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Glycemic Response and Glycemic Index of Arrowroot-Mocaf-Based Analog Rice Enriched with Pumpkin Seed Flour

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ABSTRACT: Diabetes mellitus is a carbohydrate metabolism disorder with a global prevalence of 588.7 million in 2026. Consuming foods with a low glycemic index (<55) can help maintain blood sugar levels, thereby reducing the risk of diabetes mellitus. Rice is the most widely consumed staple food in the world, with a glycemic index that is typically moderate to high. Analog rice is known to have a relatively low glycemic index. Local food ingredients that can be developed into analog rice include arrowroot tuber starch and yellow squash seed flour. This study aims to determine the glycemic response of analog rice based on arrowroot tuber starch and yellow squash seed flour as functional foods that support the prevention of diabetes mellitus.

This study used controlled crossover trial design. A total of 15 healthy participants underwent four glycemic response test sessions involving fasting blood draws and blood draws at 0, 30, 60, 90, and 120 minutes after consuming the test food. Blood glucose response was calculated using the incremental area under the curve (iAUC). Statistical analysis was performed using a t-test with a significance level of $p < 0.05$.

The rice substitute produced a postprandial glucose response (24.17 ± 9.88) and glycemic index (48.33 ± 19.75) that were significantly lower than those of white rice (36.20 ± 11.59 and 72.39 ± 23.17) ($p < 0.05$). These findings indicate that the rice substitute triggers a better glycemic response than white rice and can serve as a dietary alternative to support blood glucose control.

1. INTRODUCTION

Diabetes mellitus is a carbohydrate metabolism disorder characterized by chronic high blood sugar levels, which remains a global problem as of today. The International Diabetes Federation (IDF) estimates that by 2024, the number of new cases worldwide will reach 588.7 million and will rise to 852.5 million by 2050 [1]. Furthermore, according to the 2023 Indonesian Health Survey (SKI), the prevalence of diabetes in Indonesia reached 11.7% [2]. Diabetes-related deaths are expected to reach 3.4 million cases worldwide in 2024 [1]. This situation requires serious attention and robust problem-solving methods as people with diabetes mellitus face a higher risk of developing cardiovascular disease, dementia, retinopathy, nephropathy, and neuropathy [1,3].

Dietary management is one of the main pillars in the prevention and control of diabetes. Choosing the right amount and type of carbohydrates based on the glycemic index is positively correlated with blood glucose control [4]. A food's glycemic index

represents its ability to raise blood glucose levels. Foods are categorized by their glycemic index as low (<55), moderate (56–69), or high (≥ 70) [5]. The higher the glycemic index, the faster the food increases the glycemic response [6]. This is consistent with the results of a meta-analysis stating that a low-glycemic-index diet is beneficial for controlling blood glucose, HbA1c, and cardiometabolic risk factors [7].

Rice is one of the most widely consumed staple foods in the world. In general, rice has a moderate-to-high glycemic index and is associated with impaired glucose tolerance [8,9]. Analog rice is a functional food with the potential to prevent various diseases by combining functional components from various ingredients [10]. Analog rice developed from local food ingredients represents a promising alternative, as it is both accessible and provides various nutrients. Arrowroot starch, a byproduct of the arrowroot tuber, contains 15.9% of resistant starch and possesses various antioxidant properties that help prevent diabetes mellitus [11,12]. Modified cassava flour (mocaf) also has a low glycemic index of 42 [13]. Meanwhile, yellow pumpkin seeds were included because a plant-based diet is beneficial in reducing the prevalence of diabetes mellitus [14]. Yellow pumpkin seeds are rich in protein, with 85.5% digestibility, and contain bioactive peptides that may help manage diabetes [15].

Previous research has successfully developed an analog rice formulation using arrowroot starch, mocaf, and yellow pumpkin seed flour. The study also reported that the resulting analog rice possessed favorable physicochemical characteristics, nutritional content, and sensory acceptance [16]. Although these results indicate the product's potential as a functional food, these characteristics have not yet demonstrated the product's physiological effects on glucose metabolism after consuming analog rice. Glycemic index testing in humans is required to evaluate the product's ability to influence postprandial blood glucose responses. Therefore, scientific evidence on the potential of analog rice as an alternative staple food to prevent diabetes mellitus is required.

2. MATERIALS AND METHODS

2.1 Study Design and Setting

This study is an experimental study using a controlled crossover trial design. Each participant attended four study visits at the research center, with a six-day washout period between visits. At each visit, participants completed one test session. The two test foods were a rice analog made from arrowroot starch, modified cassava flour (MOCAF), and pumpkin seed flour, and commercial white rice purchased from a convenience store. At Visits 1 and 2, participants consumed 50 g of anhydrous dextrose dissolved in 250 mL of water as the reference. At Visit 3, participants consumed a portion of the rice analog providing 50 g of available carbohydrates. At Visit 4, participants consumed a portion of white rice providing 50 g of available carbohydrates. All participants received the reference and test foods in the same fixed order. The washout period was intended to minimize potential carryover effects.

2.2 Participants

Participants were recruited from the Faculty of Medicine, Universitas Negeri Semarang. Twenty-four individuals underwent initial screening, which included anthropometric and physiological measurements, such as height, weight, body fat, fasting blood glucose, and cholesterol levels. They also completed questionnaires on their medical history, exercise habits, smoking status, and allergy history. The inclusion criteria were being a healthy man or woman aged 18–45 years, having a body mass index (BMI) of 18.5–24.9 kg/m², and having a fasting blood glucose level <100 mg/dL. The exclusion criteria were a history of diabetes mellitus or other metabolic diseases; use of medications that affect glucose metabolism; active smoking; pregnancy or breastfeeding; and allergy to any test food ingredient. Twenty-one individuals met the eligibility criteria, were invited to participate, and provided written informed consent. Of these, six did not complete all food-test sessions: two were unable to consume the test food completely, and four did not attend one or more test sessions. Therefore, 15 participants completed all food-test sessions.

2.3 Test Meal

The foods tested included analog rice made from arrowroot starch, mocaf, and yellow pumpkin seeds in a 2:1:1 ratio, prepared according to the study by Sholehah et al. (2026) [16], as well as commercial white rice. The analog rice was cooked using conventional methods. First, fill a steamer pot with water and bring it to a boil. Then, add the weighed analog rice along with water amounting to 80% of the rice's weight. Cook for about 10 minutes until half-cooked. Next, add the remaining water

(20%) while the rice is boiling, then stir the rice. Finally, steam again until the rice is fully cooked for approximately 15 minutes. Meanwhile, white rice was also cooked using traditional methods. White rice was washed 2–3 times, then drained. Add water in a 1:2 ratio to the amount of rice. Then cook over low heat until the water is absorbed. Heat the water in the steamer pot until it boils. Transfer the stirred rice into the steamer pot. Steam the rice until cooked through, indicated by the absence of white spots in the center.

The portions of analog rice and white rice were adjusted to provide 50 grams of available carbohydrates. To calculate available carbohydrates, the amount of dietary fiber is analyzed and subtracted from the total carbohydrates. The nutritional content of the two types of rice is summarized in Table 1.

Table 1. Nutritional profile of a analog rice compared with the white rice.

Nutrition Profile	Analog Rice	White Rice
Ash (%)	0.77	0.63
Fat (%)	4.02	1.01
Water (%)	53.56	64.00
Energy (kkal/100 g)	202.75	146.57
Carbohydrate (%)	37.00	30.67
Protein (%)	4.65	3.70
Dietary Fiber (%)	2.18	2.43
Available Carbohydrate (%)	34.82	28.24
Rice Portion (g)	143.59	177.09

2.4 Procedures

Participants were informed about the study procedures and instructed to follow them throughout the study. Before each visit, they were instructed to fast for 8–10 hours and to maintain their usual eating habits and daily activities. Data collection was conducted at the Faculty of Medicine, Universitas Negeri Semarang. Each participant attended four study visits and underwent blood glucose testing at each visit. At Visits 1 and 2, participants consumed 250 mL of a glucose solution containing 50 g of anhydrous dextrose. At Visit 3, participants consumed a portion of white rice providing 50 g of available carbohydrates. At Visit 4, they consumed a portion of rice analog made from arrowroot starch, mocaf, and yellow pumpkin seed flour, which provided 50 g of available carbohydrates. All participants received the reference and test foods in the same fixed order.

Capillary blood glucose was measured before consumption (at 0 minutes). Participants then consumed the reference or test food within 15 minutes. Blood glucose concentrations were measured at 30, 60, 90, and 120 minutes after consumption using a portable glucometer (Easy Touch GCU). Participants remained at the data collection site and were asked to limit their activities until the data collection session ended. Blood glucose measurements at each time point were used to calculate the incremental area under the curve (iAUC).

2.5 Statistical Analysis

The blood glucose response was analyzed using the incremental area under the curve (iAUC) calculated via the trapezoidal method, excluding the area under the fasting blood glucose level. The glycemic index was calculated using the formula:

$$\text{Glycemic index (GI)} = \frac{\text{average food iAUC}}{\text{glucose iAUC}} \times 100$$

Glycemic load was calculated using the formula:

$$\text{Glycemic load} = \frac{\text{glycemic index} \times \text{carbohydrate content (g)}}{100}$$

Statistical analysis was performed using IBM SPSS ver. 29. All data were tested for normality and homogeneity. The iAUC data were analyzed using the Friedman test. Data related to proximate composition, glycemic index, and glycemic load were analyzed using the t-test. Statistical significance was set at p-value < 0.05.

3. RESULTS AND DISCUSSION

3.1 Participant Characteristics

This study recruited 24 subjects who met the study criteria. Three subjects withdrew from the study after recruitment, and five were unable to attend the food intake data collection sessions. As a result, 15 data sets were analyzed, and the characteristics of the respondents are shown in Table 2.

Table 2. Participant Characteristics

Characteristics	Mean $\pm$ SD
Sex (Male:Female)	4:11
Age (years)	21.20 $\pm$ 1.32
BMI (kg/m ²)	20.95 $\pm$ 3.88
Body Fat (%)	25.32 $\pm$ 5.46
Visceral Fat (%)	3.70 $\pm$ 3.98
Baseline Blood Glucose (mg/dL)	97 $\pm$ 10,21
Free Fat Mass	39.24 $\pm$ 10.23

The values shown are the mean $\pm$ standard deviation (n=15).

3.2 Glycemic Response to White Rice and Analog rices

The average iAUC values for the test samples consumed by the participants are shown in Figure 1.

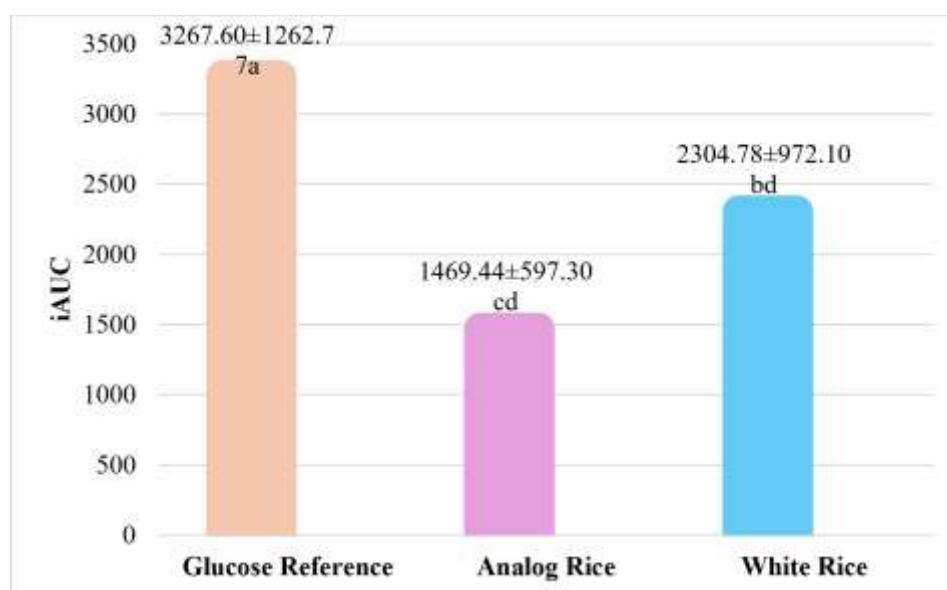


Figure 1. Incremental area under the curve (iAUC) test meals

The data were analyzed using the Friedman test. Values are presented as mean $\pm$ SD. n = 15. (a, b, c) Values with different superscripts on the y-axis of the graph indicate significant differences ($p < 0.05$).

Analysis of the glycemic response showed that the iAUC for the analog rice was lower than that for white rice and the reference glucose. Statistically, there were significant differences in iAUC between the reference glucose and the analog rice, and between the reference glucose and white rice; however, there was no significant difference between the analog rice and white rice.

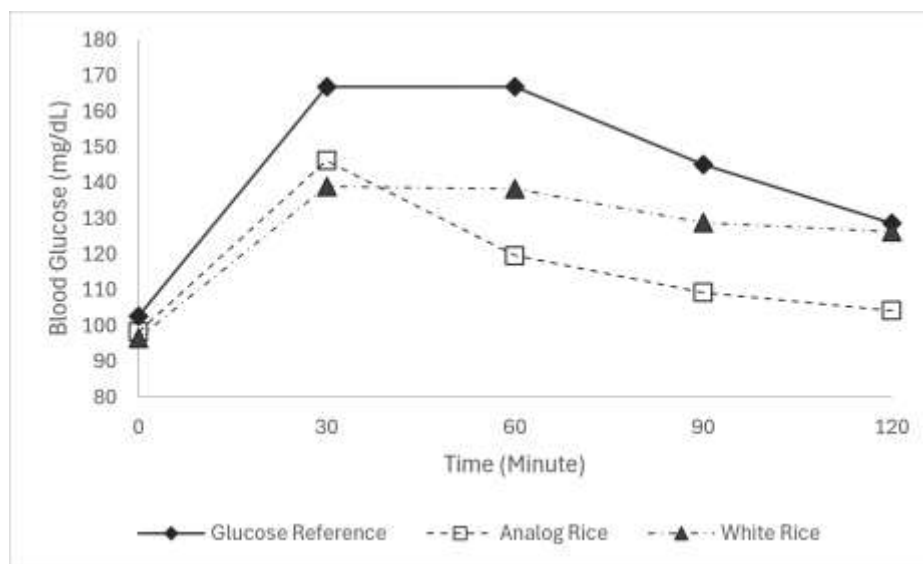


Figure 2. Temporal changes in subjects' postprandial blood glucose responses to the test meals

Figure 2 shows the temporal changes in the subjects' postprandial blood glucose responses to the test food over a 120-minute period following consumption of the test food.

3.3 Comparison of the Glycemic Index and Glycemic Load Values of Test Foods

The glycemic index and glycemic load values of the test foods, based on postprandial glucose measurements, are shown in Table 3.

Table 3. Glycemic index and glycemic load of test meals

	Analog Rice	White Rice
Glycemic Index*	48.33 $\pm$ 19.75 ^b	72.39 $\pm$ 23.17 ^a
Glycemic Load*	24.17 $\pm$ 9.88 ^b	36.20 $\pm$ 11.59 ^a

The data were analyzed using a t-test. Values are presented as mean $\pm$ SD. n = 15 *) There were significant differences among the formulations ($p < 0.05$). a, b, c) Values with different superscripts in the same row indicate significant differences ($p < 0.05$).

Analog rice has a lower glycemic index than white rice, and the difference is statistically significant ($p < 0.05$). The same is true for the glycemic load. The glycemic load of analog rice is lower than that of white rice, and the difference is statistically significant ($p < 0.05$).

3.4 Discussion

The results of this study show that analog rice produces a lower postprandial glycemic response compared to white rice. Consumption of analog rice results in an earlier and lower glycemic peak, followed by a faster decline in blood glucose levels back to baseline. In contrast, white rice results in a greater increase in blood glucose over the 120-minute postprandial period. Consequently, the analog rice treatment yielded a significantly lower incremental Area Under the Curve (iAUC) compared to white rice. The glycemic index values in this study were obtained by testing healthy adult participants in accordance with the recommendations of ISO 26642:2010 [17], which recommends using healthy individuals to determine the glycemic index of

foods. Previous studies have shown that glycemic index determinations in both healthy individuals and patients with diabetes yield relatively similar values, although interindividual variations in glycemic response are greater in groups with impaired glucose metabolism [18]. This is because patients with diabetes mellitus experience impaired insulin secretion, reduced insulin sensitivity, impaired suppression of hepatic glucose production, and altered responses of other hormones, resulting in a higher and more variable postprandial glycemic response [19]. Therefore, it is recommended to use healthy subjects.

The incremental Area Under the Curve (iAUC) value was then used to calculate the glycemic index (GI) of the test foods. The results showed a significant difference in the glycemic index between analog rice and white rice. Analog rice produced a lower glycemic response of 48.33, which is categorized as a low-glycemic-index food. Meanwhile, white rice has a glycemic index of 72.39, which is considered high.

The beneficial glycemic response observed after consuming analog rice is attributed to the starch structure and differences in its macronutrient composition. This analog rice is formulated using arrowroot starch, mocaf, and yellow pumpkin seeds. Arrowroot starch and mocaf have low glycemic indices of 14 and 42, respectively. It indicates slower carbohydrate absorption, resulting in controlled blood glucose spikes [11,13]. In addition to their low glycemic index profiles, the ingredients used to produce this rice contain numerous bioactive compounds, including antioxidants, that can help manage blood glucose. Arrowroot contains phenolic acids and flavonoids, whereas yellow pumpkin seed has procyanidins. All three bioactive compounds are potential antioxidants that have been proven to help manage various oxidative diseases [20,21]. In metabolic disorders, antioxidants have been linked to improved glucose metabolism and reduced carbohydrate digestion. These findings are consistent with a study indicating that a single weekly dose of ellagic acid over eight weeks can reduce blood glucose levels, HbA1c, insulin, and HOMA-IR [22]. Additionally, the protein in yellow pumpkin seeds helps manage diabetes mellitus by reducing the activity of α -amylase and α -glucosidase. The process thereby delays starch breakdown, glucose absorption, and sudden spikes in glucose, respectively. Proteins from yellow pumpkin seeds produce hypoglycemic bioactive peptides via enzymatic hydrolysis and may exert antidiabetic effects by modulating the nutritional composition and digestive properties of products within the food matrix [15].

Previous research has indicated that the analog rice developed in this study contains 25.32% resistant starch [16]. Meanwhile, the resistant starch content in white rice is estimated to be <4% [23]. The current findings are consistent with previous research evaluating the effect on glucose response when consuming rice high in resistant starch compared to conventional rice, which found that rice high in resistant starch can reduce the spike in blood glucose [24]. Resistant starch has lower digestibility compared to easily digestible starch. Resistant starch improves fasting blood glucose levels by increasing insulin production and reducing insulin resistance [25]. Resistant starch regulates several metabolic enzymes, including glycogen synthase (GS), phosphoenolpyruvate carboxykinase (PEPCK), and α -glucosidase, thereby achieving a hypoglycemic effect [26]. In addition, resistant starch can modulate the gut microbiota by influencing metabolic, endocrine, and immune functions. An important product of the gut microbiota is short-chain fatty acids (SCFAs). SCFAs can increase the secretion of two important gut hormones: glucagon-like peptide-1 (GLP-1) and peptide YY (PYY). Increased secretion of both enzymes enhances satiety by acting on the gut-brain axis. Through this pathway, SCFAs can indirectly reduce appetite and food intake, potentially preventing weight gain and thereby lowering the risk of diabetes. SCFAs can also regulate blood glucose levels by increasing GLP-1-mediated insulin secretion [26]. Collectively, these findings suggest that the beneficial glycemic effects of analog rice are likely mediated through the synergistic action of resistant starch, macronutrients, and bioactive phytochemicals, which simultaneously and integratively delay carbohydrate digestion and glucose absorption.

In addition to the glycemic index, another important index related to the glycemic response is the glycemic load. Despite differences in glycemic index values, both foods still have high glycemic load, as it is determined not only by the quality of carbohydrates as reflected by the glycemic index, but also by the amount of available carbohydrates consumed in a single serving. In this study, the test food portions were adjusted to provide 50 g of available carbohydrates in accordance with the method for determining the glycemic index (ISO 26642:2010). This amount of carbohydrates maintained both foods' glycemic loads in the higher category, even though the analog rice had a lower glycemic index.

These findings indicate that improving carbohydrate quality by lowering the glycemic index does not always correspond to a reduction in glycemic load to a lower category. Therefore, in addition to selecting foods with a low glycemic index, portion control remains necessary to reduce postprandial glucose levels. In clinical practice, a combination of low-glycemic-index foods and appropriate portion sizes is more effective at controlling postprandial blood glucose than focusing solely on the glycemic

index. Further studies are needed to evaluate postprandial glycemic responses to these foods in individuals with diabetes mellitus, as findings from healthy participants may not be directly generalizable to this population.

4. CONCLUSION

This study shows that analog rice produces a significantly lower postprandial glycemic response than commercial white rice. Analog rice has a low glycemic index and a significantly lower glycemic load, indicating it slows the blood glucose response after consumption. These results confirm the potential for utilizing local food ingredients as functional foods with improved glycemic characteristics. These findings support the potential of analog rice as a food alternative that can improve postprandial glycemic control.

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AUTHOR CONTRIBUTIONS

Astrid Noviana: Conceptualization, Investigation, Methodology, Writing—Review & Editing, Supervision.

Safrina Oksidriyani: Methodology, Laboratory Analysis, Writing—Review & Editing.

Safira Chairani Dimarti: Data Curation, Formal Analysis, Writing—Review & Editing.

Syifa Qolbiyah Nasir: Data Curation, Formal Analysis, Writing—Review & Editing.

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CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest. The authors declare that the funders of this project had no involvement in the design and conduct of the experiments or in the analysis of the results and preparation of this manuscript.

ETHICS STATEMENT

This study has been approved by the Research Ethics Committee (KEP) of Universitas Negeri Semarang under number B/7172/UN37.3.1/KEP.00/2026 issued on July 10th, 2026.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials; further inquiries can be directed to the corresponding author.

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