Mal J Nutr 30(1): 095-106, 2024

Effects of nut and legume powder substitution in crackers prepared with wheat flour on postprandial plasma glucose response among healthy Thai adults

Wongdokmai Rossukon[1], Sridonpai Pimnapanut[2] & Prachansuwan Aree[2*]

[1]*Faculty of Science and Technology, Uttaradit Rajabhat University, Uttaradit, Thailand;* [2] *Food and Nutrition Academic and Research Cluster, Institute of Nutrition, Mahidol University, Nakhon Pathom, Thailand*

ABSTRACT

Introduction: Crackers, one of the most consumed baked products, primarily contain refined wheat flour and have a moderate glycaemic index (GI). Nut and legume powders are used in baked goods to help regulate postprandial glycaemia; however, their glycaemic responses remain controversial. Our study aimed to compare the postprandial glycaemic responses between crackers with 30% wheat flour substitution by white kidney beans, cashew nuts, and almonds versus standard wheat crackers. **Methods:** Twelve adults were recruited for a five-session randomised controlled crossover study. In each session, they were randomly assigned to receive 50g carbohydrates from either a glucose solution or one of the four crackers. Plasma glucose levels were measured at baseline and 15, 30, 45, 60, 90, and 120 minutes after consumption. Satiety and hunger were evaluated using 100mm visual analogue scales at baseline and every 30 minutes until 120 minutes. **Results:** Mean incremental area under the curve (IAUC) for plasma glucose did not differ between the alternatives and wheat crackers, but was lowest for almond crackers. Compared with GI value of glucose solution, that of wheat, cashew nut, white kidney bean, and almond crackers were 39.97±23.13, 37.66±24.66, 35.85±10.86, and 28.09±17.92, respectively. Almond cracker consumption resulted in the highest mean IAUC for satiety and lowest for hunger, though non-significant. **Conclusion:** Crackers with 30% wheat flour substitution by nut and legume powders tended to improve postprandial glycaemia more than the standard crackers; however, acute responses on insulin and glucagon-like peptide-1 require further examination.

Keywords: cracker biscuit, flour substitutes, glycaemic response

INTRODUCTION

Postprandial hyperglycaemia is defined as a significant increase in plasma glucose levels after food consumption. It has a substantial effect on the development of type 2 diabetes, as well as microvascular and macrovascular complications linked to other illnesses (Ratner, 2001). Large quantities of starchy foods, especially refined grains, contribute to an elevation in blood glucose levels in addition to sugar. More consumption of refined grain has been reported to be strongly associated with higher fasting blood glucose levels (Radhika *et al.*, 2009). On the other hand, consuming intact whole grains results in a lower glycaemic response value than consuming refined

*Corresponding author: Dr Prachansuwan Aree
Food and Nutrition Academic and Research Cluster, Institute of Nutrition, Mahidol University, Nakhon Pathom, Thailand
Tel: (+66)2800-2380 ext. 131; Fax: (+66)24419344; E-mail: aree.prc@mahidol.ac.th
doi: https://doi.org/10.31246/mjn-2023-0056

grains (Musa-Veloso *et al.*, 2018). Similar to other epidemiological findings, increased consumption of nuts and legumes is associated with a reduced risk of diabetes and cardiovascular disease (Afshin *et al.*, 2014; Aune *et al.*, 2016). Hence, it is challenging and intriguing to develop functional foods containing whole grains, nuts or legumes to better control glycaemic responses and reduce the prevalence of diabetes.

Currently, the consumer demand for a variety of foods and/or baked products consisting of low glycaemic index (GI) flour, particularly alternative powders such as nut and legume powders is increasing. This expanding demand aims to regulate blood glucose levels and achieve more nutritional benefits (Hussain *et al.*, 2020; Lestari, Huriyati & Marsono, 2017). Cracker biscuits, typically known as crackers, are one of the most popular baked snack foods manufactured primarily from more than 80% refined wheat flour (WF) (Chavan *et al.*, 2016). According to Atkinson *et al.* (2021), plain crackers have a moderate GI. Despite this, excessive intake of crackers might be detrimental to health; therefore, the development of innovative low GI crackers is essential. Numerous studies have focused on formulating crackers by replacing WF with other ingredients, such as cashew nut flour, almond drink dregs-based flour, pigeon pea (PP) flour, soy flour, and rice bran (Gbenga-Fabusiwa *et al.*, 2019; Mishra & Chandra, 2012; Owiredu, Laryea & Barimah, 2014; Santoso & Pamungkaningtyas, 2022).

In the production of crackers, the highest overall acceptance score has been obtained when up to 30% of nut and legume powders are substituted for WF (Owiredu *et al.*, 2014; Wongdokmai & Prachansuwan, 2023). A limited number of studies have investigated the GI of newly developed crackers. In a recent study, the GI of biscuits produced with WF only was higher than that of biscuits made with PP flour and WF (Gbenga-Fabusiwa *et al.*, 2019). Similarly, water chestnut and barley flours were mixed together to produce a cracker with a low GI of 30.2 (Hussain *et al.*, 2020). The predicted GI of biscuits containing lentil or legume flour was reported to be slightly lower than those without lentil or legume flour (Di Cairano *et al.*, 2021). Hence, it has been proposed that crackers produced with WF partially substituted with alternative powders might be helpful for people with diabetes and/or those needing to control their blood glucose levels.

In the International Tables of Glycemic Index and Glycemic Load Values 2021 (Atkinson *et al.*, 2021), the glycaemic responses of a number of foods are provided; nevertheless, information on nuts, legumes, and their products remains scarce. Previously, we developed alternative crackers by replacing 30% of WF with three alternative powders: cashew nut, almond, and white kidney bean powders, which yielded the highest overall acceptance score (Wongdokmai & Prachansuwan, 2023). Nevertheless, it is necessary to comprehend the glycaemic response of our recently developed crackers to ensure that these crackers can help in postprandial plasma glucose management. Therefore, the present study aimed to compare the postprandial glycaemic response of crackers made with alternative powders (white kidney bean, cashew nut, and almond powders) with that of standard crackers among healthy Thai adults.

MATERIALS AND METHODS

Study design

This study was a single-blind, randomised controlled crossover trial. The participants attended one screening visit and five test visits involving the consumption of four different types of

Table 1. Formulation of wheat and alternative crackers

Component	*Content (g)*			
	Wheat	*Cashew nut*	*Almond*	*White kidney bean*
Wheat flour	100	70	70	70
Cashew nut powder	-	30	-	-
Almond powder	-	-	30	-
White kidney bean powder	-	-	-	30
Butter	30	30	30	30
Monk fruit sweetener	15	15	15	15
Plain milk (liquid)	15	15	15	15
Salt	1	1	1	1
Egg	13	13	13	13
Vanilla powder	1.7	1.7	1.7	1.7
Milk powder	5	5	5	5
Baking powder	0.3	0.3	0.3	0.3

crackers and a standard 50 g glucose solution as reference.

Sample size

According to a review by the Food and Agriculture Organization (1998)/ World Health Organization, analyses of glycaemic response and GI in humans have been mostly conducted among ten individuals. In the current investigation, a sample size of twelve participants was considered adequate to account for inter-individual variability.

Study participants

Twelve healthy adults (six men and six women) were recruited to participate in the study. The inclusion criteria were males and females (non-pregnant and non-lactating), aged between 20 and 60 years, with body mass index (BMI) between 18.5 and 22.9 kg/m^2, non-smoking and non-alcohol drinking, and no history of food allergies. The exclusion criteria were diabetes, liver disease, kidney disease, thyroid disease, heart disease, and other diseases that could affect glucose metabolism, as well as the use of oral hypoglycaemic agents, insulin therapy, nutritional supplements, herbal medicines, and other medications including antipsychotics, antihypertensives, oral contraceptives, and anti-osteoporotic drugs within the past month prior to the study. All participants signed an informed consent form before participating in the study. This study was conducted following the principles of the Declaration of Helsinki. The study protocol was approved by the Naresuan University-Network of Research Ethics Committee (COA No. 0020/2022), and was registered in the Thai Clinical Trials Registry (TCTR) (TCTR20221211001; (https://www.thaiclinicaltrials.org/show/TCTR20221211001, accessed on 10 December 2022).

Description of cracker products

Four types of crackers were produced using the same formulation, except for the types of flour used. Standard crackers were formulated with 100% WF and other ingredients (butter, egg, milk, erythritol, vanilla powder, salt, and baking soda). The other three types of crackers were made with alternative powders including cashew nut, almond, and white kidney bean powders, which replaced 30% of WF. The ingredient details of the crackers are illustrated in Table 1. All crackers were prepared according to the same process: briefly,

butter was beat with salt until it became creamy, then sugar, eggs, and milk were added. Thereafter, flour and other dry ingredients were sieved, mixed, and blended until they became well-homogenised. The dough was kneaded manually and pressed into a 2 mm thick sheet, cut into 3.5 × 4.5 cm pieces, and baked at 150°C for 15 minutes.

Study protocol

1. Screening visit

Eligible volunteers were requested to fast overnight before coming into the hospital in the morning for screening. Informed consent was obtained before any measurements or blood draws were done.

Anthropometric measurements

Height was measured using a stadiometer (Seca Limited, Birmingham, West Midlands, Middlesex, UK), while body weight and body composition were measured using a bioelectrical impedance analysis machine (Tanita BC-418, Tokyo, Japan). BMI was calculated using the standard formula: weight (in kilograms) divided by height (in meters) squared.

Biochemical measurements

A 5-mL sample of whole blood was collected from a forearm vein by a registered nurse. Blood glucose, insulin, and haemoglobin A1C were analysed using the enzymatic method (Cobas C501 analyser, Germany), electrochemiluminescence immunoassay method (Cobas E801 analyzer, Germany), and turbidimetric inhibition immunoassay method (Cobas C501 analyser), respectively. The intra-assay and inter-assay coefficients of variation were 1.90% and 1.97% for plasma glucose, 2.38% and 4.9% for serum insulin, and 1.99% and 2.64% for haemoglobin A1C (HbA1c), respectively. The Homeostasis Model Assessment–Insulin Resistance (HOMA-IR) index was calculated and presented for the general characteristics.

Clinical measurements

Systolic and diastolic blood pressures were measured using an automatic blood pressure monitor (Omron HEM-8712, Vietnam).

Dietary assessments

Participants were requested to record their food consumption for three days (two weekdays and one weekend day) before the screening visit. Energy, carbohydrate, protein, and fat intakes were calculated using the INMUCAL-Nutrients software version 4.0, Mahidol University. All dietary data were used for standardised dinner estimation and preparation.

2. Test visit

Participants were given a standardised dinner the night before every test visit (before 8 p.m.). The standardised meal consisted of rice and stir-fried chicken, based on their energy and nutrient requirements. The participants were asked to refrain from performing vigorous activities and consuming caffeine and alcohol on the day before the test visit. The participants were randomly assigned to the sequences of treatments using an online computer software (randomizer.org). All five test visits were separated by at least a 1-week washout period to minimise the carry-over effects.

For each test visit, the participants consumed 50 g of available carbohydrates from either the crackers or glucose solution along with 200 mL of plain water. The nutritional values of each cracker are listed in Table 2. The nutritional values of the crackers were analysed in duplicate according to standard methods. Protein, fat, moisture, ash, and dietary fibre contents were evaluated using the Kjeldahl's method (AOAC

Table 2. Proximate composition of wheat and alternative crackers

Component	*Content (g)*			
	Wheat	*Cashew nut*	*Almond*	*White kidney bean*
Energy (kcal)	458±0	469±1	482±0	446±0
Moisture (g/100 g)	0.23±0.00	0.30±0.09	0.16±0.01	0.64±0.03
Carbohydrate (g/100 g)	78.95±0.13	73.72±0.00	70.62±0.13	77.26±0.07
Fat (g/100 g)	12.59±0.02	15.44±1.00	17.65±0.01	11.28±0.02
Protein (g/100 g)	6.97±0.11	8.84±0.02	9.82±0.09	9.11±0.08
Dietary fibre (g/100 g)	2.37±0.06	3.13±0.01	3.24±0.11	9.58±0.53
Ash (g/100 g)	1.27±0.00	1.70±0.00	1.74±0.00	1.81±0.00

991.20), the direct extraction method (ISO 2450), the drying method (AOAC 990.19), the drying ash method (AOAC 920.10), and the enzymatic gravimetric method (AOAC 985.29), respectively. Carbohydrate contents were calculated as follows: 100 – moisture – protein – fat – ash, based on the Atwater factor (4 kcal for protein and carbohydrates, and 9 kcal for fat). The obtained values were calculated for 50 g of available carbohydrates as follows: available carbohydrate = 100 – (moisture+ protein + fat + dietary fibre + ash).

When the participants arrived at the appointed time, an indwelling intravenous cannula was inserted into a forearm vein by a registered nurse. A 3-mL baseline blood sample was taken after a 10- to 12-hour overnight fast. Subsequently, the participants were instructed to consume either the crackers or glucose solution within 10 minutes. Postprandial blood samples were collected at 15, 30, 45, 60, 90, and 120 minutes to analyse the plasma glucose levels. Throughout the test visit, the catheter line was kept covered with 3 mL of normal saline to prevent blood clotting. The participants were asked to sit and limit physical movements during the intervention. After 120 minutes, the catheter was removed, and the test visit was completed. The same protocol was repeated for all test visits. The plasma was centrifuged at 2,000 rpm for 10 minutes. Glucose levels from the plasma samples at each time point were determined using the enzymatic method (Cobas C501 analyzer, Germany).

One hundred-millimetre continuous-line visual analogue scales (VASs) were utilised to measure subjective feelings of satiety and hunger. The participants were asked to answer the VAS questionnaires at baseline and every 30 minutes until 120 minutes. Each feeling was rated by placing a mark across each line on the paper and the participants were not able to refer to their previous ratings when completing the questionnaires.

Incremental area under the curve (IAUC) calculation

The IAUC for plasma glucose, satiety, and hunger for reference food and test crackers were calculated geometrically using the trapezoidal rule via Prism version 5.01 (GraphPad, USA). All areas below the baseline were excluded from the calculations. Mean and standard deviation (*SD*) of IAUC for the reference food and test crackers were calculated.

Glycaemic index (GI) and glycaemic load (GL) calculations

The GI values were calculated by expressing the IAUC for glucose response of test crackers as a percentage of the IAUC for glucose response of the standard glucose solution for each participant. The GL of the crackers was

Table 3. General characteristics of the study participants (*N*=12)

Characteristic	*Value*†
Sex, *n* (%)	
Male	6 (50.0)
Female	6 (50.0)
Age, year	26.8±8.8
BMI, kg/m^2	21.3±1.5
Waist circumference, cm	73.9±5.4
Body composition	
Body fat, %	18.8±10.8
Lean body mass, kg	44.5±8.7
Systolic blood pressure, mmHg	116±10
Diastolic blood pressure, mmHg	74±12
Fasting plasma glucose level, mmol/L	4.9±0.4
Fasting serum insulin level, pmol/L	57.9±23.4
HbA1c level, %	5.1±0.3
HOMA-IR index	1.8±0.8

BMI: Body mass index; HOMA-IR: Homeostasis model assessment–insulin resistance
†The values are presented as *n* (%) or mean±*SD*

computed by multiplying the GI of each cracker by the proportion of available carbohydrates in a usual portion size (30 g of crackers) divided by 100.

Statistical analysis

Statistical analysis was performed using the PASW Statistics for Windows, Version 18.0 (SPSS Inc., Chicago). Data were expressed as means±*SD*s. Two-tailed $p<0.05$ was considered significant. Distribution of data was analysed using the Shapiro–Wilk test. Repeated measures analysis of variance (ANOVA) was used to evaluate postprandial plasma glucose level, satiety score, and hunger score, testing for time × treatment interactions and the effect of time and test crackers separately. One-way ANOVA with Bonferroni's test was used to determine the significance of mean differences between the groups.

RESULTS

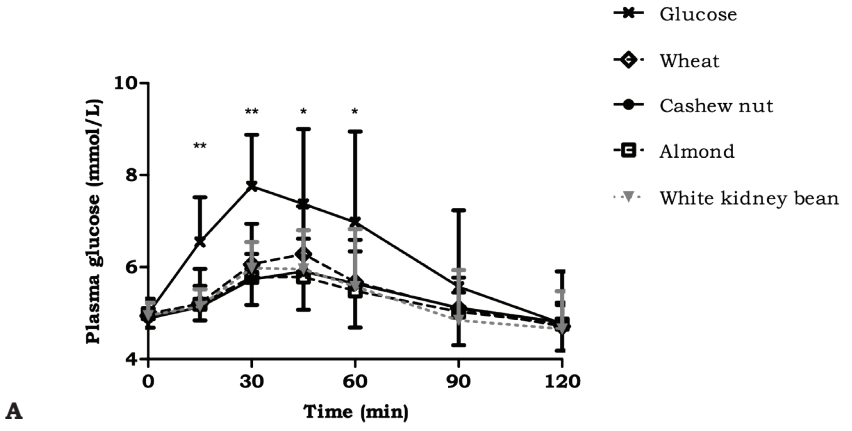
Characteristics of the study sample

Twelve healthy Thai adults completed the study, and their general characteristics are shown in Table 3. Equal numbers of men and women were recruited. Mean BMI was 21.3±1.5 kg/m^2. The participants were apparently healthy and had normal BMI, plasma glucose level, HbA1c level, and HOMA-IR index.

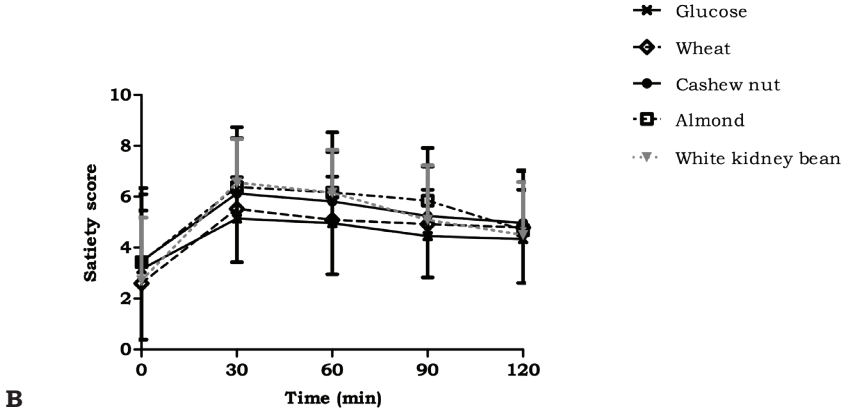
Comparison of plasma glucose responses

Figure 1A displays the plasma glucose responses following consumption of the glucose solution and four test crackers. Plasma glucose concentration peaked at 30 minutes after consuming either the glucose solution or the test crackers and then returned to baseline levels within 2 hours, as shown in Supplementary Table 1. Mean IAUC for plasma glucose was substantially higher after glucose solution consumption than after test cracker consumption (Table 4). Although the mean IAUC for plasma glucose after test cracker consumption was not significantly different from that after wheat cracker consumption, it appeared to be lower, especially for almond crackers (Table 4).

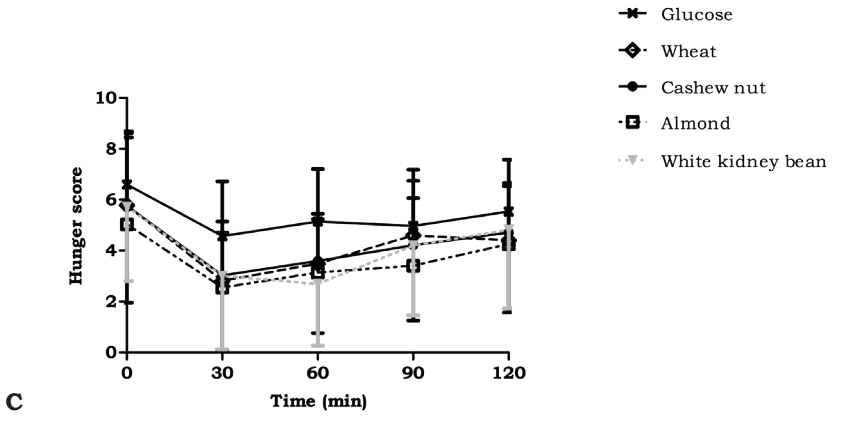
The GI values of wheat, cashew nut, white kidney bean, and almond crackers



A



B



C

Figure 1. Acute response effects on plasma glucose level (A), satiety score (B), and hunger score (C) after consumption of glucose solution and four test crackers. The values are presented as mean±*SD*. The mean values are significantly different from each other: $^{*}p<0.05$, $^{**}p<0.01$, which were determined using repeated measures ANOVA with Bonferroni's correction for *post-hoc* comparisons between treatments.

Table 4. IAUC for plasma glucose, hunger, and satiety in response to consumption of glucose solution and four test crackers in healthy Thai adults

Parameter	*Glucose solution*	*Cracker*			
		Wheat	*Cashew nut*	*Almond*	*White kidney bean*
Glucose IAUC (mmol min/L)	179±107[a]	71±46[b]	63±36[b]	50±32[b]	64±44[b]
Satiety IAUC (score min)	549±180[a]	577±219[a]	643±208[a]	674±236[a]	641±177[a]
Hunger IAUC (score min)	623±156[a]	480±152[a]	482±182[a]	412±212[a]	455±222[a]

IAUC: Incremental area under the curve
The values are presented as mean±*SD*. The IAUC was calculated using Prism version 5.01. The mean values at each treatment (same row) with different superscript letters are significantly different ($p<0.05$), which were determined using one-way ANOVA with Bonferroni's correction for *post-hoc* comparisons.

were 39.97±23.13, 37.66±24.66, 35.85±10.86, and 28.09±17.92, respectively, in comparison with glucose solution. When considering a standard portion of crackers, the GL values for the wheat, cashew nut, white kidney beans, and almond crackers were observed to be low (≤10), with values of 9.18, 7.97, 7.28, and 5.68, respectively.

Comparison of satiety and hunger scores

Satiety scores reached their peak at 30 minutes after consuming either the glucose solution or test crackers and then returned close to baseline levels within 2 hours (see Supplementary Tables 2 and 3). As illustrated in Figures 1B and 1C and Table 4, ingestion of almond crackers was likely to result in the mean IAUC for satiety being the highest and for hunger being the lowest. Mean IAUC for satiety for wheat crackers and glucose solution tended to be lower than that for the three test crackers, although the differences were not significant. Moreover, there was no difference in the mean IAUC for hunger between the four test crackers and glucose solution.

DISCUSSION

The present study demonstrated that even though there was no significant difference between alternative crackers and wheat crackers, the crackers partially made with nut and legume powders tended to yield greater benefits on postprandial glycaemic responses among healthy Thai participants than the standard crackers. This finding could be attributed to the sugar-free cracker recipe we created. In the study, newly developed crackers were prepared using a non-nutritive sweetener in place of sugar; therefore, no significant difference was observed between the crackers. Consistently, our wheat crackers appeared to have a lower GI than those in a previous report (Atkinson *et al.*, 2021).

Herein, it was observed that the postprandial glycaemic response of alternative crackers had a slightly beneficial impact on regulating plasma glucose levels compared to wheat crackers, potentially attributable to the substitution of nut and legume powders. Generally, nuts have a relatively low GI of 22±1, whereas legumes have a slightly higher GI of 34±14 (Atkinson *et al.*, 2021). The glycaemic response values of alternative crackers made with almonds, cashew nuts, and white kidney beans as a substitute for 30% of WF were therefore slightly higher than the previously reported values of nuts and legumes (Atkinson *et al.*, 2021). In

Supplementary Table 1. Baseline and postprandial plasma glucose concentrations after consumption of test diets at the different time points

Time (*min*)	*Plasma glucose concentration (mmol/L)*				
	Glucose solution	*Wheat cracker*	*Cashew nut cracker*	*Almond cracker*	*White kidney bean cracker*
0	4.99±0.28[a]	4.94±0.37[a]	4.89±0.42[a]	4.99±0.30[a]	4.94±0.28[a]
15	6.55±0.97[b]	5.21±0.75[a]	5.13±0.46[a,b]	5.19±0.35[a,b]	5.14±0.37[a,b]
30	7.76±1.12[c]	6.06±0.88[b,c]	5.73±0.55[b]	5.78±0.60[b]	5.98±0.57[b,c]
45	7.37±1.63[b,c]	6.28±1.04[b,c]	5.91±0.71[b]	5.79±0.72[b]	5.95±0.85[b,c]
60	6.98±1.97[b,c]	5.67±0.92[a,b]	5.64±0.70[a,b]	5.48±0.79[a,b]	5.58±1.25[b,c]
90	5.57±1.66[a]	5.10±0.67[a,b]	5.12±0.33[a,b]	5.03±0.73[a,b]	4.84±1.09[a,b]
120	4.77±1.13[a]	4.71±0.52[a,b]	4.80±0.38[a]	4.76±0.58[a]	4.65±0.83[a,b]

The values are presented as mean±*SD*. The means values at each time of measurements (same column) with different superscript letters are significantly different ($p<0.05$), which were determined using repeated measures ANOVA and Bonferroni's correction for *post-hoc* comparisons.

Supplementary Table 2. Satiety scores at baseline and after consumption of test diets at the different time points

Time (*min*)	*Satiety score*				
	Glucose solution	*Wheat cracker*	*Cashew nut cracker*	*Almond cracker*	*White kidney bean cracker*
0	3.2±2.3[a]	2.6±2.2[a]	3.5±2.6[a]	3.4±2.9[a]	2.7±2.5[a]
30	5.1±1.6[a]	5.5±2.1[b]	6.1±2.2[b]	6.4±2.3[b]	6.6±1.7[b]
60	5.0±1.8[a]	5.1±2.1[b]	5.8±1.9[b]	6.2±2.4[b]	6.2±1.7[b,c]
90	4.5±1.8[a]	4.9±2.1[b]	5.2±1.9[a,b]	5.8±2.1[b]	5.1±2.2[c]
120	4.3±1.9[a]	4.8±2.2[a,b]	5.0±2.0[a,b]	4.7±2.3[a]	4.5±2.1[a,c]

The values are presented as mean±*SD*. The means values at each time of measurements (same column) with different superscript letters are significantly different ($p<0.05$), which were determined using repeated measures ANOVA and Bonferroni's correction for *post-hoc* comparisons.

Supplementary Table 3. Hunger scores at baseline and after consumption of test diets at the different time points

Time (*min*)	*Hunger score*				
	Glucose solution	*Wheat cracker*	*Cashew nut cracker*	*Almond cracker*	*White kidney bean cracker*
0	6.6±2.0[a]	5.8±2.9[a]	5.8±2.7[a]	5.0±3.1[a]	5.7±2.9[a]
30	4.6±2.1[a]	2.8±1.9[a]	3.0±2.1[a]	2.5±2.5[a]	3.0±2.9[a,b]
60	5.1±2.1[a]	3.5±1.7[a]	3.6±1.9[a]	3.1±2.4[a]	2.7±2.4[b]
90	5.0±2.2[a]	4.6±2.2[a]	4.2±1.9[a]	3.4±2.1[a]	4.2±2.7[a,b]
120	5.5±2.0[a]	4.4±2.2[a]	4.7±1.8[a]	4.3±2.7[a]	4.8±3.1[a]

The values are presented as mean±*SD*. The means values at each time of measurements (same column) with different superscript letters are significantly different ($p<0.05$), which were determined using repeated measures ANOVA and Bonferroni's correction for *post-hoc* comparisons.

a review, the postprandial glycaemic response value of food products enriched with legumes appeared to be lower than that of original food products, depending on the level of substitution (Binou, Yanni & Karathanos, 2022).

In a previous study, biscuits made with PP flour mixed with WF at a ratio of 25% to 75% displayed a lower GI than biscuits made with WF by at least 5% (25% PP, 55.60±0.53; 50% PP, 51.16±1.12; 75% PP, 44.70±0.52; WF, 60.59±0.37) (Gbenga-Fabusiwa *et al.*, 2019). Another prior study revealed that mixed nuts significantly reduced the 2-hour postprandial glycaemic response when combined with 50 g of available carbohydrates from white bread in a dose-response manner (Kendall *et al.*, 2011). Similarly, consuming 30, 60, or 90 g of almonds along with white bread can blunt the postprandial glycaemic response of white bread in a dose-dependent manner, as shown by a GI of 106, 63, and 45, respectively (Josse *et al.*, 2007). These results confirmed the findings of the current investigation that substituting 30% of WF with nut or legume powders could achieve a postprandial glycaemic response reduction of 4% or higher. Hence, the level of substitution or quantity of legume or nut powders is one of the crucial factors influencing postprandial glycaemic response of food products.

Although there were no significant differences in the glycaemic responses of the four test crackers, the crackers produced with almond powder had the lowest glycaemic response value. This finding could be explained by the fact that almond crackers have a higher energy density than cashew nut, white kidney bean, and wheat crackers. In a prior study, there was a positive correlation between increased energy and gastric-emptying time after consumption of a meal containing different energy and macronutrients (Westphal *et al.*, 2004). Food products with a higher energy density and fat content would slow down the rate of gastric emptying, consequently reducing postprandial glycaemic response and increasing satiety (Tan, Dhillon & Mattes, 2014). Our almond crackers consistently contained the highest number of calories and fat among the crackers; this might be the reason why a better glucose response and increased satiety were achieved from almond crackers.

In the present study, the responses in terms of blood glucose levels and satiety scores after consumption of the white kidney bean and cashew nut crackers were similar. These results may be explained by the fact that white kidney bean crackers have greater dietary fibre content than cashew nut crackers, which have higher fat content. The comprehensive review by Russell *et al.* (2016) revealed that the type and amount of fibre play a key role in slowing the rate of carbohydrate digestion and absorption, as well as gastric emptying, resulting in beneficial effects on postprandial glycaemic control and insulinemic response. Likewise, as aforementioned, consuming oil/fat could slow the gastric-emptying rate and delay a rise in blood glucose, insulin, and glucose-dependent insulinotropic polypeptide levels in people with type 2 diabetes (Gentilcore *et al.*, 2006). It would be plausible to state that dietary fibre or fat content affects satiety level and glycaemic response.

This study had some strengths. Firstly, the crossover study was conducted among the same individuals and the participants were given a standardised dinner meal to control inter-day alterations. Secondly, the crackers were prepared with the same ingredients, except for the ratio of alternative powders to WF, so the effects

on plasma glucose would arise from the nut and legume powders. However, iso-calories and iso-macronutrients, as well as a similar serving size could not be provided to the participants, which might have influenced gastric emptying and gut hormone secretion, consequently leading to different glycaemic responses. Additionally, the study protocol did not strictly adhere to ISO26642:2010 guidelines, especially concerning the lack of repeated tests for the reference food or glucose solution. Ideally, this response should have been assessed repeatedly, with each participant undergoing the test at least three times. This non-adherence could potentially contribute to an increase in the effect of day-to-day variations in glucose tolerance.

CONCLUSION

Based on the present findings, crackers produced with 30% WF substitution by nut and legume powders tended to have more benefits on postprandial glycaemia than standard crackers prepared with 100% WF. However, the acute responses on insulin and glucagon-like peptide-1 should be further examined.

Acknowledgements

This research project was supported by Thailand Science Research and Innovation (Basic Research Fund: Fiscal Year 2022), with contract number 052/2022. The authors would like to thank all volunteers for participating in and contributing to this project and acknowledge the Food and Nutrition Programme, Faculty of Science and Technology, Rajabhat Uttaradit University, for allowing the use of its facilities.

Authors' contributions

Wongdokmai R, performed the study, collected the data, and reviewed the manuscript; Sridonpai P, analysed the data and reviewed the manuscript; Prachansuwan A, conceptualised and designed the study, prepared the draft of the manuscript, and finalised the manuscript.

Conflicts of interest

The authors declare no conflicts of interest.

References

Afshin A, Micha R, Khatibzadeh S & Mozaffarian D (2014). Consumption of nuts and legumes and risk of incident ischemic heart disease, stroke, and diabetes: A systematic review and meta-analysis. *Am J Clin Nutr* 100(1):278-288.

Atkinson FS, Brand-Miller JC, Foster-Powell K, Buyken AE & Goletzke J (2021). International tables of glycemic index and glycemic load values 2021: A systematic review. *Am J Clin Nutr* 114(5):1625-1632.

Aune D, Keum N, Giovannucci E, Fadnes LT, Boffetta P, Greenwood DC, Tonstad S, Vatten LJ, Riboli E & Norat T (2016). Nut consumption and risk of cardiovascular disease, total cancer, all-cause and cause-specific mortality: A systematic review and dose-response meta-analysis of prospective studies. *BMC Med* 14(1):207.

Binou P, Yanni AE & Karathanos VT (2022). Physical properties, sensory acceptance, postprandial glycemic response, and satiety of cereal based foods enriched with legume flours: A review. *Crit Rev Food Sci Nutr* 62(10):2722-2740.

Chavan RS, Sandeep K, Basu S & Bhatt S (2016). Biscuits, cookies, and crackers: chemistry and manufacture. In: Caballero B, Finglas PM, Toldrá F (eds). *Encyclopedia of Food and Health*. Oxford: Academic Press, p437-444.

Di Cairano M, Condelli N, Caruso MC, Cela N, Tolve R & Galgano F (2021). Use of underexploited flours for the reduction of glycaemic index of gluten-free biscuits: physicochemical and sensory characterization. *Food Bioproc Tech* 14(8):1490-1502.

Food and Agriculture Organization (1998). Carbohydrates in human nutrition: Report of a joint FAO/WHO expert consultation. *FAO Food Nutr Pap* 66:1-140.

Gbenga-Fabusiwa FJ, Oladele E, Oboh G, Adefegha S, Fabusiwa O, Osho P, Enikuomehin A & Oshodi A (2019). Glycemic response in diabetic subjects to biscuits produced from blends of pigeon pea and wheat flour. *Plant Foods Hum Nutr* 74(4):553-559.

Gentilcore D, Chaikomin R, Jones KL, Russo A, Feinle-Bisset C, Wishart JM, Rayner CK & Horowitz M (2006). Effects of fat on gastric emptying of and the glycemic, insulin, and incretin responses to a carbohydrate meal in type 2 diabetes. *J Clin Endocr* 91(6):2062-2067.

Hussain SZ, Beigh M, Qadri T, Ahmad I & Naseer B (2020). Development of low glycemic index crackers from water chestnut and barley flour. *Br Food J* 122(4).

Josse AR, Kendall CWC, Augustin LSA, Ellis PR & Jenkins DJA (2007). Almonds and postprandial glycemia—A dose-response study. *Metabolism* 56(3):400-404.

Kendall CW, Esfahani A, Josse AR, Augustin LS, Vidgen E & Jenkins DJ (2011). The glycemic effect of nut-enriched meals in healthy and diabetic subjects. *Nutr Metab Cardiovasc Dis* 21:S34-S39.

Lestari LA, Huriyati E & Marsono Y (2017). The development of low glycemic index cookie bars from foxtail millet (*Setaria italica*), arrowroot (*Maranta arundinacea*) flour, and kidney beans (*Phaseolus vulgaris*). *J Food Sci* 54(6):1406-1413.

Mishra N & Chandra R (2012). Development of functional biscuit from soy flour & rice bran. *Int J Agric Food Sci* 2(1):14-20.

Musa-Veloso K, Poon T, Harkness LS, O'Shea M & Chu Y (2018). The effects of whole-grain compared with refined wheat, rice, and rye on the postprandial blood glucose response: A systematic review and meta-analysis of randomized controlled trials. *Am J Clin Nutr* 108(4):759-774.

Owiredu I, Laryea D & Barimah J (2014). Evaluation of cashew nut flour in the production of biscuit. *Nutr Food Sci* 44(3):204-211.

Radhika G, Van Dam RM, Sudha V, Ganesan A & Mohan V (2009). Refined grain consumption and the metabolic syndrome in urban Asian Indians (Chennai Urban Rural Epidemiology Study 57). *Metabolism* 58(5):675-681.

Ratner RE (2001). Controlling postprandial hyperglycemia. *Am J Card* 88(6):26-31.

Russell WR, Baka A, Björck I, Delzenne N, Gao D, Griffiths HR, Hadjilucas E, Juvonen K, Lahtinen S & Lansink M (2016). Impact of diet composition on blood glucose regulation. *Crit Rev Food Sci Nutr* 56(4):541-590.

Santoso J & Pamungkaningtyas F (2022). Substitution of wheat flour with almond drink dregs-based flour and its effect on cracker quality. *IOP Conf Ser: Earth Environ Sci* 1115(1):012100.

Tan SY, Dhillon J & Mattes RD (2014). A review of the effects of nuts on appetite, food intake, metabolism, and body weight. *Am J Clin Nutr* 100(1):S412-S422.

Westphal S, Kästner S, Taneva E, Leodolter A, Dierkes J & Luley C (2004). Postprandial lipid and carbohydrate responses after the ingestion of a casein-enriched mixed meal. *Am J Clin Nutr* 80(2):284-290.

Wongdokmai R & Prachansuwan A (2023). Development of crackers partially substitution of wheat flour with alternative powders. *JNAT* 58(1):30-41.