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Postprandial glycaemic response to white vs granary wholemeal bread in Chinese and Caucasian adults

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Abstract

Previous evidence shows no significant difference in postprandial glycaemic responses (PPGRs) between wholemeal and white bread consumption. This study aimed to investigate whether a commercially available granary wholemeal bread, enriched with dietary fibre, could attenuate PPGRs compared to white bread. The study also explored differences in PPGRs between ethnic groups. Twenty healthy young adults (10 White Caucasian and 10 Chinese participants), with a body mass index (BMI) ranging from 18.5 to 24.9 kg/m², completed the study. Each participant consumed two slices of granary wholemeal bread (fibre: 6.7 g/100 g) or white bread (fibre: 2.7 g/100 g), served with 150 ml of pure orange juice, 10 g of butter, and 15 g of strawberry jam on two separate occasions at least 48 h apart after fasting for 8–12 h. Blood glucose levels were measured via finger prick at fasting (0 min), as well as at 30, 60, 90, and 120 min postprandially using a blood glucose analyser. Participant demographics including age, sex, ethnicity, body weight, height, and body fat percentage were recorded during the first visit. The results showed that both the area under the curve (AUC) and incremental AUC (iAUC) of PPGRs were significantly lower after consumption of granary wholemeal bread compared to white bread ($p = 0.027$ and $p = 0.038$, respectively). However, peak glucose values did not differ significantly between bread types. Chinese participants exhibited significantly lower fasting blood glucose levels than White Caucasians ($p = 0.033$), but no significant ethnic differences were observed in AUC, iAUC, or peak glucose values, regardless of bread type. In conclusion, granary wholemeal bread demonstrated a beneficial effect in reducing PPGRs compared to white bread. Further research is warranted to clarify the role of fibre type and dosage in modulating glycaemic responses and to investigate ethnic variations in PPGRs in larger, well-controlled studies.

Keywords: *postprandial glycaemic response, dietary fibre, bread, ethnicity*

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1. Introduction

Postprandial glycaemic response (PPGR) is recognised as an independent risk factor for type 2 diabetes mellitus (T2DM) [1]. Controlling postprandial hyperglycaemia is therefore crucial to prevent complications in individuals with T2DM, slow the progression of prediabetes, and reduce the risk of developing T2DM in the general population [2]. Dietary fibre is the part of plant material in the diet that is resistant to enzymatic digestion, which includes cellulose, non-cellulosic polysaccharides such as hemicellulose, pectic substances, gums, mucilages, and non-carbohydrate component lignin [3]. The consumption of dietary fibre has been reported to attenuate glycaemic response in healthy adults [4, 5] and in people with the metabolic syndrome [6]; it has also been shown to reduce fasting blood glucose (FBG) concentrations in patients with T2DM [7], through influencing nutrient absorption and changing gastrointestinal transit time [2].

White bread is the most popular bread and contributes to 84% (860 g/1016 g) of average bread consumption per person per week in the UK, followed by wholemeal bread consumption [8]. Wholemeal bread contains higher dietary fibre content, and a wide range of phytochemicals thus regarded as healthier compared with white bread [9]. Evidence from observational studies has shown wholegrain consumption was associated with a reduced incidence of cardiovascular diseases, T2DM, and certain cancers [10]. Most clinical trials investigating bread's impact on blood glucose and insulin responses are acute in design. Interestingly, our previous study [11] and others have shown that wholemeal bread did not attenuate PPGRs compared with white bread [12–15]. This may be attributed to wholemeal bread primarily containing insoluble fibre [16], which has shown no effect on PPGRs [17], and its microstructure is different from white bread, being conducive to rapid α-amylase digestion [15]. The discrepancy between observational and acute trial findings could be due to the longer-term effects of dietary fibre on the gut microbiota, which can influence metabolic health outcomes [10]. However, some innovative formulas of wholemeal bread may deliver the health benefit of attenuating PPGR after consumption. A recently published systematic review and meta-analysis [18] investigated the effect of regular consumption of reformulated breads on glycaemic control, based on randomised controlled trials (RCTs). It found

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that reformulated breads high in dietary fibre, whole grains, and/or functional ingredients reduced fasting blood glucose concentrations in adults, particularly in patients with T2DM, but they had no significant effect on PPGRs. However, no granary wholemeal bread was included in the review, nor has this bread type been investigated in the wider literature. In the current study, we selected a commercially available granary wholemeal bread with an added granary blend, including malted wheat flakes (9%), toasted wheat, and toasted rye that contained higher dietary fibre content than the normal wholemeal bread. The primary objective was to investigate whether this fibre-enriched wholemeal bread could reduce PPGR compared to white bread. In addition, previous studies showed inconsistent results regarding PPGRs and fasting blood glucose (FBG) concentrations between different ethnic groups [19–21]; therefore, the secondary objective of the study was to explore the difference in PPGRs and FBG concentrations between White Caucasian and Chinese participants. We hypothesised that PPGRs would be lower following consumption of the granary wholemeal bread compared to white bread and that there would be no significant differences in PPGRs or FBG levels between the two ethnic groups.

2. Method

This was an acute randomised non-blinded crossover trial. The study was approved by the Coventry University Ethics Committee (Project Reference Number P144960 and P145043 from separate ethics applications focusing on wholemeal bread and white bread consumption, respectively, but on the same participants). The study was conducted between February and May 2023 at the School of Life Sciences at Coventry University. All participants provided written consent before taking part in the study.

2.1. Participants

To minimise the potential influence of age and body weight on PPGRs [22], the inclusion criteria specified healthy young adults aged 18–35 years with a normal body weight defined by body mass index (BMI) between 18.5 and 24.9 kg/m² [23] from White Caucasian or Chinese origin. Exclusion criteria were participants with diabetes, digestive system diseases, BMI lower than 18.5 kg/m² or higher than 25 kg/m², celiac disease, other chronic diseases, blood clotting disorders, and individuals with food allergy or sensitivity to the study meals or from races other than White Caucasian or Chinese origin. The eligibility of the participants was screened via a health and lifestyle questionnaire. Purposive and convenience sampling recruitment methods were used via the application of a circulating recruitment advert and word of mouth among the university staff and students.

Twenty-five participants were screened, and five were excluded due to BMI < 18.5 kg/m² (n = 1), BMI ≥ 25.0 kg/m² (n = 2), or the fact that they belonged to other races (n = 2). Twenty participants were eligible (n = 10 White Caucasian, n = 10 Chinese) and recruited, and all completed the study (**Figure 1**).

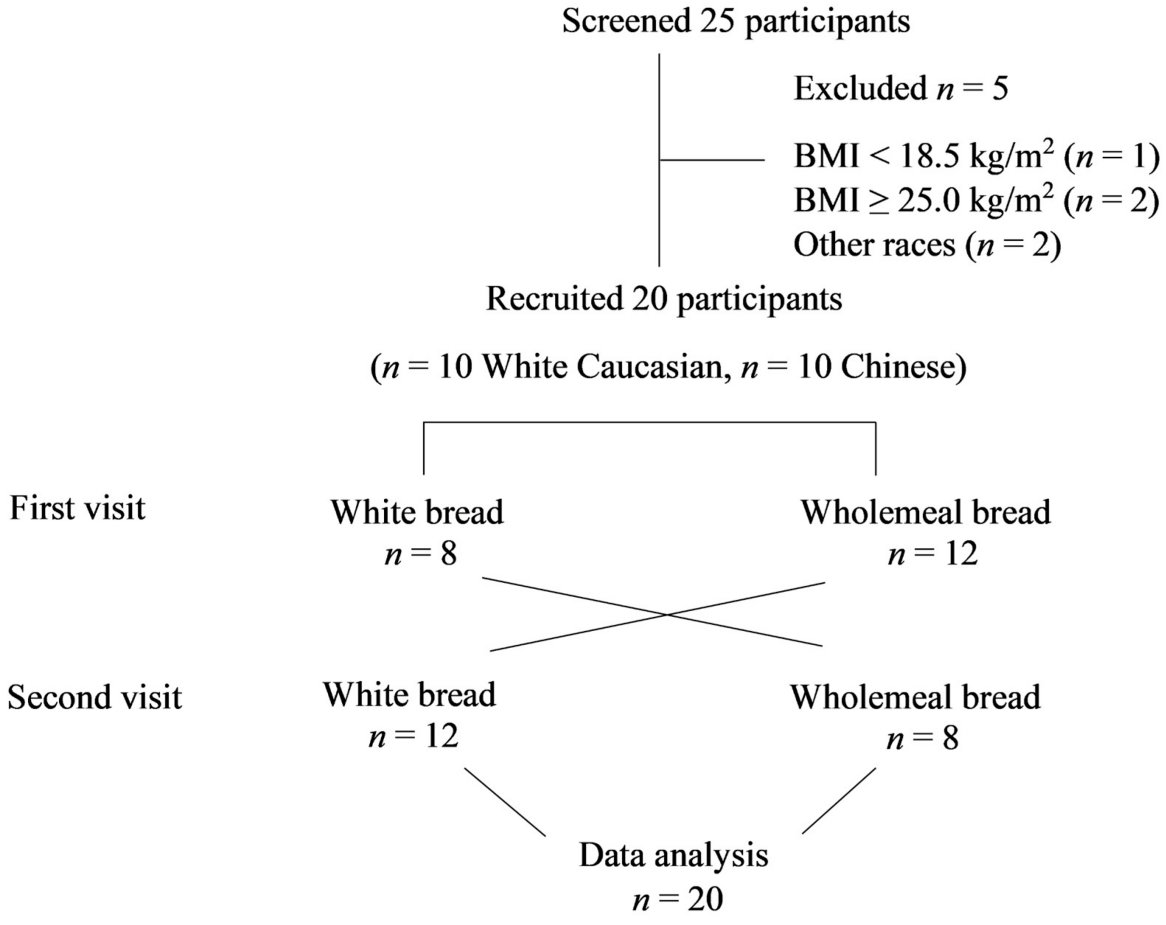

Figure 1 • Participant flow diagram.

2.2. Study design

Eligible participants attended two study visits, with each being at least 48 h apart, following an overnight fast of 8–12 h. At the first visit, participants flipped a coin to determine which bread they would consume: heads indicated white bread (WB), and tails indicated granary wholemeal bread (WMB). Consequently, 8 participants consumed WB, and 12 participants consumed WMB at their first visits (**Figure 1**). The bread was served with 150 ml of pure orange juice, 10 g of butter, and 15 g of strawberry jam to mimic a real-life meal scenario and promote palatability as referenced in similar study designs [24, 25]. To determine the order of the bread meals, participants flipped a coin: heads indicated WB would be consumed first; tails indicated WMB. As a result, eight participants received WB on their first visit, while twelve received WMB (**Figure 1**).

All food and drink items were purchased from Tesco supermarket (Welwyn Garden City, UK). The details of the meal composition and nutrient information are shown in **Table 1**. The total available carbohydrates were 68.9 g in the WB meal (44.6 g from the bread) and 61.7 g in the WMB meal (37.4 g from the bread). The dietary fibre content in two slices of WB and WMB was 2.4 g and 6.4 g, respectively, while in the corresponding meals, it was 2.7 g and 6.7 g, respectively.

Participants were asked to fast (only water was allowed) for 8–12 h, starting from the night before their visit on the following morning (between 9 AM and 10 AM). Blood glucose concentrations were measured at fasting and at 30, 60, 90, and 120 min after meal consumption by finger prick performed by the researcher using a Biosen Blood Glucose/Lactate Analyser (EKF Diagnostics, Cardiff). The coefficient of variation (CV) is less than 3%, provided by the manufacturer. Participants were asked to consume the meal within 10 min, remain sedentary, and refrain from eating and drinking anything during the study period. Setting mobile alarms was recommended to participants to make sure blood samples were collected on time. In addition, the participants were asked to consume similar meals the night before the two visits, avoid intensive physical activity and alcohol consumption, and have a good night's sleep before their visit day. Data including participant name, email/mobile (for appointment purposes), self-reported sex, age, and ethnicity were collected.

The treatment (bread) was not blind to YX, DGP, and NL, who conducted the study, nor to the participants, but HD, who analysed the data, was blind to the study.

Table 1 • Details of meal components and nutrient composition.

Nutrients	White bread	Wholemeal bread	Orange juice	Butter	Jam	White bread meal	Wholemeal bread meal
	100 g (2 slices)	94 g (2 slices)	150 ml	10 g	15 g		
Energy (kcal)	233	222	64	67	37	401	390
Fibre (g)	2.4	6.4	0.2	-	0.1	2.7	6.7
Carbohydrate (sugar) (g)	44.6 (3.5)	37.4 (2.2)	15 (15)	<0.5	9.3 (9.0)	68.9 (27.5)	61.7 (26.2)
Fat (g)	1.7	2.2	0	7.4	< 0.1	9.1	9.6
Protein (g)	8.7	10	0.9	<0.5	< 0.1	9.6	10.9

The nutrient contents were based on nutrition information provided on food packages.

2.3. Outcome measures

The PPGRs were presented by both the area under the curve (AUC) and the incremental area under the curve (iAUC), as well as the peak value (PV) of the blood glucose after the meal consumption for up to 2 h. The AUCs and iAUCs were calculated using approximated trapezoidal numerical integration [26], and only the incremental area above the fasting level was included for iAUCs. The body height was measured by a stadiometer, and body weight and body fat percentage (BF%) were measured using Tanita MC-980MA PLUS (Tanita Company, Tokyo, Japan) before taking the meals on the first visit only.

2.4. Data analysis

The sample size referred to a similar study design [27], calculated by GPower software (version 3.1.9.7, Düsseldorf, Germany). We chose the F-test and repeated measures and within–between interaction ANOVAs as the analysis methods. Twenty participants were needed to yield an effect size of 0.3 with a power of 90% and a significance level of 0.05.

Categorical data including sex and ethnicity are presented as frequency (n) and percentage (%). Continuous data including age, BMI, BF%, FBG concentration, AUCs, iAUCs, and PVs are presented as mean ± standard deviation (SD). Continuous variables (age, BMI, and BF%) between two groups were analysed using an independent sample t-test. FBGs, AUCs, iAUCs, and PVs between the two types of bread consumption were compared using a paired sample t-test. Differences in FBGs, AUCs, iAUCs, and PVs between ethnic groups (between-subject effects) were assessed using a two-way repeated measures ANOVA. The sex distribution between the two ethnic groups was analysed using the Chi-square test. Normality tests of the continuous data were carried out using the Kolmogorov–Smirnov test. All statistical analyses were carried out using IBM SPSS Statistics software v29.0.2.0 (SPSS Inc., Chicago, IL, USA), with the significance level set at $p \leq 0.05$ (two-tailed, apart from the paired sample t-tests, which were one-tailed).

3. Results

3.1. Basic information about the participants

Table 2 shows the characteristics of the 20 participants, among which 10 were White Caucasians and 10 were Chinese. Additionally, 9 were females and 11 were males. The mean age was 23.2 ± 3.3 years old, BMI was 20.9 ± 2.2 kg/m^2, and BF% was 19.8 ± 6.3%.

There was no significant difference in BMI and FB% or sex distribution between ethnic groups, except for the fact that Chinese participants were significantly younger than White Caucasians (21.6 ± 0.9 years vs. 24.7 ± 4.1 years, p = 0.042) (**Table 2**).

3.2. FBGs and PPGRs between two bread consumptions

The mean FBGs were the same (4.5 ± 0.3 mmol/l) before WB and WMB meal consumption (**Table 3**). The PPGRs over 2 h after consuming WB and WMB meals for all participants are shown in **Figure 2**. Both AUCs and iAUCs were significantly reduced after WMB meal consumption compared with WB meal consumption (p = 0.027 and p = 0.034, respectively). However, there was no significant difference in PVs between the two bread meal consumption scenarios (p = 0.165) (**Table 3**).

Table 2 • Participants' characteristics.

Participant	Number	Age (year)	BMI (kg/m^2)	BF (%)	Sex (n)
Total	20	23.2 ± 3.3	20.9 ± 2.2	19.8 ± 6.3	F(9)M(11)
White Caucasians	10	24.7 ± 4.1	20.7 ± 1.9	20.5 ± 5.3	F(4)M(6)
Chinese	10	21.6 ± 0.9	21.3 ± 2.4	19.2 ± 7.5	F(5)M(5)
p value *	-	0.042	0.653	0.520	0.664

The continuous data are presented as Mean ± SD. BF%, body fat percentage; BMI, body mass index; F, female; and M, male. * independent sample t-test for continuous variables or Chi-square test for categorical variables.

3.3. FBGs and PPGRs between ethnic groups

The FBGs in the Chinese participants were significantly lower than in the White Caucasian group (p = 0.033) (**Table 4**). However, there was no significant difference in AUCs, iAUCs, or PVs between the two ethnic groups (**Table 4**), regardless of WB or WMB consumption (**Table 4**).

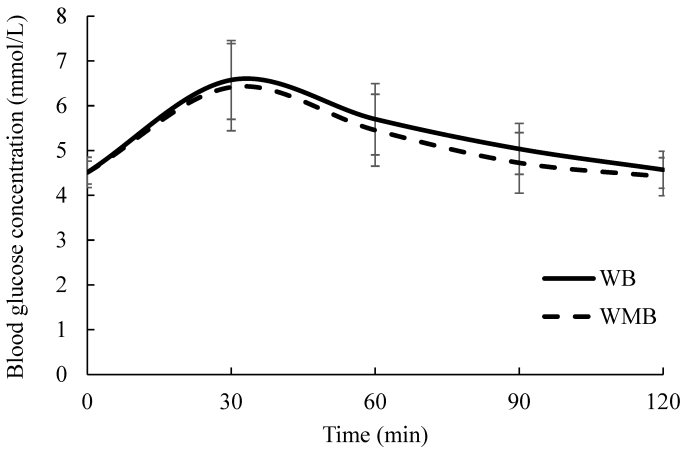

Figure 2 • Postprandial glycaemic response to white and wholemeal bread consumption. WB, white bread; WMB, wholemeal bread.

Table 3 • FBGs, AUCs, iAUCs, and PVs between two bread consumption types (n = 20).

	Mean ± SD	p value *
WB-FBG (mmol/l)	4.5 ± 0.3	0.948
WMB-FBG (mmol/l)	4.5 ± 0.3	
WB-AUC (mmol·min/l)	655.8 ± 56.6	0.027
WMB-AUC (mmol·min/l)	631.9 ± 66.8	
WB-iAUC (mmol·min/l)	116.9 ± 53.2	0.034
WMB-iAUC (mmol·min/l)	94.2 ± 54.6	
WB-PV (mmol/l)	6.7 ± 0.9	0.165
WMB-PV (mmol/l)	6.5 ± 1.0	

Data are presented as mean ± SD. AUC, the area under the curve; FBG, fasting blood glucose concentration; iAUC, incremental area under the curve; PV, peak value WB, white bread; and WMB, wholemeal bread. * paired sample t-test.

Table 4 • FBGs, AUCs, iAUCs, and PVs between ethnic groups.

	White Caucasian	**Chinese**	***p* value** *
	(*n* = 10)	**(*n* = 10)**	
WB-FBG (mmol/l)	4.7 ± 0.4	4.4 ± 0.3	0.033
WMB-FBG (mmol/l)	4.6 ± 0.3	4.4 ± 0.2	
WB-AUC (mmol·min/l)	658.2 ± 63.4	653.4 ± 52.2	0.990
WMB-AUC (mmol·min/l)	629.1 ± 73.5	634.6 ± 63.3	
WB-iAUC (mmol·min/l)	104.9 ± 62.5	129.0 ± 42.2	0.257
WMB-iAUC (mmol·min/l)	81.9 ± 56.4	106.7 ± 52.7	
WB-PV (mmol/l)	6.9 ± 0.8	6.5 ± 0.9	0.442
WMB-PV (mmol/l)	6.6 ± 1.2	6.4 ± 0.8	

Data are presented as mean ± SD. AUC, the area under the curve; FBG, fasting blood glucose concentration; iAUC, incremental area under the curve; PV, peak value; WB, white bread; and WMB, wholemeal bread. * two-way repeated measures ANOVA (between-subject effects).

4. Discussion

The current study compared PPGRs between two breads consumed, 2 slices of white bread or granary wholemeal bread enriched with dietary fibre, respectively, that are commercially available in UK supermarkets. Our results show there was a significant reduction in PPGRs represented by both AUCs and iAUC (but not PVs) after granary wholemeal bread consumption compared with white bread (p = 0.027 and p = 0.038, respectively).

Previous evidence shows wholemeal (wholewheat) bread did not attenuate PPGRs compared with white bread. In a systematic review and meta-analysis [14], seven acute randomised crossover trials were included to compare the PPGRs after wholemeal bread and white bread consumption, among which, five studies found no significant difference in PPGRs represented by AUCs (0–120 min or 0–180 min) between wholemeal and white bread consumption (−6.7 mmol min/l; 95% CI: −25.1, 11.7 mmol min/l; p = 0.477), while two other studies showed wholemeal bread significantly reduced PPGRs compared to white bread because these wholemeal breads were made with less processed wholegrains (more intact and coarsely ground grains) rather than finely milled ones. The non-effect in PPGRs after wholemeal bread consumption compared with white bread was also observed in other studies conducted in healthy participants [12, 13, 15]. Wholemeal mainly contains insoluble fibre (around 86%) (total fibre of 11.6–17.0 g/100 g, among which 10.2–14.7 g is insoluble fibre, while only 1.4–2.3 g is soluble fibre) [16]. Evidence has shown that soluble fibre, particularly viscous soluble fibre, can increase the chyme viscosity to inhibit glucose absorption and reduce the gastric emptying rate, hence significantly attenuating acute PPGRs [28], while insoluble fibre shows no acute effect on PPGR [17, 29]. In addition, the microstructure properties of whole wheat flour doughs and their breads were significantly different from their refined version, the larger particle size of wholemeal bread makes the starch more accessible to α-amylase activity, thus leading to the higher hydrolytic products of starch and high glycaemic response similar to white bread [15]. The above may help explain why wholemeal bread did not attenuate PPGRs compared with white bread despite its higher dietary fibre content. Moreover, increased fat and protein content were reported to reduce glycaemic responses [30]. All the above suggests that postprandial PPGRs after consuming wholemeal bread are influenced by multiple factors, not only by dietary fibre type or amount.

The granary wholemeal bread used in this study contains a granary blend that includes malted wheat flakes (9%), toasted wheat, and toasted rye (based on the ingredient list provided online). Malted wheat flakes are partially germinated (or sprouted) wheat grains that are then dried, giving them a flaked texture and a slightly sweet, malty flavour. They also have higher phenolic content, antioxidant levels, and antioxidant capacity compared to non-germinated wheat [31]. There is limited evidence in the literature about the effects of malted grains on PPGRs. However, an acute randomised crossover trial in obese men conducted in Canada found that PPGRs to commercially available sprouted grain bread, either containing 50 g available carbohydrates or a fixed serving of 107 g, were significantly lower compared to other wholegrain and white breads [32]. The authors suggested that this effect was unlikely to be due to increased fibre content (granary WMB in the current study contained 6.8 g fibre vs. 2.4 g per 100 g, respectively), given that malted wheat flakes are nearly full of insoluble fibre. Instead, they proposed that the higher levels of vitamins, minerals, antioxidants, and phytochemicals in sprouted grain bread may work synergistically to reduce glycaemic responses. Evidence has shown that both antioxidant- or phytochemical-rich food or extraction significantly reduced PPGRs via inhibiting digestive enzymes and specific glucose transporters in the intestinal lumen [33, 34]. This may be applicable to explain the findings of the current study, where granary wholemeal bread significantly reduced PPGRs compared to white bread.

The granary wholemeal bread used in this study also includes added toasted rye and barley fibre alongside malted wheat flakes. Both rye and barley are known to contain a higher proportion of soluble fibre compared to wheat [35]. However, it is unknown to what extent soluble fibre may have contributed to the attenuation of PPGRs because the bread label provides only total fibre content without specifying soluble and insoluble fractions.

In addition, the fat and protein contents of the two breads were very similar (**Table 1**), suggesting that any potential impact of these macronutrients on PPGRs is likely negligible. However, the lower amount of available carbohydrates in the granary wholemeal bread meal compared to the white bread meal (61.7 g vs. 68.9 g) may also contribute to the reduced PPGRs observed following the granary wholemeal bread meal. Nevertheless, our previous study found no difference in PPGRs between wholemeal and white bread meals, despite the wholemeal bread meal containing 12 g less available carbohydrate than the white bread meal [11].

While fibre content in the bread likely plays a role in PPGRs, it does not appear to be the dominant factor unless soluble, viscous fibres are specifically incorporated into the bread-making process. The nature of the ingredients and the microstructure of the bread seem to exert greater influence on glycaemic responses [32, 36].

Health professionals should be cautious when suggesting wholemeal bread over white bread to people, particularly those with diabetes, who may consider wholemeal bread as a better option over white bread and thus consume it excessively without the expected health benefit of glycaemic control [15]. This is because not all wholemeal breads can attenuate PPGRs after consumption compared with white bread [37]. Meanwhile, bakery industries need to make innovative bread products that not only increase the dietary fibre content (soluble viscous fibre) but also attenuate PPGR after consumption, like the granary wholemeal bread used in the current study.

Our study found that Chinese participants had a significantly lower FBG concentrations but similar AUC and iAUC regardless of bread type consumption compared with White Caucasians. Reports of variations in FBG and PPGRs between different ethnic groups in the literature are inconsistent. An acute randomised crossover study [38] including 10 Chinese, 10 Malays, 10 Caucasians, and 10 Indians could not find a significant difference in FBG concentration and iAUC between Chinese and Caucasians after consumption of beverages containing 50 g of sucrose or isomaltulose on two separate occasions, while another study found healthy Chinese participants (n = 49) showed the same mean of FBG concentrations as White Caucasians (n = 48) (4.7 mmol/l) but had significant higher iAUC after an oral glucose load (75 g) compared with Caucasians (214.03 ± 77.49 mmol·min/l vs. 156.67 ± 74.12 mmol·min/l, p <0.001) [39]. This finding is supported by the work of Dickinson et al. [40], in which lean and healthy Chinese participants (n = 10) showed similar FBG concentrations but significant higher iAUC after consuming 175 g white bread providing 75 g of available carbohydrate compared with their Caucasian counterparts (n = 20). Notably, the significantly lower FBG concentrations observed in Chinese participants in our study differ from the above studies [38–40], which found no ethnic difference in FBG. This discrepancy may be explained by the fact that our Chinese participants were significantly younger than their Caucasian counterparts, and age has been reported to be positively associated with FBG concentrations [41]. It is also possible that Chinese participants adhered more closely to the pre-experimental instructions (e.g., 8–12 h fast, consumption of a similar meal the evening before the fast) than their White Caucasian counterparts. However, this could not be confirmed, as adherence was not documented in the study records. The inconsistency in PPGRs across studies may be attributed to differences in sample size and/or the type and quantity of food or drink consumed.

The current study used commercially available breads, which is a strength of the study due to its applicability, but we are currently unable to identify which specific factor(s) may have accounted for the reduced PPGRs after granary wholemeal bread consumption compared with white bread because detailed information regarding ingredients (i.e., the grain/flour structure and proportion, soluble and insoluble fibre, antioxidants, phytochemical contents, etc.) and processing techniques are not available. The results of the current study are only applicable to the breads chosen and not generalisable to other wholemeal breads, long-term consumption, or patients with T2DM. Several factors that may influence PPGRs were not controlled in the current study and should be addressed in future research. Firstly, the menstrual cycle phase in women has been reported to influence PPGRs, with lower PPGRs typically observed during the follicular phase compared to the luteal phase [42]. Secondly, a standardised dinner consumed the night before each visit is necessary. Research suggests that the macronutrient composition of the evening meal can significantly affect PPGRs the following morning [43]. Due to the various factors that may influence PPGRs, serving duplicate or triplicate meals and calculating the average could improve the accuracy of PPGR measurements. Thirdly, blood glucose measurements were taken at 30 min intervals, which may not have accurately captured peak glucose levels. Using a 15 min sampling interval or continuous glucose monitoring [44] would obtain more precise PPGRs.

In addition, there are different approaches to defining the amount of bread products consumed in studies investigating their effects on PPGRs, including using 50 g of available carbohydrate as a portion size [32] (most adopted), a fixed portion size (e.g., 100 g) for different breads [32, 37], or two slices of bread [25], as was the case in the current study. All these approaches typically result in variations in energy intake and macronutrient content apart from fibre. Consequently, when interpreting the results, it is important to consider the composition of the whole bread rather than attributing effects solely to dietary fibre. Moreover, the tested breads could be consumed alone with water [37] or along with other food or drink items, for example, ham and a fruit drink [24] or margarine and strawberry jam [25], to mimic the real-life scenarios and promote palatability.

5. Conclusions

The results of the study suggest that granary wholemeal bread may be a healthy choice for individuals at higher risk of, or living with, T2DM, as not all wholemeal breads confer a beneficial effect on PPGRs. Further research should be undertaken in patients with T2DM using the same breads tested in this study and include fasting and postprandial insulin response because both are the most prevalent feature of pancreas β cell dysfunction, taking place well before impaired glucose tolerance occurs [45]. In addition, characterising the fibre types and contents and other compounds such as antioxidants and phytochemicals in the tested bread products is needed to identify the contributors to the observed effect on PPGRs through appropriate food analysis techniques. It is also warranted to investigate both the acute and long-term effects of breads containing different types (particularly viscous

soluble fibres) and amounts of dietary fibre, breads made with less processed wholegrains, and breads incorporating functional ingredients on postprandial glycaemic responses. Such studies should be conducted in larger-scale trials with study populations from various ethnic origins, taking into account the various factors discussed above that may influence the outcomes.

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Author contributions

Conceptualization, H.D. and Y.X.; methodology, H.D. and Y.X.; formal analysis, H.D. and Y.X.; investigation, D.M.G.P. and N.L.; data curation, H.D. and Y.X.; writing—original draft preparation, H.D.; writing—review and editing, Y.X.; visualization, H.D.; supervision, Y.X.; project administration, Y.X. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

The authors declare that they have no competing interests.

Data availability statement

The data supporting the findings of this publication can be made available upon request.

Institutional review board statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of Coventry University (protocol code P136390 approved on 6 May 2022).

Informed consent statement

Informed consent for participation was obtained from all subjects involved in the study.

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