because of its higher WAI, F1 also appeared to have the shortest rehydration time, which enhances water absorption and the formation of the desired texture (Shafi et al., 2016). Additionally, F1 had the highest L* value, indicating low redness (a*) and yellowness (b*), probably related to its higher taro flour content. Conversely, F2 showed high a* (5.34) and b* (27.53) values, indicating stronger redness and yellowness, attributable to its higher proportion of sweet corn flour, which consistently exhibited the highest a* and b* values (Table 3).

Table 4. Physical characteristics of instant porridge.

Treatment	Bulk density (g/cm³)	Water absorption index (WAI g/g)	Water solubility index (WSI %)	Rehydration time (s)	Color values		
					*L**	*a**	*b**
F1	0.52±0.0[b]	5.70 ± 0.0[a]	8.93±0.8[b]	8.50±0.0[c]	79.25±0.2[a]	4.25±0.0[c]	22.63±0.2[b]
F2	0.47±0.0[c]	4.58 ± 0.0[b]	19.23±0.9[a]	16.13±0.2[b]	77.13±0.2[b]	5.34±0.1[a]	27.53±0.5[a]
F3	0.61±0.0[a]	4.56 ± 0.0[b]	17.63±0.8[a]	17.35±0.1[a]	77.17±0.7[b]	4.68±0.1[b]	22.08±0.1[b]

Note: Means with different letters (a,b,c) in the same column were significantly different at $p < 0.05$. (*) refers to the CIELAB color space. Proportion of taro flour to sweet corn flour, and red bean flour, F1= 50:25:25, F2= 25:50:25, and F3= 25:25:50.

3.5. Hedonic Quality of Instant Porridge

Significant differences were observed among the sensory attributes of all instant porridge formulas based on the proportion of taro flour to sweet corn and red bean (Figure 1A). The results showed that F3 had the highest acceptance across all sensory attributes except texture.

The high rating for the taste of sample F3 could be attributed to a preference for bean flavor, due to the higher proportion of red bean used in the formula. All sensory attributes for the three instant porridge formulations scored above the acceptability threshold of 4.00, with averages of F1 (5.00), F2 (5.26), and F3 (5.35). A food product with a score above four on the seven-point hedonic scale for overall acceptability is considered to have reasonable or adequate quality.

Therefore, the overall acceptance of all formulations in this study meets the threshold and can generally be regarded as good quality products (Meilgaard, Civille, & Garr, 2016).
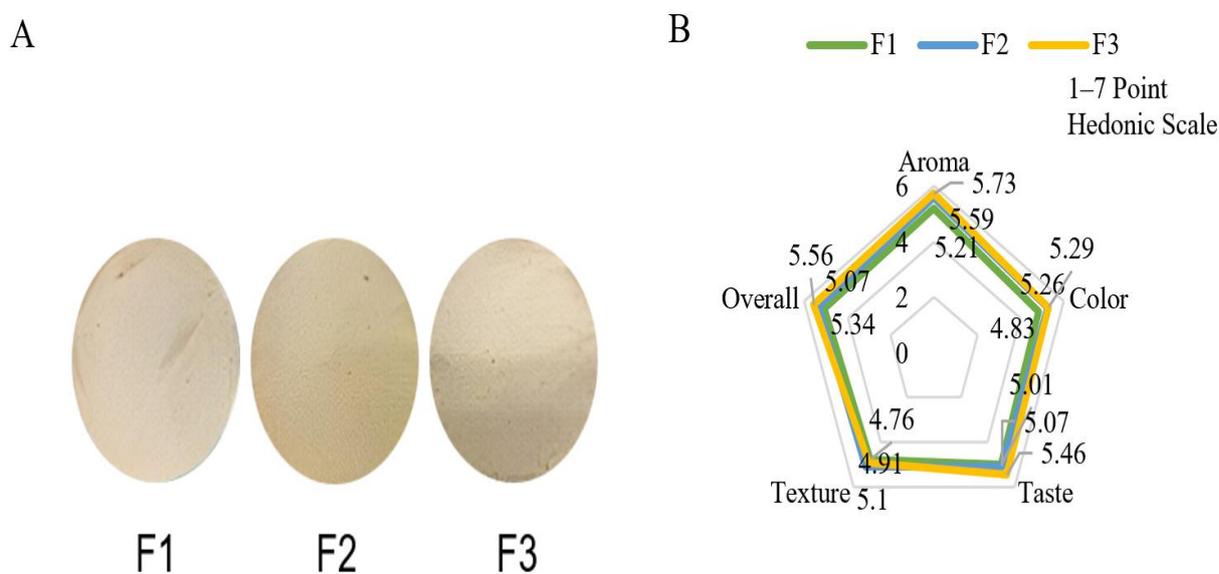

Figure 1. A. Instant porridge product, B. Hedonic test scores of instant porridges.

Note: (N=70; 1–7 Hedonic Scale, 1 = Very unfavorable, 7 = Very favorable).

3.6. The Optimal Instant Porridge Formula

The selection of the optimal formulation was primarily guided by factors such as dietary fiber, protein, and resistant starch content, given their recognized inverse correlation with GI (Afandi et al., 2021; Manullang et al., 2020). Sensory characteristics were crucial in determining product acceptability. F3 was identified as the optimal formula, with a high dietary fiber content (17.45%), a moderate level of resistant starch (4.51%), and the highest sensory acceptance score (5.36 out of 7). Physical characteristics were not considered in the selection process because they showed no correlation with GI, although they may still influence sensory properties and consumer preferences.

3.7. Sensory Profile of the Optimal Instant Porridge Formula

Through the focus group discussion, 33 sensory attributes of instant porridge products (a mixture of taro, sweet corn, and red bean) were identified. These attributes, shown in Table 5, included color, texture, aroma, taste, flavor, and mouthfeel. Panelists defined and agreed on specific terminology for these new attributes.

Table 5. Sensory attributes of the optimal instant porridge formula (formula 3).

Parameter	Attribute	Definition	Test Method
Color	Brownish yellow Ivory Purple	Brown with a yellow undertone Yellow with a cream undertone Purple dominant	Visual
Aroma	Grain Starchy Roasted Nutty Malty Vanilla Caramel	The aroma resembles cooked pasta The aroma associated with raw starch Distinct roasted aroma with no burnt notes Nut-like aroma Sweet cereal or grain aroma Vanilla aroma The aroma of caramelized sugar	Orthonasal
Taste	Umami Sweet	The basic taste sensation characteristic of monosodium glutamate Sugar-like sweetness	Mastication
Flavor	Grain Starchy Roasted Caramel Milky Vanilla Nutty Tuberous	The complex flavor is perceived as characteristic of cooked pasta The flavor associated with raw starch Distinct toasted flavor with no burnt notes Sweet caramel flavor Dairy milk flavor Vanilla flavor Nutty flavor Sweet and earthy flavor	Retronasal
Mouthfeel	Lumpy Sticky Grainy Rough	A discrete aggregate on the tongue The adhesive quality of the material that sticks to the teeth and the roof of the mouth The tactile sensation of small, distinct particles perceived on the oral surfaces A coarse, uneven tactile sensation	Mouth Tactile
Aftertaste	Bitter Starchy Nutty Sweet Sour	Residual bitter taste Residual starch or flour-like taste Residual nutty flavor Residual sweetness Residual sour taste	Retronasal after swallowing
Texture	Sticky Lumpy Rough	The sticky texture of the product The lumps of porridge A coarse texture resembling a surface that lacks smoothness	Finger Tactile

The Principal Component Analysis biplot graph in Figure 2 provides a visualization of the sample distribution within quadrants (score plot). When two attributes are located far from the center and are adjacent in the biplot, they exhibit a strong positive correlation. Samples in the same quadrant suggest shared characteristics (Vidal et al., 2020). Sample F3 displayed a more diverse sensory profile compared to the other two commercial products, including 15 attributes such as sticky texture, sticky mouthfeel, sour aftertaste, rough mouthfeel, brownish-yellow color, umami taste, bitter aftertaste, nutty aroma, nutty flavor, nutty aftertaste, sandy mouthfeel, starchy flavor, starchy aftertaste, roasted aroma, and roasted flavor. The nutty flavor is positively associated with umami taste, starchy flavor, and sandy mouthfeel. Since the product contains red kidney beans, which are predominant in the sample and high in protein, glutamic, and aspartic acids, the umami taste is intensified in the sensory evaluation (Yeasmin, Prasad, & Sahu, 2024). The starchy flavor is influenced by the starch content of the ingredient used in this study. Additionally, the rough mouthfeel results from particle size and insoluble fiber, which absorb water and create a coarse texture (Shewry et al., 2023). The milky flavor negatively correlates with roasted aroma and flavor attributes, which are related to pyrazine compounds formed during the Maillard reaction in legume products (Pedron, Jaouhari, & Bordiga, 2025). In the F3 product, the milky flavor, influenced by skim milk in the formulation, is masked by the dominant roasted aroma and flavor.
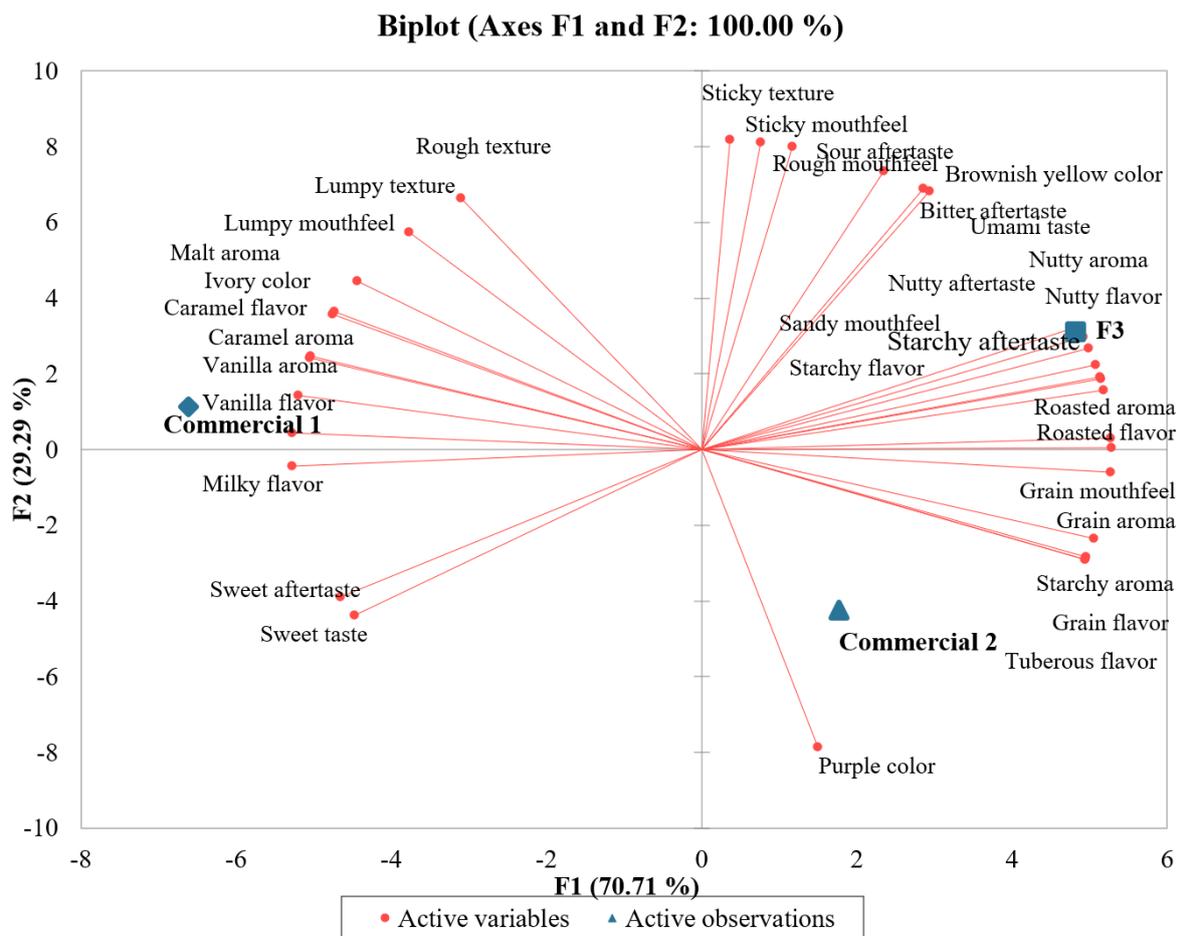
Biplot (Axes F1 and F2: 100.00 %)

Figure 2. Biplot principal component analysis (PCA.

Commercial 1 exhibited seven attributes, including rough and lumpy texture, lumpy mouthfeel, malty aroma, ivory color, caramel flavor, caramel aroma, vanilla flavor, and vanilla aroma. The lumpy texture in Commercial 1 is associated with the high concentration of whey protein in the composition. According to Laiho, Williams, Poelman, Appelqvist, and Logan (2017), the addition of whey protein to food products can cause a lumpy texture when dissolved in water.

Commercial 2 exhibited four attributes: starchy aroma, grain flavor, tuberous flavor, and purple color. The addition of inulin may influence the starchy aroma and fibrous mouthfeel attributes in this product. Inulin, a non-digestible polysaccharide classified as a fructan, consists of fructose chains linked by β-(2-1)-D-fructosyl-fructose bonds. When added to food products, inulin enhances the starchy aroma and flavor in rice starch and imparts a fibrous texture (Wang, Wan, Liu, Xia, & Ding, 2019). The grain-like aroma and flavor attributes in commercial sample 2 are primarily due to oat flour as the main ingredient. Additionally, purple sweet potato contributes a tuber-like flavor and purple hue to the product used in this study.

The sample's attributes are distributed across different quadrants, highlighting its distinctive sensory properties. During development, the product's sensory characteristics are distinguishable from those of other commercialized products, such as cereals and instant porridge. This comparison emphasizes the F3 sample's unique features and potential market position.

3.8. Glycemic Index Value of the Optimal Instant Porridge Formula

The determination of the GI value for the optimal instant porridge formula (Formula 3) was based on the average GI values of ten subjects, as shown in Table 6. The GI of Formula 3, with an available carbohydrate content of 42.19% WB, was 35 ± 6.88 (reference food, glucose = 100). Formula 3 was classified as low GI (<55) (Rimbawan & Siagian,

2004). The raw materials used in this study contributed to the low GI of the instant porridge, as their GIs ranged from moderate to low. F3, which had the highest proportion of red bean with the lowest GI among the materials used (26), also had the highest dietary fiber and resistant starch, contributing to the low GI results (Afandi et al., 2021; Manullang et al., 2020).

Table 6. Glycemic index values of Formula 3 instant porridge from ten participants.

Subjects	Glucose iAUC (mg/dL)	Formula 3 iAUC (mg/dL)	Glycemic index	Glycemic load
1	4114.89	1672.50	41	
2	7610.33	2877.50	38	
3	5388.75	1545.00	29	
4	6905.29	2039.31	30	
5	5531.51	1156.97	21	
6	6236.25	2895.00	46	
7	4685.21	1659.00	35	
8	12206.20	4155.00	34	
9	2786.29	975.00	35	
10	3872.95	1436.25	37	
Mean ± standard deviation			35 ± 6.88	9.9

Dietary fiber and resistant starch, classified as non-digestible carbohydrates, slow postprandial blood glucose rise due to their physiological effects that delay glucose absorption (Bin Arif et al., 2013). Slow glucose absorption results in a gradual increase in blood glucose levels, leading to a small incremental area under the curve (iAUC) for the test food (F3 instant porridge), thus producing low GI values.

Interactions among carbohydrate components, protein, fat, and phenolic compounds can form complexes with cross-linking bonds, making them difficult to digest into absorbable glucose (López-Barón, Gu, Vasanthan, & Hoover, 2017). Compared to other instant porridges, commercial oat instant porridge has a higher GI of 66, significantly exceeding the GI of the instant porridge in this study (Foster-Powell, Holt, & Brand-Miller, 2002). The GL of a 45 g serving was 9.9, classifying it as a low GL (<10).

GL is used to assess the impact of carbohydrate intake, considering the GI (Franz, 2012). These findings confirm that the optimal formula (F3) has a low GI and GL, making this instant porridge product suitable as a functional dietary intervention for regulating blood glucose levels.

4. CONCLUSION

Taro was classified as moderate-GI with a value of 60. The physicochemical properties of taro, sweet corn, and red bean flours were measured and used to develop an instant porridge. Results indicated significant differences among the ingredients.

Increasing the red bean content in the formula raised protein, dietary fiber, and resistant starch levels, all associated with lower GI values. Formula F3 (25:25:50) was notable for having the highest dietary fiber (17.45%), resistant starch (4.51%), and protein (24.21%), along with the best sensory acceptance score (5.36/7). F3 exhibited the greatest variety of sensory attributes compared to similar products, reflected in its distribution across different quadrants of the biplot graph.

It also had a low GI of 35 ± 6.88 and a glycemic load (GL) of 9.9, which may support improved blood glucose regulation. This formulation could guide future development of low-GI products. Further research should explore the long-term glycemic response, including hemoglobin A1c (HbA1c) levels.

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