Wholegrain Particle Size Influences Postprandial Glycemia in Type 2 Diabetes: A Randomized Crossover Study Comparing Four Wholegrain Breads

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OBJECTIVE

Wholegrain foods vary in the extent of processing. We investigated whether wholegrain particle size in bread influences postprandial glycemia in type 2 diabetes.

RESEARCH DESIGN AND METHODS

Postprandial glycemia (incremental area under the blood glucose curve [iAUC]) was measured after consumption of three breads made with roller-milled wholegrain flour and added grains and a fourth made with stone-ground flour. All flours and grains were 100% wholegrain wheat. Breads were nutrient matched.

RESULTS

Fifteen adults (64 ± 10 years, HbA_{1c} 58 ± 13 mmol/mol) completed the study. iAUC for the three breads made with roller-milled flour ranged from 376 to 641 $mmol^{-1}min^{-1}$, inverse linear trend for grain particle size $P = 0.039$. The iAUC for stone-ground wholegrain bread (503) was smaller than predicted from mean particle size.

CONCLUSIONS

Wholegrain structural integrity in bread is a determinant of glycemic response. These findings have implications for dietary advice and the definition of the term "'wholegrain."

Diets high in whole grains are associated with reduced incidence and mortality from several noncommunicable diseases (1) and are recommended in the management of type 2 diabetes (2). Although wholegrain bread has been a staple food in many cultures for thousands of years (3), wholegrain bread currently available in the food supply is frequently made from finely milled reconstituted components of whole grains (4). The structural integrity of food has been shown to influence cardiometabolic risk factors in people with type 2 diabetes (5). We have considered the extent to which the structural integrity of whole grains in bread, measured by particle size, influences postprandial glycemia in adults with type 2 diabetes.

RESEARCH DESIGN AND METHODS

This single-center, randomized, crossover study was prospectively registered (ACTRN12617000328370, anzctr.org.au) and conducted in New Zealand with Health and Disability Ethics Committee approval (17/STH/41).

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Participants diagnosed with type 2 diabetes aged 18–75 years were recruited by advertising through community groups. Any change in medication potentially influencing blood glucose control in the past 3 months excluded participation, but the presence of comorbidities did not.

Participants were randomized to the order of testing four breads with a 1:1:1:1 allocation ratio using statistical software. The randomization sequence was sealed in an opaque envelope. Participants were blinded to the composition of breads, although there were differences in their appearance.

On test days after resting for at least 5 min, two capillary blood glucose measures were taken. Participants then consumed bread and 250 mL of water within 10 min. Postprandial blood glucose measurements were taken at 15, 30, 45, 60, 90, 120, 150, and 180 min from meal commencement. On the day preceding each test, participants were instructed to consume the same evening meal, forgo alcohol, minimize physical activity, and fast from 10:00 P.M. Routine medications, including insulin, were taken as usual.

Four wholegrain wheat flour breads were made with industrial bread-making techniques from commercially available flours and grains. Recipes were matched for macronutrients, fiber, sodium, and amount of wholegrain wheat. The only intentional difference between breads was the wholegrain milling: 100% roller-milled wholegrain flour; 50% wholegrain flour and 50% kibbled grain; 40% wholegrain flour, 30% kibbled wheat, and 30% intact grain; or 100% stone-ground wholegrain flour. For each test meal, participants were served approximately four slices, providing 1,193 $\pm$ 13 kJ of energy and 50 g of available carbohydrate determined by the residual method (6). Particle size was measured by sieve analysis (7) using five sieves from 150 to 1,680 μm. On three further occasions under the same conditions, participants consumed 50 g glucose in 250 mL water.

Statistical Analysis

We based our sample size of 14 adults on a power calculation with an α of 0.05 and power of 0.80 to detect a between–wholegrain bread difference in the primary outcome variable, a 30% difference in postprandial glycemia. Incremental area under the blood glucose curve (iAUC) was calculated over 3 h with the trapezoidal method ignoring the area below the baseline (8). We considered a linear trend using median particle size and postprandial glucose variables in a random-effects mixed model that included terms for intervention order and fasting blood glucose. Data are expressed as mean $\pm$ SD or, when comparing between breads, as an effect size standardized to the SD with 95% CIs. The author responsible for statistical analyses was not involved in data collection and blinded to the interventions. Analysis was performed using Stata 15 (StataCorp, College Station, TX).

RESULTS

We randomized 18 participants; 15 (83%) completed all bread tests. The mean age was 64 $\pm$ 10 years, and 66% were male. Mean HbA_{1c} was 58 $\pm$ 13 mmol/mol and mean diabetes duration 11 $\pm$ 8 years. Five (33%) participants identified as Māori or Cook Island Māori and 10 (67%) were of European descent. Five (33%) were on metformin, four (27%) were on metformin and gliclazide, and six (40%) received insulin and metformin. Mean BMI was 32 $\pm$ 7 kg/m^2, and waist circumference was 111 $\pm$ 16 cm. Mean systolic blood pressure was 145 $\pm$ 21 mmHg.

Unadjusted postprandial blood glucose responses to the four wholegrain breads are shown in Table 1. There was an inverse linear trend between particle size and iAUC response for breads made with roller-milled flour ($P = 0.039$). Bread made with stone-ground flour did not follow this trend. The iAUC ($P \leq 0.003$), mean postprandial glucose level ($P \leq 0.006$), and glucose value at 3 h after eating ($P < 0.001$) were lowest for the bread with the largest particle size when compared with all other breads. The differences between each bread and the glucose standard are also shown in Table 1. The bread crumb structure is shown in Supplementary Fig. 1. No adverse events were reported.

CONCLUSIONS

The consumption of wholegrain bread made with more intact and coarsely ground whole grains reduced postprandial glycemia in adults with type 2 diabetes when compared with wholegrain bread made with finely milled whole grains. The four breads tested were made with the same ingredients but differed in the degree of wholegrain milling. When considering the three breads made with roller-milled wholegrain flour, there was an inverse association indicating the larger the wholegrain particle size, the smaller the postprandial response. For these three breads, >30% of wholegrain particles were smaller than 150 μm. In contrast, only 8.5% of the wholegrain particles in stone-ground flour particles were smaller than 150 μm, suggesting a possible reason why, when based on mean particle size, the stone-ground flour bread produced a smaller than expected postprandial blood glucose response.

Several plausible mechanisms exist to support our overall observation (4,9). Processing whole grains into flour shears fiber structures (10), exposing them to digestion (10). Less processed whole grains can pass into the colon for digestion by the microbiome into short-chain fatty acids (11) without influencing blood glucose levels. Furthermore, there are multiple characteristics of the food matrix, in part determined by the structural integrity of the grain and the release of starch and gluten, that can vary the rate of starch digestion between foods (12).

Our results are potentially of clinical relevance to people with diagnosed diabetes and to dietary recommendations aimed at those with prediabetes and populations with a high proportion of obese individuals at risk for diabetes. Unlike previous studies, we used bread recipes matched for macronutrient, fiber, and wholegrain content (13,14). We tested bread given its importance in many parts of the world; however, findings are likely to be relevant to other grain-containing foods. Importantly, we used commercial bread-making techniques and milled wheat products to increase the relevance of our findings to breads currently available. This study has some limitations. We did not have sufficient participant numbers to enable subgroup analyses by sex, ethnicity, or medical treatment. Further acute tests of other wholegrain products that vary in particle size and trials with longer-term measures of glycemia and in free-living populations are necessary to support these initial findings in order to be certain of the potential clinical relevance of our results.

Järvi et al. (5) demonstrated the importance of food structure on glycemic control in type 2 diabetes by comparing interventions of identical meals where one intervention involved fine milling to reduce particle size of the meals. Jenkins

Table 1—*Part A*: Measures of grain particle size of the four wholegrain breads and postprandial glycemic response. *Part B*: Standardized effect sizes and differences (with 95% CI) in iAUC values between wholegrain breads and glucose standards

Part A: Wholegrain bread constituents	Median grain size, μm (IQR)	Grain fraction <150 μm	Fasting blood glucose value (mmol/L)	Glycemic index	iAUC	3-h mean blood glucose (mmol/L)	Mean blood glucose after 3 h (mmol/L)
Roller-milled wholegrain flour (100%)	75 (0)	77%	7.21 ± 1.9	81	641 ± 373	10.17 ± 3.2	10.35 ± 2.9
Roller-milled wholegrain flour (50%), kibbled whole grains (50%)	1,265 (2,165)	39%	7.76 ± 2.4	75	595 ± 337	10.39 ± 2.6	10.17 ± 3.1
Roller-milled wholegrain flour (40%), intact whole grains (30%), kibbled whole grains (30%)	2,240 (2,165)	31%	7.56 ± 1.7	47	375 ± 280	9.30 ± 2.6	8.24 ± 2.8
Stone-ground wholegrain flour (100%)	640 (300)	9%	8.29 ± 2.7	63	503 ± 327	10.62 ± 3.0	10.45 ± 2.8

Part B:		iAUC standardized effect size			
	Bread with roller-milled wholegrain flour	1.08 (0.74–1.57)	2.07 (1.38–3.11)	1.32 (1.05–1.65)	0.58 (0.41–0.83)
	26 (−105 to 157)	Bread with roller-milled wholegrain flour and kibbled wheat	1.92 (1.30–2.86)	1.22 (0.89–1.68)	0.54 (0.35–0.83)
iAUC differences (mmol L^{-1} min^{-1})	252 (112–392)	226 (90–362)	Bread with roller-milled wholegrain flour with whole and kibbled wheat	0.64 (0.47–0.86)	0.28 (0.19–0.42)
	96 (18–173)	70 (−40 to 180)	−156 (−260 to −52)	Bread with stone-ground wholegrain flour	0.44 (0.34–0.58)
	−187 (−309 to −66)	−213 (−360 to −66)	−439 (−575 to −303)	−283 (−375 to −190)	Average of glucose standards

Part A: Results are mean ± SD, $n = 15$. iAUC is presented as mmol L^{-1} min^{-1}. The mean iAUC to the glucose standards was 793 ± 297 mmol L^{-1} min^{-1}. The glycemic index value of each bread was calculated as the mean iAUC of the test food divided by the mean iAUC of the glucose standards, multiplied by 100. *Part B*: Results of the iAUC standardized effect size between tests are shown above the diagonal, and results of the iAUC differences between tests are shown below the diagonal.

and colleagues (13,14) considered wheat and rye products, or breads of varying ratios of wholemeal and wholegrain flour, reporting that more intact grains reduced postprandial response. Our study complemented these findings by comparing a range of bread products that were controlled for macronutrient and fiber content, and it is the first to demonstrate a linear relationship between wholegrain particle size and postprandial glycemia.

Our findings have implications as to how whole grains should be defined, in the context of their health benefits. Current definitions of whole grains permit inclusion of intact grains or the dehulled, ground, milled, cracked, or flaked grain equivalent, or even parts separated during processing and reconstituted (15). Our work suggests that if the term wholegrain is used to imply a health benefit, the definition should also consider the degree of processing.

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