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Influence of Brown Rice Flour Waffles on Blood Glucose, Appetite, and Satiety in Healthy Participants: A Randomized Controlled Trial

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Abstract

Waffles are a popular dessert, typically prepared with wheat flour—a source of simple carbohydrate. Excessive consumption of simple carbohydrates has been linked to an increased risk of non-communicable diseases, especially diabetes mellitus. Therefore, substituting wheat flour with brown rice flour may benefit blood glucose control, a hypothesis that has not yet been evaluated. In this single-blinded, parallel, randomized controlled trial, coded (AB) block randomization was implemented in 20 healthy participants with body mass index ranging from 18.5-22.9 kg/m^2. Sensory acceptance was assessed using a 5-point hedonic scale evaluating parameters such as odor, taste, texture, appearance, and overall acceptability. In a single-meal intervention, blood glucose and hunger-satiety levels were measured in an experimental room at baseline and at 30, 60, 90, and 120 min after consumption of a randomized waffle formulation. Sensory acceptance testing revealed that waffles prepared with brown rice flour received significantly lower ratings for taste, texture, and overall appeal (p<0.05). Blood glucose responses in the brown rice group showed significant differences at 30, 60, and 90 min (p<0.001, p<0.001, and p=0.045, respectively), with percentage reductions in blood glucose levels observed at intervals of 0-60 (+27.89 vs. +34.04), 0-90 (+17.44 vs. +21.69), and 0-120 min (+5.78 vs. +8.01) compared to waffles made with wheat flour. No significant differences were found between the groups with respect to incremental area under the curve or hunger-satiety levels (p > 0.05). In conclusion, incorporating brown rice flour into waffles may help reduce blood glucose levels and enhance satiety, indicating potential for further product development to broaden its consumer acceptance.

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Introduction

In modern times, the prevalence of metabolic disorders—such as hypertension, dyslipidemia, and hyperglycemia—has emerged as a significant public health concern (Hu et al., 2022). Lifestyle modifications, including dietary changes and increased physical activity, are widely recognized as effective strategies for restoring and maintaining metabolic homeostasis (Gradinariu et al., 2023). Regulating blood glucose levels is particularly critical for preventing the progression of prediabetes to type 2 diabetes mellitus (T2DM) and mitigating associated health risks (Bin Rakhis et al., 2022). Although internal risk factors such as age, genetics, and sex are non-modifiable (Ahmad et al., 2014), external factors—especially dietary habits—offer a practical avenue for intervention. Specifically, reducing the intake of high-glycemic foods such as refined white bread and sugary beverages, while promoting nutrient-dense, lower-glycemic alternatives, is essential for glycemic control (Nabila et al., 2023). Appropriate modification of these dietary factors may facilitate long-term reductions in blood glucose levels.

Brown rice flour (*Oryza sativa* L.), derived from whole grain Asian rice, is a promising candidate for dietary interventions aimed at metabolic health. As a complex carbohydrate with a moderate glycemic index (GI = 65), it digests more slowly compared to wheat flour (GI = 86), resulting in a gradual release of glucose into the bloodstream (Atkinson et al., 2021; Borczak et al., 2018). This slower glucose response is partly attributable to its higher fiber content. Specifically, brown rice flour contains approximately 4 g of insoluble fiber per serving, rich in resistant starch (amylose), which is less susceptible to digestion in the human gastrointestinal (GI) tract. This characteristic delays glucose absorption and prolongs gastric emptying, thereby enhancing satiety (Tuaño et al., 2021; Kim et al., 2024, Guo et al., 2023a).

In addition, brown rice flour provides 1 g of soluble fiber per 100 g (Albarracín et al., 2019) and is abundant in bioactive compounds such as polyphenols, γ-aminobutyric acid (GABA), thiamine, and magnesium. These components not only support metabolic health but also facilitate improved glycemic regulation (Watchararparpaiboon et al., 2010; Wu et al., 2022). Several clinical investigations further reinforce the benefits of dietary fiber; for example, Giuntini et al. (2022) demonstrated that complete meals enriched with soluble fiber significantly attenuate postprandial glycemic responses, while Cioffi et al. (2106) reported enhanced satiety and reduced sensations of hunger following whole-grain pasta consumption without notably affecting subsequent energy intake Given its nutritional profile and functional properties, incorporating brown rice flour into familiar food products such as waffles offers a practical and attractive strategy to support blood glucose regulation and overall metabolic support.

Developing such functional foods provides a preventive strategy against T2DM and other chronic noncommunicable diseases, aligning with modern dietary trends that prioritize health promotion. Sensory evaluation is a statistical analytic method employed in new product development based on human sensory experiences. Organoleptic tests assess attributes such as odor (olfactory perception), appearance (visual perception), texture (mechanical perception during mastication), taste (gustatory perception), and overall acceptance (Wu et al., 2023). However, a notable gap exists in the literature: no prior randomized controlled trials (RCTs) have compared brown rice flour waffles with wheat flour waffles. Additionally, the justification for selecting waffles as the product matrix and defining the target population—whether healthy or diabetic subjects—is underdeveloped. The primary objective of this study was to evaluate the sensory acceptance of brown rice flour waffles and to examine their effects on postprandial blood glucose responses and satiety in healthy adults, with the intent of expanding the research to noncommunicable disease clinics. The study hypothesized that brown rice flour waffles would be sensorially acceptable and would produce a lower postprandial blood glucose response and higher satiety levels compared to conventional refined wheat flour waffles.

Materials and methods

1. Participants

The sample size was calculated based on differences in blood glucose levels between the two groups reported in a previous study (Panlasigui & Thompson, 2006), using a 95% confidence level and 90% statistical power. Using the formula for comparing the means of two independent groups, it was initially determined that at least 8 participants per group were required. To account for an anticipated dropout rate of 20% (n=2), the sample size was adjusted to 10 participants per group, yielding a total of 20 individuals. Participants were then allocated into 2 groups: the intervention group, which received brown rice flour waffles (n = 10), and the control group, which received wheat flour waffles (n = 10). Most participants resided in the Saensuk district of Chonburi province, Thailand, and the data collection was performed from April to June 2023.

Inclusion criteria were: 1) age between 18 and 35 years (Wu et al., 2022), 2) body mass index (BMI) between 18.5 and 22.9 kg/m², classified as normal weight by Asian population standards (Okawa et al., 2025), and 3) being apparently healthy individuals, with no diagnosed metabolic conditions such as diabetes, hypertension, or dyslipidemia. Exclusion criteria included: 1) a known history of allergies to milk, eggs, wheat flour, brown rice flour, or gluten, and 2) regular alcohol consumption and smoking. Termination criteria were established as follows: 1) the occurrence of adverse effects during the trial, 2) failure to complete the collection of all five blood spot samples, and 3) unwilling to continue participation.

2. Waffles preparation and nutritional composition

All waffle formulations utilized identical baking components, with the only variable being the proportions of wheat flour and brown rice flour. Although the external appearance of the waffles remained consistent, differences in the flour component were evident. The formulations comprised either wheat or brown rice flour, white sugar, baking powder, salt, fresh milk, chicken eggs, unsalted butter, natural flavoring, and vanilla essence. All ingredients were thoroughly mixed, and the batter was baked using a standardized waffle machine until fully cooked. Nutritional information—including energy, carbohydrates, protein, fat, sodium, and fiber—was obtained using data from INMUCAL-Nutrients version 4.0 (Mahidol University, Thailand) (INMU, 2019), the Thai Food Composition Table 2016 (Charrondiere & Burlingame, 2011), and the United States Department of Agriculture (Ahuja et al., 2013).

3. Sensory acceptance and satisfaction evaluation

All participants completed a questionnaire to evaluate their sensory acceptance and satisfaction with the waffles. The questionnaire assessed 5 sensory attributes—appearance, odor, taste, texture, and overall acceptance—using a 5-point hedonic scale. Numbers for the sensory evaluation were randomized with a coded (AB) block randomization table (Kim & Shin, 2014). The investigators were blinded to the randomization table and code assignments. All evaluations were conducted under controlled conditions, including standardized sensory booths, lighting, and temperature.

Untrained participants rated their pleasure level for each waffle trait on a scale from 1 to 5, where 1 indicated dissatisfaction, 2 slight contentment, 3 moderate satisfaction, 4 extreme satisfaction, and 5 very satisfied. Each item on the questionnaire included a 5-point scale: 5 = very satisfied, 4 = extremely satisfied, 3 = moderately satisfied, 2 = slightly satisfied, and 1 = unsatisfied. There was no predefined criterion for each level, allowing participants to rate their experience based on personal perception. Mean scores for satisfaction and sensory acceptability were interpreted using the following ranges: 4.50-5.00 = the most satisfied; 3.50-4.49 = most satisfied; 2.50-3.49 = satisfied; 1.50-2.49 = slightly satisfied; and 1.00-1.49 = unsatisfied, respectively (Belmes, 2019).

4. Clinical trial protocol

This study was designed as a single-blind, parallel-group randomized controlled trial to evaluate the effects of brown rice flour waffle consumption on glycemic response and satiety. Only the participants were blinded to the type of flour used in each waffle formulation. Randomization was conducted via a coded (AB) block randomization table that assigned participants through a numerical random sampling procedure (Kim & Shin, 2014). The investigators were blinded to both the randomization schedule and the corresponding code assignments.

Research data were collected in the medical science (MS) building at Burapha University in rooms 308, 309, and 310, located in Chonburi, Thailand. Participants who met the inclusion criteria were contacted by the research team to confirm their participation and to receive study instructions. Specifically, participants were instructed to fast for at least 8 hr before the scheduled appointment—allowing only small sips of water to alleviate thirst—and to maintain their usual dietary and physical activity routines without any imposed restrictions.

On the day of the experiment, baseline measurements were recorded, including body weight, height, and body mass index (BMI). Body composition was assessed using bioelectrical impedance analysis (BIA) with the InBody 230 device (Biospace Corp., Seoul, Korea), and blood pressure was measured using an automated blood pressure monitor (Omron HEM-7111, Omron Healthcare, Thailand). Capillary blood samples were collected from the fingertips, and hunger and satiety levels were evaluated before waffle consumption (0 min).

Participants were instructed to consume 70 g of waffles within a 5-min period, ensuring the entire portion was eaten. They received either brown rice flour or wheat flour waffles; both formulations had a similar average nutrient composition per piece (242.5 Kcal of energy, 34.7 g carbohydrates, 5.4 g of protein, 9.7 g of fat, 212 mg of sodium, and 0.65 g of dietary fiber).

Blood samples were obtained using a single-use lancing device (Accu-Chek Safe T-Pro UNO, Roche Diagnostics, Thailand) to draw blood onto a blood glucose test strip (Accu-Chek Guide, Roche Diagnostics, Thailand), and glucose measurements were taken with an Accu-Chek Guide glucometer (Roche Diagnostics, Thailand); all devices were calibrated prior to use. Blood glucose levels, along with hunger and satiety evaluations were measured at baseline (0 min) and subsequently every 30 min (at 30, 60, 90, and 120 min, respectively) after waffle ingestion. During the intervention trial, participants were instructed to refrain from engaging in any additional physical activity remaining seated and quietly waiting in the designated experimental room. Fig. 1 illustrates a flow diagram depicting the progression of participants through the study.

5. Hunger and satiety levels

Hunger and satiety were evaluated using a visual analogue scale (VAS) to quantify participants' subjective perceptions before, during, and after food intake (Hill & Blundell, 1982). Six questions were posed: 1) "How hungry do you feel?" with scores ranging from 'not hungry at all' to 'very hungry'; 2) "How full do you feel?" with scores ranging from 'not feeling full' to 'very full'; 3) "How invigorated do you feel?" with scores ranging from 'having no energy at all' to 'having a lot of energy'; 4) "How much do you think you could consume now?" with scores ranging from 'not eating at all' to 'eating a great amount of energy'; 5) "How much do you feel the urge to eat?" with scores ranging from 'no motivation at all' to 'very motivated'; and 6) "How preoccupied are you with thoughts of food? with scores ranging from 'not thinking about food' to 'thinking about food all the time.' Each question was assessed using a 7-point Likert scale, with 1 representing the lowest and 7 representing the highest score. Data for the hunger and satiety assessments were collected concurrently with each blood glucose measurement at baseline (0 min) and every 30 min thereafter (30, 60, 90, and 120 min) following waffle ingestion. Standardized instructions were provided to all participants to ensure consistent interpretation of the VAS.

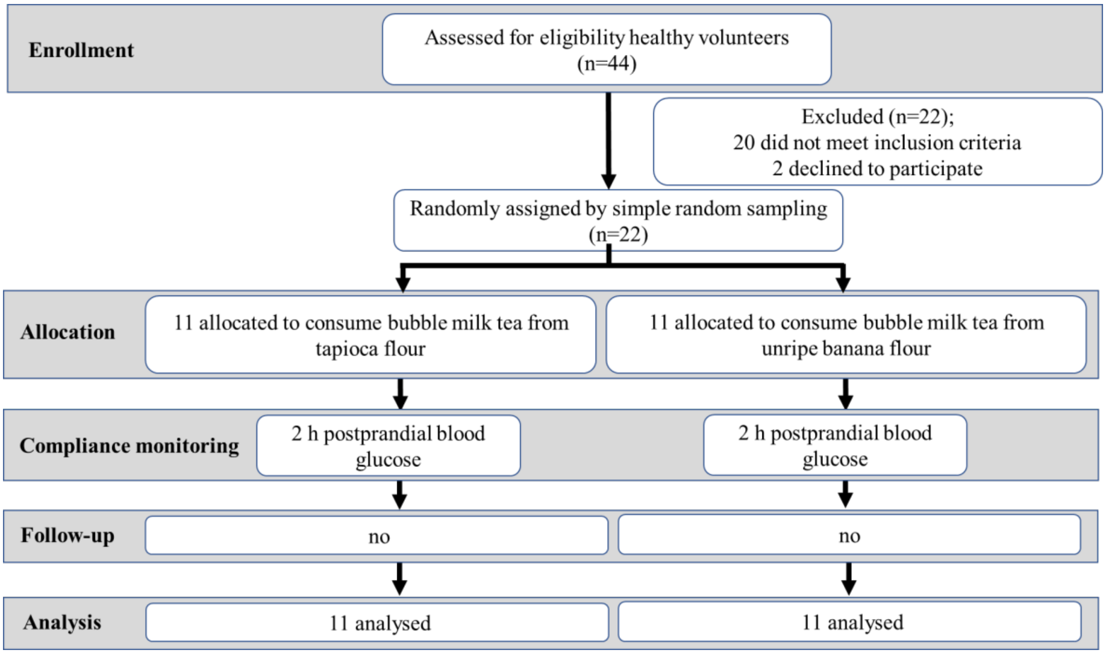

Fig. 1 CONSORT diagram of the study

6. Statistical analysis

Descriptive statistics and comparative analyses—including baseline characteristics, blood glucose levels, hunger and satiety scores, as well as sensory acceptability and satisfaction ratings—were conducted using IBM SPSS Statistics Version 29.0. All data are presented as mean±standard deviation (SD). Baseline characteristics of the sample population, (gender, reported as frequency and percentage; height; body weight; and body composition) were compared between groups using independent samples t-tests. Blood glucose responses and hunger-satiety levels were compared between the intervention (brown rice flour waffle) and the control (wheat flour waffle) groups using independent samples t-tests. Within-group changes in blood glucose responses and hunger-satiety levels were analyzed using one-way analysis of variance (ANOVA) with Tukey's post-hoc test, while differences in the incremental area under the curve (iAUC) for blood glucose were assessed using one-way analysis of covariance (ANCOVA), incorporating subgroup analysis based on percent body fat (PBF). Differences in mean satisfaction scores between the two waffle groups were evaluated using independent samples t-tests. Statistical analyses were conducted with a 95% confidence interval, and statistical significance was set at p-value < 0.05.

7. Ethical consideration

This experimental study received ethical approval from the Human Research Ethics Review Committee of Burapha University (approval number IRB1-057/2566, project code HS010/2566). Prior to participation, all participants were fully informed about the research procedures, potential risks, and benefits, and they provided written informed consent. The study protocol was registered with the Thai Clinical Trials Registry under the identifier TCTR20250309012.

Results and discussion

1. Baseline characteristics

From the start of the sensory and acceptability assessment to the end of the intervention, the average age of participants was classified as early adult (20-22 years). Both experimental groups comprised predominantly female participants (80-90%) compared to male participants (10-20%). Baseline assessments –body composition data obtained via BIA (skeletal muscle mass, fat-free mass, total body water, protein, mineral content, percentage of body fat, and waist-to-hip ratio, and basal metabolic rate), as well as systolic and diastolic blood pressure, fasting blood glucose, and body mass index—were all within an acceptableranges, with no substantial differences observed between groups. The study's limitations regarding baseline characteristics include a small sample size, a narrow age range (18–35 years), a relatively short blood glucose monitoring period (120 min), and the abs `ence of sensory optimization measures. These limitations highlight the need for further refinement in future research. Table 1 details the participants' background information.

Table 1 Participants' general characteristics, body composition, blood pressure, and basal metabolic rate

Baseline parameters	Control (*n*=10)	Intervention (*n*=10)	*p*-value	95% CI
Age (years)	21.20±0.63	20.80±0.42	0.113	-0.11-0.91
Sex [female (%)/ male (%)]	9 (90)/ 1 (10)	8 (80)/ 2 (20)	0.557	-0.11-0.92
Body weight (kg)	52.50±6.94	53.88±6.14	0.643	-7.79-4.17
Height (cm)	159.80±8.90	161.2±7.13	0.703	-9.29-5.89
BMI (kg/m^2)	20.49±1.44	20.71±1.62	0.761	-1.65-1.04
Systolic blood pressure (mmHg)	113±15.40	114.30±7.30	0.812	-12.62-10.02
Diastolic blood pressure (mmHg)	71.60±6.40	73.60±5.85	0.475	-7.76-3.76
Fasting blood glucose (mg/dL)	89.90±5.15	90.00±6.82	0.971	-5.57-5.57
Skeletal Muscle Mass (kg)	19.09±3.59	19.44±3.52	0.828	-3.69-2.99
Body Fat Mass (kg)	16.75±3.60	17.43±4.20	0.702	-4.36-3.00
Total Body Water (kg)	26.16±4.33	26.65±4.40	0.805	-4.59-3.61
Fat-Free Mass (kg)	35.75±5.89	36.45±5.99	0.795	-6.28-4.88
Protein (kg)	6.97±1.2	7.12±1.17	0.781	-1.27-0.97
Minerals (kg)	2.61±0.38	2.69±0.43	0.690	-0.46-0.31
Percent Body Fat (%)	31.9±5.26	32.41±7.13	0.858	-6.39-5.37
Waist-to-Hip Ratio	0.85±0.37	0.83±0.27	0.183	-0.01-0.05
Basal Metabolic Rate	1142.60±127.47	1157.50±129.15	0.798	-135.46-105.66

Remark: All variables were expressed in mean± SD, CI = Confidence interval of the difference

2. Nutritional analysis of wheat and brown rice flour waffles

Nutritional values for wheat and brown rice flour waffles (net weight of 70 g/serving size/recipe) were determined using the INMUCAL-Nutrients program version 4.0, along with a database compiled from various Thai and international sources. Macronutrient and micronutrient profiles significantly influence health outcomes, with energy, carbohydrates, protein, fat, sodium, and dietary fiber content being key factors. While most nutritional components were comparable between wheat and brown rice flour waffles, dietary fiber was notably higher in the brown rice flour waffles. Specifically, brown rice flour waffles contain 56% more dietary fiber

(0.9 g/serving) than wheat flour waffles (0.4 g/serving). The increased dietary fiber—particularly resistant starch from the amylose structure—may offer additional benefits by improving glucose homeostasis and attenuating postprandial blood glucose release (Mao et al., 2021). This finding aligns with an earlier study examining the effects of substituting brown rice flour for wheat flour in sponge cakes, which reported nearly twice (40-50%) the crude fiber content (p<0.05), lower calorie content, and higher nutritional value compared to wheat flour (Na Ayutthaya et al., 2018). Additionally, Jan et al. (2022) found that replacing rice flour with whole wheat flour in pretzels found that replacing rice flour with whole wear flour in pretzels resulted in a 61% increase in crude fiber compared to white rice flour (Jan et al., 2022). Table 2 presents the nutrient analysis of the 2 waffle recipes.

Table 2 Nutritional composition of wheat and brown rice flour waffles (per 70g serving)

Nutrient values/waffle (net weight = 70 g/serving size)*						
Recipe	**Energy (Kcal)**	**Carbo-hydrates (g)**	**Protein (g)**	**Fat (g)**	**Sodium (mg)**	**Dietary fiber (g)**
Wheat flour waffle	241.0	36.6	6.1	8.9	214.4	0.4
Brown rice flour waffle	244.1	32.8	4.7	10.5	209.6	0.9

Remark: *Analyzing the nutrient composition data by using the database from INMUCAL-Nutrients version 4.0, Thai food composition table 2016, and USDA.gov

3. Sensory acceptance and satisfaction evaluation on each waffle recipe

The sensory acceptability and satisfaction of wheat versus brown rice flour waffles were evaluated across in 5 attributes: odor, taste, texture, appearance, and overall perception. Results indicate that brown rice flour waffles received significantly lower scores than wheat flour waffles in flavor, texture, and overall acceptability (p=0.025, 0.025, and 0.049, respectively), while no significant differences were observed for odor and appearance (p=1.00 and 0.33, respectively).

Consistent with earlier research on sponge cakes incorporating with varying proportions of the brown rice flour (10-50% substitution) of brown rice flour (Na Ayutthaya et al., 2018), increasing the brown rice flour content was associated with decreased ratings for softness, texture, flavor, and overall acceptability. Furthermore, the inherent properties of brown rice flour, such as its propensity to lose sponginess—resulting in reduced elasticity and diminished capacity to recover its original form after compression—may contribute to these finding (Xu et al., 2012). The lower gluten content in brown rice flour compromises the formation of a continuous network essential for trapping gas and achieving a desirable product volume, thus reducing softness (Luo et al., 2021). Additional studies have demonstrated that the elevated fiber content from brown rice flour confers a chewier texture, a darker tan color, a stronger nutty flavor relative to wheat flour-based products, which may further lower sensory acceptability (Dhillon et al., 2024). Similarly, biscuit formulations containing up to 20% brown rice flour (from *Oryza sativa* L.) exhibited significant declines in color, flavor, texture, and overall perception compared with wheat flour (from *Triticum aestivum* L.) counterparts (Islam et al., 2012).

Enhancements in the quality of brown rice flour waffles may be achieved by modifying textural properties, optimizing flavor profiles, or incorporating types of flour. Notably, reducing the brown rice flour content to 10% of the total flour blend appears to improve sensory acceptance and satisfaction across all attributes while potentially contributing to improved glycemic control in healthy individuals. Table 3 presents the sensory acceptability and satisfaction scores for each waffle formulation.

Table 3 Sensory acceptability and satisfaction evaluation of waffle formulations

Sensory aspects	**Sensory acceptance scores**		
	Wheat flour waffle	**Brown rice flour waffle**	***p*-value**
Odor	4.25±0.72	4.25±0.85	1.000
Taste	4.40±0.68	3.95±0.76	0.025*
Texture	4.45±0.69	4.00±0.92	0.025*
Appearance	4.65±0.49	4.55±0.61	0.330
Overall	4.55±0.51	4.20±0.70	0.049*

Remark: All variables were expressed in mean± SD
* Statistically significant difference between groups (p<0.05)

4. Effects of brown rice and wheat flour waffle intake on blood glucose levels

Glycemic responses did not differ significantly between participants consuming waffles prepared with wheat or brown rice flour. However, within-group comparisons of blood glucose from baseline to 30, 60, 90, and 120 min revealed significant increases at 30, 60, and 90 min for the wheat flour group (p<0.001, p<0.001, and, p=0.003, respectively) and at 30 and 60 min in the brown rice flour group (p<0.001, and, p=0.001, respectively). These findings concur with a systematic review and meta-analysis of randomized controlled trials reported in prior research (Musa-Veloso et al., 2018).

Notably, although blood glucose levels were slightly higher in the wheat flour group during the first 30 min (122.50±11.97 vs. 117.00±14.00 mg/dL), the brown rice flour group exhibited marginally elevated values from 60 to 120 min (115.10±12.39 vs. 120.50±16.91 mg/dL at 60 min; 95.20±14.78 vs. 97.10 mg/dL at 120 min). These observations align with findings from studies evaluating blood glucose responses. Furthermore, the incremental increases in blood glucose at 60, 90, and 120 min were lower in the brown rice flour group—25.10±16.20 versus 30.60±18.31 mg/dL at 60 min, 15.70±13.38 versus 19.50±8.29 mg/dL at 90 min, and 5.20±11.81 versus 7.20±7.05 mg/dL at 120 min—a pattern similar to that observed in previous investigations of glycemic response to whole wheat versus white bread (Al-Zuhairy & Al-Hamdani, 2022). Nonetheless, between-group differences in blood glucose levels at 30, 60, 90, and 120 min were not statistically significant ($p>0.05$).

In comparison, the percentage increases in blood glucose levels from baseline differed between waffle formulations. Specifically, the wheat flour waffle group exhibited increases of +34.04% (0–60 min), +21.69% (0–90 min), and +8.01% (0–120 min), whereas the brown rice flour waffle group showed increases of +27.89%, +17.44%, and +5.78% over the corresponding intervals. The higher resistant starch content in brown rice flour—particularly amylose (4.7 g/100 g), compared to wheat flour (0.4 g/100 g)—likely accounts for its slower digestibility, delayed glucose absorption in the small intestine, and consequently, a more moderated glycemic response (Belobrajdic et al., 2019).

According to a systematic review and meta-analysis of 19 randomized controlled trials, modified products containing resistant starch—such as breads, crackers, and beverages—produced significant reductions in fasting plasma glucose and homoeostatic model assessment insulin resistance (HOMA-IR) compared to those containing digestible starch (Xiong et al., 2021). The differential concentrations of amylose and amylopectin may underpin the observed resistance to digestion. Resistant starch, possessing prebiotic

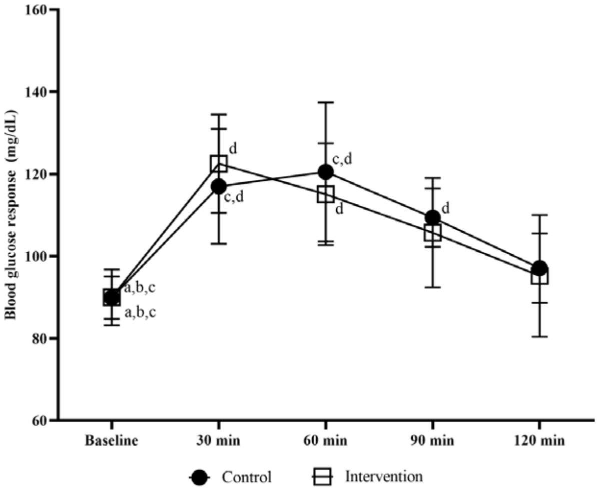

Fig. 2 Comparison of glycemic responses from baseline, 30, 60, 90, and 120 min, following consumption of wheat and brown rice flour waffles

Remark: [a-d] Different within the group when compared with 30, 60, 90 and 120 min, respectively ($p<0.05$).

Table 4 Postprandial Blood Glucose Responses Following Consumption of Wheat and Brown Rice Flour Waffles

Time (min)	Blood glucose responses				Blood glucose differentiations when compared with baseline					
	Control (n=10)	**Intervention (n=10)**	***p*-value**	**95% CI**	**Control (*n*=10)**	**Intervention (*n*=10)**	**% Change in the Control**	**% Change in the Intervention**	***p*-value**	**95% CI**
0	89.90±5.15[abc]	90.00±6.82[abc]	0.971	-5.57-5.57			-			
30	117.00±14.00[d]	122.50±11.97[cd]	0.357	-17.74-6.74	27.10±15.10	32.50±13.48	30.14	36.11	0.410	-18.85-8.05
60	120.50±16.91[cd]	115.10±12.39[d]	0.426	-8.52-19.32	30.60±18.31	25.10±16.20	34.04	27.89	0.486	-10.74-21.74
90	109.40±7.14[d]	105.70±13.32	0.449	-6.40-13.74	19.50±8.29	15.70±13.38	21.69	17.44	0.457	-6.66-14.26
120	97.10±8.47	95.20±14.78	0.728	-9.41-13.21	7.20±7.05	5.20±11.81	8.01	5.78	0.652	-17.14-11.14

Remark: All variables were expressed in mean± SD, CI = Confidence interval of the difference.
[a-d] Different within the group when compared with 30, 60, 90 and 120 min respectively ($p<0.05$).

properties, is not hydrolyzed in the small intestinal; rather, it is fermented by commensal bacteria in the colon to yield short-chain fatty acids (SCFAs) such as acetate, butyrate, and propionate. These SCFAs serve as energy substrate and modulate immunological responses in the colon while also contributing to improved glycemic control, enhanced weight loss, and optimized fat metabolism (Bojarczuk et al., 2022).

The consumption of brown rice flour may have significant clinical and public health implications, particularly for populations with metabolic disorders. Table 4 and Fig. 2 illustrate the blood glucose responses and other related changes following waffle consumption.

5. Incremental area under the curves of blood glucose after wheat and brown rice flour waffles consumption

The glucose area under the curve (AUC), reflecting the total glucose excursion after carbohydrate ingestion, is widely employed to determine the glycemic index and to evaluate interventions targeting postprandial hyperglycemia (Sakaguchi et al., 2016). After ingestion of brown rice flour waffles, the incremental AUC (iAUC) for blood glucose exhibited a smaller increase compared to wheat flour waffles during 0-0.5 h (3,103.5±220.96 vs. 3,187.5±210.74 mg/dL·min) and 0-1.0 h (10,228.5±924.89 vs. 10,315.5±728.46 mg/dL·min), but greater at 0-1.5 (20,574±1,796.75 vs. 20,251.5±1,251.7 mg/dL·min) and 0-2.0 h (32,964±2,265.81 vs. 32,305.5±2,251.03 mg/dL·min). These data indicate a mitigated glycemic response during the first hour and stabilization of blood glucose concentrations between 1.5-2.0 h, a pattern that concurs with previous on high-amylose rice and glycemic modulation based on iAUC results (Li et al., 2024). Furthermore, the findings suggest that a brown rice formulation fosters prolonged satiety by maintaining blood glucose stability and inhibiting ghrelin secretion (Mani et al., 2019).

No significant differences in iAUC were detected between the groups, corroborating earlier investigations on postprandial glycemic responses following the ingestion of whole wheat pasta (Jenkins et al., 1982), whole meal bread (Lappi et al., 2010), and sourdough bread (Scazzina et al., 2009). Additionally, a study evaluating glycemic responses in patients with type 2 diabetes compared conventional wheat bread with between genetically engineered formulated with a 50% high-amylose barley flour blend. This formulation resulted in an 11% lower iAUC compared to wheat bread, indicating improved postprandial glycemic control (Bohl et al., 2024). Consequently, further experimental investigation into the effects of brown rice flour on glycemic regulation in conditions characterized by abnormal glucose metabolism, such as diabetes, is warranted. Fig. 3 illustrates the incremental area under the blood glucose curve following the consumption of wheat flour and brown rice flour waffles at 0, 30, 60, 90, and 120 min, respectively.

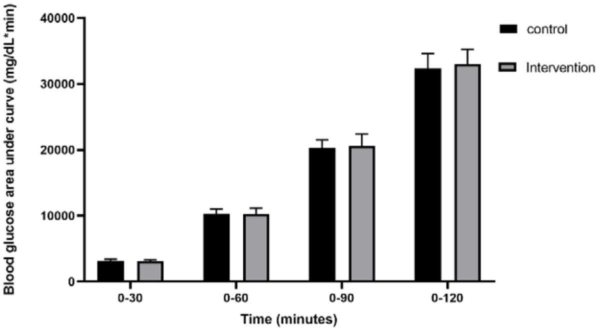

Fig. 3 Incremental area under the curve (iAUC) of blood glucose responses following wheat and brown rice flour waffle consumption over 0–30, 0–60, 0–90, and 0–120 min

6. Hunger and satiety levels after wheat and brown rice flour waffle consumption

A Visual Analogue Scale (VAS) was employed to evaluate hunger and fullness after consumption of waffles produced with wheat and brown rice flour. Sensations of emptiness and satisfaction were assessed across several parameters, including hunger, intensity, satiety, anticipated amount of food consumed, desire to eat, and food-related concerns. No statistically significant differences in hunger or satiety were observed between the groups following ingestion.

Consistent with previous studies comparing whole grain barley, wheat, and refined rice-based meals on short-term satiety and calorie intake, neither wheat nor rice consumption significantly reduced hunger before lunchtime (Felix et al., 2016; Schroeder et al., 2009). Although brown rice flour waffles produced modestly lower scores for appetite (3.80±1.81 vs. 3.40±0.97), higher satiety (3.60±1.51 vs. 3.70±0.48), and reduced immediate desire to eat (4.20±2.20 vs. 4.00±1.05) at 120 min compared to wheat flour waffles, the differences were not statistically significant. In a related study, Filipino adults who consumed white and brown rice exhibited significantly reduced hunger and enhanced fullness with brown rice, an effect attributed to its higher fiber content despite comparable ghrelin levels (a satiety-inducing hormone) (Gubat et al., 2016). Conversely, another study suggested that white and brown rice are similarly satiating and more filling than a glucose beverage (Wang, 2013). Additionally, research on the acute administration of resistant starch reported its potential to diminish subsequent food intake, a finding that is reflected in the VAS data for hunger and satiety (Bodinham et al., 2010; Guo et al., 2023b).

Table 5 presents detailed responses to the six VAS questions assessing hunger and satiety levels in both groups.

Table 5 Impact of wheat and brown rice flour waffle consumption on subjective hunger and satiety levels

Hunger and satiety questions	Hunger and satiety level			
	Time (Min)	Wheat flour (n=10)	Intervention (n=10)	*p*-value
1. How hungry do you feel?	0	3.30±1.42	2.70±1.25	0.329
	30	3.00±0.94	2.90±1.52	0.862
	60	3.10±1.20	2.60±1.08	0.339
	90	3.20±1.62	3.10±0.88	0.866
	120	3.80±1.81	3.40±0.97	0.546
2. How full do you feel?	0	4.30±1.34	5.00±1.49	0.284
	30	4.40±1.51	4.00±1.33	0.537
	60	4.20±1.55	3.80±1.23	0.530
	90	4.10±1.52	3.70±1.25	0.529
	120	3.60±1.51	3.70±0.48	0.845
3. How invigorated do you feel?	0	5.10±0.88	5.20±1.48	0.856
	30	5.40±0.84	5.30±1.34	0.844
	60	4.60±1.58	5.00±1.33	0.548
	90	5.20±1.23	5.10±0.99	0.844
	120	5.30±1.34	4.80±1.40	0.425
4. How much do you think you could eat now?	0	3.80±1.48	3.60±1.58	0.773
	30	4.20±1.81	3.50±1.18	0.320
	60	3.50±1.78	3.30±1.25	0.775
	90	3.90±1.85	3.30±1.06	0.386
	120	4.20±2.20	4.00±1.05	0.800
5. How intense is your urge to eat?	0	3.40±1.65	3.60±1.43	0.775
	30	3.80±1.62	3.50±0.97	0.622
	60	3.30±1.70	2.90±1.10	0.541
	90	3.70±1.77	3.40±0.84	0.634
	120	3.60±2.12	3.70±1.16	0.898
6. How much are you preoccupied with thoughts about food?	0	3.10±1.29	3.10±1.52	1.000
	30	3.00±1.25	3.20±1.48	0.747
	60	2.70±1.16	3.10±1.45	0.504
	90	2.90±1.29	3.20±1.40	0.624
	120	3.20±1.75	3.70±1.49	0.501

Remark: All variables were expressed in mean±SD each question was scored on a scale from 1 to 7, indicating low and high perception, respectively.

Conclusion

Brown rice flour, a complex carbohydrate, contains higher levels of resistant starch and fiber compared to wheat flour. Consequently, regular consumption of products containing brown rice flour may aid in regulating blood glucose levels, thereby reducing the risk of diabetes and obesity. Brown rice flour waffles were observed to decelerate blood glucose release between 30 and 120 min post-consumption, while hunger and satiety ratings did not differ between the two waffle types. Nonetheless, sensory evaluations indicated only moderate consumer acceptance of the brown rice flour waffles. Future research should involve larger RCTs over longer intervention periods, incorporate additional clinical endpoints such as insulin, GLP-1 levels, and explore formulation modifications to enhance consumer acceptability across a broader demographic spectrum.

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