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Bambara Bean Substitution Improves the Nutritional Content and Increases the Satiety Index of Purple Sweet Potato Bread

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ABSTRACT: This study aimed to develop tuber bread from purple sweet potato and bambara beans with high satiety and low glycemic index (GI). Different ratios of purple sweet potato to bambara bean were used: 100:0 (F0), 80:20 (F1), 60:40 (F2), and 40:60 (F3). The satiety index (SI) was determined by assessing the consumption of a 240 kcal isocaloric food and collecting data through a visual analog scale. Blood samples were collected from 11 subjects to determine the GI of the test food. This was achieved using the finger-prick capillary blood sampling method or an EasyTouch glucometer. The results showed that tuber-bread F1 was categorized as high-fiber sources (6.92±0.03 g), whereas F2 and F3 were classified as fiber sources (5.50±0.07 and 5.14±0.11 g, respectively). Significant differences were observed among all formulas. Additionally, formula F3 showed a high SI (160.12%±18.38%) and GI (81.94±2.13), suggesting that the consumption of fiber-rich food may promote feelings of fullness and reduce food cravings. The satiety score analysis of the selected products against standard food yielded a regression equation ($y=-0.257x+66.648$), showing that tuber-bread F3 extended satiety by up to 95 min compared with white bread. As a result, tuber-bread F3 may help to reduce the consumption of additional food, which is frequently a significant contributor to excessive calorie intake.

Keywords: dietary fiber, glycemic index, satiety response, sweet potato

INTRODUCTION

The prevalence of obesity in adults aged 18 years and over has increased from 25% in 1990 to 43% in 2022. According to the World Health Organization (2024), one out of eight people worldwide were obese in 2022. The World Obesity Atlas 2024 (2024) predicts that the prevalence of obesity will increase from 0.81 billion people in 2020 to 1.53 billion people by 2035. Obesity negatively affects overall health, potentially resulting in sugar and fat metabolism disruptions through complex interactions between different tissues. These disruptions often lead to metabolic syndrome, which is characterized by increased blood pressure, high blood sugar levels, excess fat around the waist, and abnormal cholesterol or triglyceride levels (Ikizler and Sahinoz, 2022). These conditions increase the risk of noncommunicable diseases, including type 2 diabetes mellitus, cardiovascular diseases, cancer, and premature death (Naghipour et al., 2021).

High-fiber and high-protein diets have been found to have beneficial effects on weight loss and the risk factors of metabolic syndrome. Research has shown that these diets not only promote satiety and reduce hunger but also improve metabolic health. Glynn et al. (2022) found that the regular consumption of high-protein and high-fiber shakes before meals led to greater weight loss and improved metabolic markers in overweight adults compared with that of lower-protein and lower-fiber shakes. This kind of diet has been shown to improve satiety, glycemic control, and cardiometabolic risk factors. According to Bakr and Farag (2023), fiber-rich food can aid weight loss by slowing digestion, increasing fullness, and reducing calorie intake, which helps prevent obesity and related health issues. Consuming food with a high satiety index (SI) can help decrease the likelihood of overnutrition, which in turn can reduce the risk of developing degenerative diseases. Moreover, the glycemic index (GI) of a food can be influenced by the presence of fiber (Fernandes et al., 2005; Trinidad et al., 2010). Fiber can delay the passage of food through the digestive system and impede enzyme activity, which slows down starch digestion and results in a lower blood glucose response.

Purple sweet potato (*Ipomoea batatas* L. Poir) is a fiber-rich food. According to the FoodData Central from the US Department of Agriculture (USDA, 2020), 100 g of purple sweet potato contains 85 kcal of energy, 1.54 g of

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protein, 20 g of carbohydrates, and 3.1 g of fiber. Moreover, purple sweet potato contains antioxidants and offers multiple health benefits. Additionally, its low GI (54 – 68) helps protect against oxidative stress and inflammation while also aiding in blood sugar regulation (Palupi et al., 2023). Furthermore, it promotes satiety, making it beneficial for weight management.

A good amino acid profile can prevent lipogenesis (Green et al., 2016; Wang et al., 2022). The consumption of food that are high in fiber, have a low SI and GI, and have a good amino acid profile can help a person feel full longer and improve blood lipid profiles (Porter Starr et al., 2017; Palupi et al., 2023). Purple sweet potato contains a complete range of amino acids. However, its lysine content is low. This deficiency can be supplemented by the consumption of lysine-rich legumes, including bambara beans (Walter et al., 1984; Damayanthi and Aamalia, 2016). Similar to purple sweet potato, bambara beans (*Vigna subterranea* L. Verdcourt) possess considerable potential for development. They boast a low GI value (40.1) (Oyeyinka et al., 2017). Moreover, they contain 18.8 g of protein, 1.4 g of fat, 50.2 g of carbohydrates, and 10.3 g of total fiber per 100 g of material (Yao et al., 2015). Aside from lysine, bambara beans are also rich in amino acids, such as isoleucine, leucine, methionine, phenylalanine, threonine, and valine. Among them, lysine (80.2 mg/g crude protein) and leucine (102.1 mg/g crude protein) are the major amino acids in bambara beans (Yao et al., 2015). Thus, bambara beans can be used to complement the amino acid content of purple sweet potato.

According to data from the Central Bureau of Statistics (2023), bread production in Indonesia has exhibited a substantial annual increase, rising from 22,749 Mg in 2015 to 35,586 Mg in 2023. This growth can be attributed to diverse innovations in bread products and the increasing consumer preference for convenient and nutritious food options. Furthermore, market expansion and enhanced distribution networks have significantly contributed to this production increase. Since 2020, bakery products, including the Korean goguma ppang, have gained significant popularity in Indonesia and have become prevalent in large- and small-scale bakeries. In Indonesia, the recipe for goguma ppang has been widely replicated and commercialized. The majority of bakeries distribute goguma ppang through online platforms, including social media and e-commerce websites.

Based on these considerations, the present study aimed to demonstrate the potential of processed purple sweet potato products to enhance fiber consumption among the Indonesian population by developing purple sweet potato filling products incorporating bambara beans, which are expected to have a high SI and low GI because of their fiber and amino acid content.

MATERIALS AND METHODS

This study was conducted in three primary phases: (1) formulation of tuber bread, (2) assessment of the quality of tuber-bread formula, and (3) measurement of the selected formula's SI and GI. This study was approved by the ethics committee of IPB University (approval number 1189/IT3.KEPMSM-IPB/SK/2024).

Product development

The development of tuber bread made from purple sweet potato and bambara beans was inspired by the original recipe of goguma ppang, which was modified because of a lack of supply of Korean flour (Irmawati, 2024). To determine the most suitable ratio of purple sweet potato and bambara bean, the creation of this new product involved a process of trial and error. This stage aimed to assess the feasibility of the product concept and determine the formula for the optimal quality of the final product. The final formulas (F0, F1, F2, and F3) for the filling and crust, which were used to produce tuber-bread products, are presented in Table 1. The ratio of purple sweet potato to bambara bean was varied [100:0 (F0), 80:20 (F1), 60:40 (F2), 40:60 wet basis (F3)]. The following tools were used in developing the tuber bread: a container, sieve or masher, pot, oven, oven tray or aluminum foil, stopwatch, spoon, food scale, and chopper.

To prepare the product, bambara beans were first soaked in water for 12 h. Afterward, they were mashed and steamed. Meanwhile, purple sweet potatoes were roasted for 60 min at 200°C and then mashed into a smooth consistency. These two ingredients were then mixed with butter, sugar, and milk powder to be used later as a filling. The crust was made from a mixture of rice flour and milk, which was heated over medium heat until it reached a thick consistency. The mixture was then stirred together with tapioca flour, sugar, honey, oil, and eggs before the addition of butter, salt, and flour. Afterward, the dough was mixed until it became soft. Subsequently, it was left to rest in a chiller for an hour. After 1 h, the dough was weighed and filled with the filling with cheese in the middle. The dough was coated with purple sweet potato flour and baked at 150°C for 20 min (Fig. 1).

Quality evaluation

To evaluate the quality of the tuber-bread formula, sensory evaluation and nutritional content analyses were conducted. The results of the analyses will serve as reference in determining the chosen tuber-bread formula, which will then be analyzed in the subsequent stage. Sensory or organoleptic evaluation uses human sensory perception as the primary analytical tool for assessing

Table 1. Purple sweet potato and bambara bean tuber-bread formulas

Ingredient (g/%)	F0 (100:0)	F1 (80:20)	F2 (60:40)	F3 (40:60)
Filling ingredients				
Purple sweet potato	100 (64.5%)	80 (51.6%)	60 (38.7%)	40 (25.8%)
Bambara bean	0 (0%)	20 (12.9%)	40 (25.8%)	60 (38.7%)
Butter	10 (6.5%)	10 (6.5%)	10 (6.5%)	10 (6.5%)
Sugar	5 (3.2%)	5 (3.2%)	5 (3.2%)	5 (3.2%)
Milk powder	5 (3.2%)	5 (3.2%)	5 (3.2%)	5 (3.2%)
Cheese	35 (22.6%)	35 (22.6%)	35 (22.6%)	35 (22.6%)
Total	155 (100%)	155 (100%)	155 (100%)	155 (100%)
Crust ingredients				
Tapioca flour	14 (34.7%)	14 (34.7%)	14 (34.7%)	14 (34.7%)
Glutinous rice flour	3 (7.5%)	3 (7.5%)	3 (7.5%)	3 (7.5%)
Wheat flour	3 (7.5%)	3 (7.5%)	3 (7.5%)	3 (7.5%)
Milk	5 (12.4%)	5 (12.4%)	5 (12.4%)	5 (12.4%)
Sugar	3 (7.4%)	3 (7.4%)	3 (7.4%)	3 (7.4%)
Egg	4 (9.9%)	4 (9.9%)	4 (9.9%)	4 (9.9%)
Honey	2 (5%)	2 (5%)	2 (5%)	2 (5%)
Coconut oil	2 (5%)	2 (5%)	2 (5%)	2 (5%)
Butter	4 (9.9%)	4 (9.9%)	4 (9.9%)	4 (9.9%)
Salt	0.3 (0.7%)	0.3 (0.7%)	0.3 (0.7%)	0.3 (0.7%)
Total	40.3 (100%)	40.3 (100%)	40.3 (100%)	40.3 (100%)

F0, tuber bread with 100% purple sweet potato filling; F1, tuber bread with 80% purple sweet potato and 20% bambara bean filling; F2, tuber bread with 60% purple sweet potato and 40% bambara bean filling; F3, tuber bread with 40% purple sweet potato and 60% bambara bean filling.

F0 F1 F2 F3

Fig. 1. Visual appearance of purple sweet potato and bambara tuber-bread product. F0, tuber bread with 100% purple sweet potato filling; F1, tuber bread with 80% purple sweet potato and 20% bambara bean filling; F2, tuber bread with 60% purple sweet potato and 40% bambara bean filling; F3, tuber bread with 40% purple sweet potato and 60% bambara bean filling.

products. This evaluation approach incorporates the analysis of a product's visual appearance, taste perception, smell sensation, and texture characteristics. Nutritional content analysis is conducted to determine the quality and nutritional value of food products. The nutrients examined in this investigation included proteins, fat, carbohydrates, and fiber.

Sensory evaluation of tuber-bread formula

Affective evaluations of tuber-bread products were conducted through hedonic acceptance tests, which aimed to gauge the acceptance level of the products by consumers, represented by panelists. There were 35 panelists (20 females and 15 males) aged 18–30 years old. The criteria that were typically established for selecting panelists included the following: interest in the sensory test and willingness to participate; consistency in decision-making; physical capability; absence of ear, nose, and throat disorders; normal color vision; absence of allergies to the food being evaluated; abstention from eating for 1 h prior to the organoleptic test; avoidance of consuming highly spicy food beforehand; and refraining from using strongly scented cosmetics such as perfumes (Standar Nasional Indonesia 01-2346-2006). The attributes examined in this study included aroma, color, texture, taste, mouthfeel, aftertaste, and overall acceptance. These attributes were assessed using a 9-point hedonic scale, ranging from 1 (very strong dislike) to 9 (very strong like), to determine the panelists' preferences. The panelists were selected from individuals who were initiated assessors or panelists and had a good understanding of the sensory testing rules but had not yet been selected as official assessors. The panelists were given 20–30 g of product samples for each formula, and they evaluated all attributes.

Nutritional content analysis

The assessment of the nutritional content in purple sweet potato and bambara bean tuber bread involves determining the moisture content using the gravimetric method based on the AOAC International standard (AOAC 952.10, 2005), measuring the ash content using the gravimetric method (AOAC 923.03, 2005), calculating the lipid content using the direct extraction method with a Soxhlet apparatus (AOAC 922.06, 1922), determining the protein content using the Kjeldahl method (AOAC 920.87, 1920), and estimating the total fiber content using the enzymatic-gravimetric method (AOAC 985.29, 2003). The available carbohydrate content was determined by calculating the percent remaining after measuring all other components (Charrondiere et al., 2004). Prior to nutritional content analysis, purple sweet potato and bambara bean tuber-bread samples were pulverized using a mortar and pestle, food processor, or blender to achieve a fine consistency.

SI and GI measurements

The SI was determined by assessing the consumption of a 240 kcal isocaloric food and collecting data through a visual analog scale (VAS) satiety score questionnaire at various time intervals post-consumption. Specifically, the scores were collected at 0, 30, 60, 90, 120, 150, and 180 min, and the area under the curve was calculated for each type of tuber-bread formula and compared with that of white bread to determine the SI (%) for each subject. Moreover, trapezoidal calculations were performed to assess satiety parameters, including hunger, satiety, craving, and food intake. The resulting curves were scaled in units of sampling time (calculated in hours) and SI, with the area under the curve expressed as mm× hours (Forde, 2018). The GI was measured following the ISO 26642 method, which required the average glucose response of at least 10 healthy subjects. The food provided to each subject included purple sweet potato tuber bread, purple sweet potato and bambara beans, tuber-bread selected formula, as well as the standard food for SI measurements is white bread and GI measurements is pure glucose (D(+)-Glucose anhydrous for biochemistry Reag. Ph Eur, Merck), respectively, in a 50 g dose (Forde, 2018). White bread served as the reference food control for variations in satiety among individuals, which are attributed to body mass, physical activity levels, and other variables. Unprocessed glucose was utilized to verify normal glucose tolerance. This substance also served as the standard against which all other food was evaluated, and the measurement method was similar to that used in determining the GI of various food items (Holt et al., 1995). The subjects were given the test food on seven distinct occasions, with the stipulation that the same type of food will be given to all subjects on each day. A three-day interval or washout period was observed between test food administrations, considering that the subject's physiological state might return to its original condition (Nolan et al., 2016). Becker et al. (2022) recommended a minimum washout period of two days. Prior to taking measurements, all subjects were required to fast for 10 h to standardize their physiological conditions. When the measurements were taken, subjects were given an amount of the chosen purple sweet potato and bambara bean tuber-bread product formula, which provided 240 kcal for SI evaluation. For GI assessment, a portion containing 50 g of carbohydrates was utilized, and subjects were given a maximum of 15 min to consume the products.

The subjects were selected using a purposive sampling method based on specific inclusion and exclusion criteria. Subjects who were aged between 18 and 30 years, have a normal body mass index (BMI, 18.5–24.9 kg/m^2), have no allergies or food intolerances, have a normal fasting blood sugar level of less than 110 mg/dL, have a healthy condition as certified by a doctor, engage in light to moderate physical activity, and are willing to have their blood glucose levels measured were eligible for the study. Subjects who had a history of diabetes mellitus, were pregnant or breastfeeding, experiencing digestive disorders, consuming alcohol, undergoing medication, or smoking were excluded.

Eleven subjects with normal nutritional status (BMI= 21.20±1.11) and an average age of 22.91±1.30 years were included in this study. These subjects participated in the SI and GI assessments. Data homogeneity analysis was conducted using the relative standard deviation (RSD) and coefficient of variation (CV) Horwitz values as reference. The results indicate that the RSD values for age and BMI were lower than the CV Horwitz values, suggesting that the characteristics of subjects within each group were homogeneous (Table 2).

Statistical analysis

Microsoft Excel 365 and Statistical Product and Service Solution (SPSS) 24.0 for Windows (IBM Corp.) were used for data processing, including the physical test results for color and texture, sensory evaluation, analysis of nutritional and fiber content, and analysis of the SI and GI of purple sweet potato and bambara bean tuber bread. The sensory test data were tabulated and analyzed descriptively using Microsoft Excel 365 based on the average percentage value of panelists' assessment of tuber-bread products. Subsequently, one-way analysis of variance (ANOVA) was conducted using SPSS, followed

Table 2. Characteristics of subjects

Subject code	Sex	Age (years)	BMI (kg/m^2)
01	Female	21	20.5
02	Female	24	20.2
03	Female	24	22.5
04	Female	25	21.2
05	Female	24	21.0
06	Female	22	20.8
07	Female	23	18.8
08	Male	23	21.5
09	Male	22	20.3
10	Male	21	21.8
11	Male	23	22.7
Mean±SD		22.91±1.30	21.20±1.11
RSD		0.06	0.05
CV Horwitz		2.49	2.53

BMI, body mass index; SD, standard deviation; RSD, relative standard deviation; CV, coefficient of variation.

by a Tukey multiple range test to determine if there was a significant effect on the treatment. The SI and GI analyses of formulas F0 and F3 were conducted using a paired sample *t*-test.

RESULTS AND DISCUSSION

Nutritional and sensory characteristics

The results of ANOVA concerning the nutrient content of each component revealed considerable variations in energy, protein, fat, and fiber levels across all formulations. However, carbohydrates were distinctly different between F0 and F1, F2, and F3. The Indonesian Food and Drug Authority regulation 01/2022, which governs the supervision of claims on food labels and processed food advertisements, classifies F1 tuber-bread products as high-fiber food (6 g/100 g of food) and F0, F2, and F3 tuber-bread products as fiber-source food (3 g/100 g of food). The results of nutritional and sensory characteristic analysis are presented in Table 3.

According to the analysis results, formula F3 contained the highest protein content among all formulas, which might be attributed to its higher proportion of bambara beans. By contrast, formula F3 had a lower fiber content than formulas F1 and F2 but higher than that in formula F0. Conversely, F1 contained the highest fiber content among all formulas; however, its protein content was lower than that in F2 and F3. These findings suggest that the incorporation of bambara beans can significantly enhance the protein and fiber content of food products. Macronutrients play an important role in determining the level of satiety that individuals experience. They are a group of essential nutrients that must be consumed in substantial amounts, including carbohydrates, proteins, and fat (Savarino et al., 2021). Proteins provide the highest level of satiety followed by carbohydrates and fat (Chambers et al., 2015). Moreover, certain food fibers can influence satiety by slowing down gastric emptying (Guo et al., 2021).

The attributes that were assessed in the hedonic test of tuber-bread products included appearance, aroma, tex-

Table 3. Nutrient content, energy value (100 g), and Hedonic characteristics of tuber bread

	Formula			
	F0	F1	F2	F3
Nutrient content and energy value				
Energy (kcal)	256.12±0.80^c	237.45±1.98^a	247.22±3.57^b	246.53±0.84^b
Protein (g)	5.73±0.05^a	6.69±0.05^{ab}	6.78±0.18^{bc}	7.18±0.14^c
Lipid (g)	6.63±0.01^a	6.70±0.21^b	7.17±0.11^b	7.43±0.29^c
Carbohydrate (g)	47.28±0.19^b	44.51±0.94^a	44.40±1.02^a	42.87±0.40^a
Available carbohydrate (g)	43.39±0.26^b	37.59±0.92^a	38.90±0.95^a	37.74±0.30^a
Total fiber (g)	3.89±0.07^a	6.92±0.03^d	5.50±0.07^c	5.14±0.11^b
Soluble fiber (g)	2.60±0.08^b	5.62±0.17^c	0.58±0.04^a	0.80±0.03^a
Insoluble fiber (g)	1.29±0.01^a	1.30±0.14^a	4.56±0.15^b	4.70±0.10^b
Moisture (mL)	38.72±0.15^a	40.47±0.87^{ab}	39.97±1.09^{ab}	40.80±0.26^b
Hedonic characteristics				
Appearance	6.69±1.45^a	7.23±1.09^a	7.11±1.16^a	7.00±1.41^a
Aroma	6.94±1.21^b	6.49±1.65^{ab}	6.31±1.35^{ab}	5.80±1.62^a
Texture	6.34±1.49^a	6.54±1.42^a	6.29±1.30^a	6.49±1.34^a
Taste	6.83±1.36^a	6.66±1.45^a	6.37±1.48^a	6.26±1.70^a
Mouthfeel	6.49±1.12^a	6.37±1.17^a	5.97±1.50^a	6.31±1.64^a
Aftertaste	6.60±1.09^a	6.34±1.51^a	6.09±1.27^a	6.14±1.50^a
Overall acceptance	6.80±1.16^a	6.83±1.27^a	6.54±1.17^a	6.60±1.48^a

Values with different superscript letters (a-d) in a row are significantly different at P<0.05.
F0, tuber bread with 100% purple sweet potato filling; F1, tuber bread with 80% purple sweet potato and 20% bambara bean filling; F2, tuber bread with 60% purple sweet potato and 40% bambara bean filling; F3, tuber bread with 40% purple sweet potato and 60% bambara bean filling.

ture (finger feel), taste, mouthfeel, aftertaste, and overall acceptance. The results in Table 3 indicate that F1, F2, and F3 had lower scores for flavor properties, including aroma, texture, taste, mouthfeel, and aftertaste, than F0. Based on the analysis, this is attributed to the presence of nut flavors that are less preferred by panelists, including the taste and aroma of langu that emerge. This aroma is caused by the activity of lipoxygenase enzymes that are naturally present in nuts (Aydar et al., 2020). Furthermore, the addition of bambara bean increases the product's water content, thereby affecting its texture and mouthfeel. The increase in water content after the addition of bambara bean is a result of the processing method of bambara bean, which involves steaming. The findings of the hedonic test indicated that the presence of varying proportions of purple sweet potato and bambara beans did not have a statistically significant impact ($P<0.05$). The average level of liking for all attributes among panelists was between 5 and 7, suggesting that they generally enjoyed all formulas of the tuber-bread products.

SI

The SI is a measure that evaluates the level of satiety produced by a test food in relation to standard food and is expressed as a percentage (Forde, 2018). In other words, this index assesses the degree of fullness or satisfaction derived from a given food compared with a reference food. One of the factors that affect satiety is the macronutrient content of a meal (Blundell et al., 2010). Various macronutrients provide different levels of satiety. According to Palupi et al. (2023), the total fiber content, soluble fiber, insoluble fiber, and nutrient density of a meal demonstrated significant relationships with satiety scores ($P<0.05$). In the present study, participants were given a 240 kcal isocaloric test diet in the form of white bread and tuber-bread formulas (F0 and F3). The nutritional content of the test diet, which is equivalent to 240 kcal, is detailed in Table 4.

The research findings demonstrated a notable dissimilarity in satiety ratings between the F3 test food and the standard white bread. In this study, F3 elicited the least feeling of hunger, the most prolonged sense of satiety, the least desire for more food, and the ability to consume the least amount of food. The SI was calculated by dividing the average satiety score for the test food satiety indicator by the average satiety score for the white bread satiety indicator and then multiplying the result by 100%. The results demonstrated that the SIs for F0 and F3 were 123.80%±11.06% and 160.12%±18.38%, respectively. These findings indicate that F0 and F3 have a high SI exceeding that of white bread, which serves as the standard food (100%). According to Holt et al. (1995), cake has a low SI of 65%. Hence, it can be considered that F0 and F3 have a high SI.

No significant difference was observed between the F0 and F3 test food. The SI values between F0 and F3 were not significantly different because the composition of the test food and the amount of test food given were almost identical. The high SI score of F0 and F3 can be attributed to their high protein and fiber content, which classifies them as low-energy-dense food. This is consistent with the viewpoint of Rolls et al. (2005), which posits that food with low energy density are typically

Table 4. Nutritional characteristics of test food (240 kcal) used to assess the satiety index and the assessment results

	Test food		
	White bread	F0	F3
Nutrient content and energy value			
Protein (g)	$9.91±0.42^c$	$5.37±0.06^a$	$6.99±0.16^b$
Lipid (g)	$5.80±1.72^a$	$6.21±0.02^b$	$7.23±0.25^c$
Carbohydrate (g)	$48.64±0.01^a$	$44.30±0.04^a$	$41.74±0.53^a$
Available carbohydrate (g)	$39.49±0.11^b$	$40.65±0.12^c$	$36.74±0.41^a$
Total fiber (g)	$9.15±0.05^a$	$3.65±0.08^a$	$4.99±0.20^a$
Soluble fiber (g)	$4.48±0.06^a$	$2.44±0.09^a$	$0.56±0.04^a$
Insoluble fiber (g)	$10.85±0.02^a$	$1.21±0.01^a$	$4.43±0.16^a$
Moisture (mL)	$34.54±0.52^a$	$36.28±0.26^a$	$39.72±0.12^b$
Weight per 240 kcal (g)	100	93.71	97.35
Satiety score			
Hunger (mm×h)	$24.21±3.09^a$	$21.98±3.27^a$	$19.32±3.21^a$
Fullness (mm×h)	$21.35±2.14^a$	$26.07±3.03^{ab}$	$32.28±2.74^b$
Desire to eat (mm×h)	$27.69±2.59^a$	$23.70±3.36^a$	$21.25±3.75^a$
Food intake (mm×h)	$27.10±2.91^a$	$23.65±3.20^a$	$21.73±3.80^a$
Satiety index (%)	—	123.80±11.06	160.12±18.38

Values with different superscript letters (a-d) in a row are significantly different at $P<0.05$.
F0, tuber bread with 100% purple sweet potato filling; F3, tuber bread with 40% purple sweet potato and 60% bambara bean filling; —, not available.

high in fiber and water content and low in fat, such that when consumed in the same number of calories as high-energy-dense food, the volume or weight of the food will be greater, thereby causing greater satiety than high-energy-dense food.

Fig. 2 illustrates that the base of the F0 and F3 test food curve surpasses that of the white bread standard food curve, indicating that F0 and F3 test food can provide a more extended sense of satisfaction compared with white bread. This graph also shows that the VAS score for satiety at 180 min for F3 was 44.7 mm. This score was subsequently utilized in conjunction with the regression equation derived from white bread as a reference ($y=-0.257x+66.648$). Using this equation, the calculation showed that white bread required 85 min to induce the same level of fullness. Thus, the consumption of tuber bread led to an extended feeling of fullness by 95 min compared with that of white bread. This result can be attributed to the higher fiber and protein content in F3 than in F0 and white bread. This finding aligns with the outcomes of Palupi et al.'s (2024) study, which found that consuming high-fiber food can enhance satiety and suppress food cravings. Dietary fiber assists in retaining water, which enhances weight and reduces nutrient concentration, thereby prolonging the feeling of fullness and diminishing the frequency of food consumption. Moreover, fiber binds bile acids/salts, limiting their absorption and lowering blood cholesterol levels. Bacteria produce short-chain fatty acids by fermenting fiber in the colon, which stimulate hormone secretion, reducing blood glucose levels and cholesterol biosynthesis (Ridwan et al., 2024).

Aside from dietary fiber, the quantity and quality of protein intake play a crucial role in promoting a sense of fullness. The quality of proteins is determined by the type and proportion of amino acids (Kranz et al., 2017). Essential amino acids can activate the mammalian target of rapamycin signaling pathway in the brain, thereby triggering the release of leptin and peptide YY (PYY) hormones (Xiao and Guo, 2021). PYY is secreted in response to fat, proteins, and carbohydrates and acts on receptors in the hypothalamus to send signals to the brain that suppress appetite. Furthermore, PYY slows down the rate at which the stomach empties into the small intestine, resulting in longer-lasting feelings of fullness (Halford and Harrold, 2012). Branched-chain amino acids (BCAAs), including leucine, isoleucine, and valine, have a synergistic effect in increasing satiety. Consuming BCAAs can reduce levels of the hormone ghrelin (Lueders et al., 2022). The ghrelin hormone plays a significant role in regulating hunger. Higher levels of ghrelin in the body correspond to increased hunger, whereas lower levels of ghrelin are associated with satiety. Additionally, ghrelin influences the secretion of insulin and contributes to the regulation of blood glucose levels (Dornonville de la Cour et al., 2004). The higher the protein quality, the greater its impact on satiety mechanisms.

GI

The measurement of the GI of the test food is conducted by initially obtaining blood samples from the subject. The glycemic response is the effect of consuming specific foods on blood glucose levels (Venugopal et al., 2021). The glycemic responses to standard food and test food, which were given after consuming pure glucose as the standard food and F0 and F3 test food, were assessed. As shown in Fig. 3, the subject's glycemic response to F0 and F3 test food was below the glycemic response curve of pure glucose, indicating that all test food had a value below 100. The peak glucose level in the F0 test food occurred at the 30th minute with an average glu-

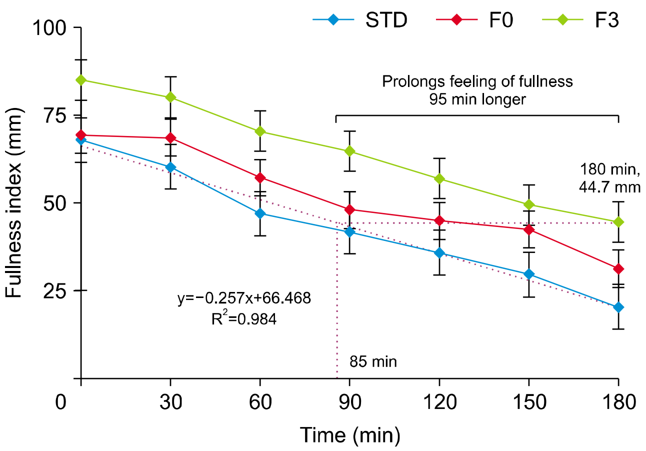

Fig. 2. Visual analog scale for the satiety index at fasting intervals of 30, 60, 90, 120, 150, and 180 min after the consumption of test food. STD, white bread; F0, tuber bread with 100% purple sweet potato filling; F3, tuber bread with 40% purple sweet potato and 60% bambara bean filling.

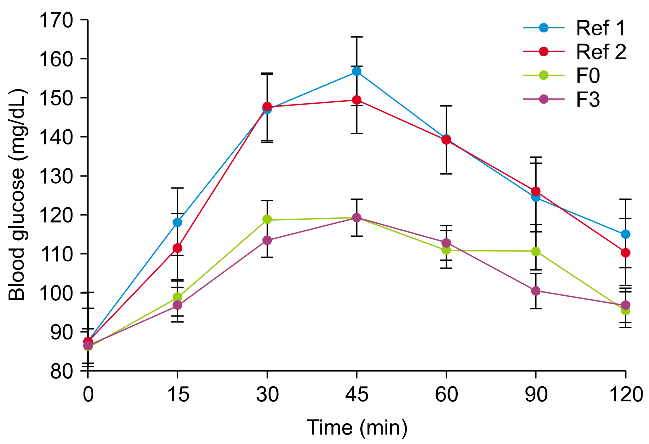

Fig. 3. Glycemic response of subject. Ref 1, reference 1 glucose; Ref 2, reference 2 glucose; F0, tuber bread with 100% purple sweet potato filling; F3, tuber bread with 40% purple sweet potato and 60% bambara bean filling.

Table 5. Glycemic index (GI±standard error of the mean) of the test food

Time of sampling (min)	Test food			
	Ref 1	Ref 2	F0	F3
0	87±1.33[a]	87±1.71[a]	86±0.89[a]	86±1.48[a]
15	118±3.34[b]	112±4.37[b]	99±2.95[a]	97±2.83[a]
30	147±6.74[b]	148±7.10[b]	119±5.75[a]	113±4.80[a]
45	157±5.76[b]	149±10.04[b]	119±5.42[a]	119±6.16[a]
60	139±7.27[b]	139±10.24[b]	111±5.56[a]	113±5.45[a]
90	124±4.27[b]	126±9.11[b]	111±4.33[ab]	100±2.89[a]
120	115±6.23[c]	110±5.68[bc]	96±3.34[a]	97±3.45[ab]
GI±SE	–	–	84.14±2.36[a]	81.94±2.13[a]

Values with different superscript letters (a-d) in a row are significantly different at $P<0.05$.
Ref 1, reference 1 glucose; Ref 2, reference 2 glucose; F0, tuber bread with 100% purple sweet potato filling; F3, tuber bread with 40% purple sweet potato and 60% bambara bean filling; SE, standard error; –, not available.

cose level of 119±5.75 mg/dL, whereas that in the F3 test food occurred at the 45th minute with an average glucose level of 119±6.16 mg/dL. The glucose levels at 30 and 45 min were significantly different ($P<0.05$) between Ref 1 and Ref 2 with F0 and F3.

The blood glucose level exhibited a gradual decline after 45 min and was nearly indistinguishable from the fasting blood glucose level at 120 min. The F3 test food had a lower curve compared with the F0 test food, suggesting that the F3 test food had the lowest GI among the tested formulas.

Table 5 shows that the tuber-bread products produced using formulas F0 (84.14±2.36) and F3 (81.94±2.13) are categorized as high GI. The GI is typically classified into three categories in accordance with ISO 26642 (2010): low GI (≤55), medium GI (55–70), and high GI (>70). These results are not much different from those of Shishehbor et al.'s (2020) study on white bread (73.17±18.23), bread with 25% oak flour (75.88±11.92), and bread with 50% oak flour (77.3±11.91). The present study found that incorporating purple sweet potato and bambara bean enhanced the fiber content, but unexpectedly failed to lower the GI.

The results of the paired sample *t*-test on tuber-bread products F0 and F3 indicated no notable disparity in the GI for each formula. According to Arif et al. (2013), several factors can influence the GI of food products, including the food fiber, amylose, amylopectin, fat, and protein content; starch digestibility; and processing methods. This is consistent with the results of nutrient content analysis of F0 and F3 tuber-bread products, which showed differences in the content of some nutrients, suggesting a potential variation in the GI of the two products.

Based on the findings, the tuber-bread product can be used as a source of dietary fiber and prolongs the feeling of fullness compared with the reference food. As a result, it may help to reduce the consumption of additional food, which is frequently a significant contributor to excessive calorie intake.

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AUTHOR DISCLOSURE STATEMENT

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Concept and design: MR, EP, BS. Analysis and interpretation: MR, EP. Data collection: MR. Writing the article: MR, EP, BS, RARH. Critical revision of the article: EP, BS. Final approval of the article: all authors. Statistical analysis: MR. Obtained funding: EP, BS. Overall responsibility: EP.

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