Diabetologia (2021) 64:1385–1388
https://doi.org/10.1007/s00125-021-05400-y

SHORT COMMUNICATION

Gelatinisation and milling whole-wheat increases postprandial blood glucose: randomised crossover study of adults with type 2 diabetes

Mona M. Elbalshy[1] · Andrew N. Reynolds[1,2,3] · Evelyn Mete[1,2,4] · Caleb Robinson[1,2,4] · Indrawati Oey[2,4] · Pat Silcock[2,4] · Jillian J. Haszard[1] · Tracy L. Perry[5] · Jim Mann[1,2,3] · Lisa Te Morenga[2,6,7]

Received: 31 August 2020 / Accepted: 7 December 2020 / Published online: 7 March 2021

Abstract

Aims/hypotheses We examined the effects of milling and cooking whole grains in water to achieve starch gelatinisation on postprandial blood glucose using a randomised crossover open-label design. Participants were adults with type 2 diabetes whose body weight or medications had not changed in at least 3 months.

Methods Postprandial blood glucose (measured as incremental AUC [iAUC]) was measured following consumption of four nutrient-matched whole-wheat porridge test-meals. Test-meals included gelatinised or native starch and were made with either finely milled or intact whole-wheat.

Results Eighteen adults (63.1 ± 9.8 years, HbA_{1c} 57.0 ± 11.5 mmol/mol [7.4 ± 3.2%]) completed the study. iAUC was higher following cooked meals (gelatinised starch) than following uncooked meals (native starch) (mean difference [MD] 268, 95% CI 188, 348 mmol/l × min). Consuming finely milled whole-wheat produced a higher iAUC compared with intact whole-wheat (MD 173, 95% CI 80, 266 mmol/l × min). There was no evidence of an interaction effect ($p = 0.841$).

Conclusions Both the nature of starch and the grain structure of whole-wheat influence the glycaemic response of adults with type 2 diabetes mellitus.

Funding Baking Industry Research Trust of New Zealand and the Riddet Centre of Research Excellence.

Trial registration www.anzctr.org.au ACTRN12617000328370

Keywords Acute blood glucose · Diet · Digestion · Food processing · Metabolism · Whole grain

Introduction

Whole-grain foods are widely recommended as a preferred source of carbohydrate for people with diabetes [1, 2]. Regular consumption of whole grains has been associated with a reduced risk of developing type 2 diabetes, and improved blood glucose or other cardiovascular risk factors in those with diabetes [3, 4]. Recent reports, however, have indicated that food processing techniques, such as milling, attenuate the blood glucose improvements expected from whole-grain consumption [5, 6].

Although starch is the largest contributor to energy within the diet [7], starch structure and the nature of starch is not yet considered in advice for those with diabetes [1]. Native starches are present within whole grains, but many lose structure and gelatinise when heated with water. There is evidence in adults with normal glucose tolerance that gelatinised starch is digested more rapidly than native starch [8].

✉ Lisa Te Morenga
l.temorenga@massey.ac.nz

[1] Department of Human Nutrition, University of Otago, Dunedin, New Zealand

[2] Riddet Institute, Palmerston North, New Zealand

[3] Department of Medicine, University of Otago, Dunedin, New Zealand

[4] Department of Food Science, University of Otago, Dunedin, New Zealand

[5] Division of Sciences, University of Otago, Dunedin, New Zealand

[6] School of Health, Te Herenga Waka - Victoria University of Wellington, Wellington, New Zealand

[7] Present address: Research Centre for Hauora and Health, Massey University, Wellington, New Zealand

Research in context

What is already known about this subject?

- Whole grains are widely promoted for the prevention and management of type 2 diabetes
- Food processing techniques, such as milling, attenuate the blood glucose improvements expected from whole-grain consumption
- Postprandial response after heating meals for starch gelatinisation does not appear to have been measured before in individuals with type 2 diabetes

What is the key question?

- To what extent does starch gelatinisation by cooking and grain milling of whole-grain cereals have an impact on postprandial glycaemic response in individuals with type 2 diabetes?

What are the new findings?

- Both starch gelatinisation and milling independently influence blood glucose levels following the consumption of whole grains by adults with type 2 diabetes
- Our research shows an additive relationship between particle size and starch gelatinisation of whole-grain wheat on postprandial blood glucose levels in adults with type 2 diabetes

How might this impact on clinical practice in the foreseeable future?

- Breakfast cereals will have a reduced glycaemic response if they contain largely intact whole grains, and if consumed in a 'muesli type' product or soaked overnight, rather than if eaten as hot, cooked porridge

In several countries, breakfast cereals are a primary source of whole grains [9], and may vary by extent of milling or whether the grains have been cooked to achieve starch gelatinisation. In this study, we examined how milling and cooking of whole grains influence their effect on blood glucose using four whole-wheat breakfast meals which differed by preparation method and grain milling.

Methods

This randomised crossover study was approved by the New Zealand Health and Disability Ethics Committee (17/STH/41) and prospectively registered (ACTRN12617000328370). Informed consent was obtained from all participants.

Individuals with type 2 diabetes aged 18–75 years were eligible to participate if their weight was stable and their medication had not changed over the past three months. Exclusion criteria included pregnancy, lactation, wheat or gluten allergies and coeliac disease. Participants were recruited through advertising in community groups and diabetes clinics.

On separate days, participants received four test-meals and three glucose standards in a randomised order (computer-generated). Each sequence was sealed in an opaque envelope. Established postprandial blood glucose testing protocols described in detail elsewhere [5] were followed regarding participant preparation, testing frequency and test-meal administration [10].

The test-meals consumed were a wet whole-wheat porridge balanced for ingredients and not commercially available. Four test-meals were administered, consumed hot or cold, with either finely milled (particle size <150 μm) or coarse kibbled whole-wheat (particle size ≥1680 μm) (Champion Flour, Christchurch, New Zealand). All meals were prepared with natural unsweetened yoghurt and water then sealed in foil packages for at least 12 h. Each test-meal provided 1300 kJ of energy. On test days, meals were either cooked to >85°C for 15 min to gelatinise starch and served at ≥65°C to prevent retrogradation, or uncooked and served cold (10–15°C). Each test-meal and glucose standard provided 50 g of available carbohydrate.

Statistical analysis Our sample size estimate of 17 adults was calculated with a within-person correlation of 0.3 and power of 0.90 to detect a one SD difference in postprandial blood glucose between test-meals, as measured by the incremental AUC (iAUC). iAUC was calculated over 3 h with the trapezoidal method ignoring the area below the baseline [11]. Data were analysed with mixed-effects regression models using a robust variance structure to account for heteroskedasticity. The predictor variable was binary for starch gelatinisation (yes/no) or particle size (fine/kibbled). Participant ID was included as a random effect to account for repeated measures. Analyses were performed in Stata 15.1 (StataCorp, TX, USA), and data are expressed as mean differences (MD) with 95% CI. The statistician was blinded to intervention.

Table 1 Differences in postprandial blood glucose due to starch gelatinisation and whole-wheat milling in whole-grain porridge (n=18)

Exposures tested		iAUC due to whole-wheat milling		Mean iAUC difference
		Finely milled whole-grain	Coarse kibbled whole-grain	
iAUC due to starch gelatinisation	Hot, cooked gelatinised starch	535±311	369±209	−166 (95% CI −273, −60)
	Cold uncooked native starch	275±163	94±86	−180 (95% CI −245, −115)
Mean iAUC difference		−261 (95% CI −376, −146)	−275 (95% CI −346, −205)	

Data are expressed as mmol/l × min. The mean iAUC to the glucose standards was 732 ± 279 mmol/l × min

Results

Eighteen participants [mean age 63.1 ± 9.8 (range 36–75) years, HbA_{1c} 57.0 ± 11.5 mmol/mol (7.4 ± 3.2%), BMI 33.0 ± 7.5 kg/m^2, diabetes duration 9.5 years] were randomised and completed the study between June 2017 and January 2018. Seven (39%) participants were female. Four (22%) participants identified as Māori, three (17%) as Pacific peoples, one (6%) as Sri Lankan and ten (55%) as New Zealand European. Four participants dropped out of the study.

Results from test-meals and glucose standards are shown in Table 1. Postprandial blood glucose was 59% lower (95% CI 42, 77%) after consuming uncooked, ungelatinised (native starch) whole-wheat porridge compared with cooked, gelatinised whole-wheat porridge. Similarly, postprandial blood glucose was 43% lower (95% CI 20, 66%) after consuming more intact whole-wheat than consuming finely milled whole-wheat. The overall iAUC difference was 268 mmol/l × min (95% CI 188, 348 mmol/l × min) between gelatinised and native starch, and 173 mmol/l × min (95% CI 80, 266 mmol/l × min) between finely milled and coarse kibbled whole-wheat. The p value for an interaction between nature of starch and whole-wheat particle size was 0.841. No adverse events were reported.

Discussion

This study has shown that two commonly applied food processing techniques, starch gelatinisation and milling, have the potential to independently influence blood glucose levels following the consumption of whole grains by adults with type 2 diabetes.

Numerous studies in normoglycaemic individuals have reported that starch gelatinisation is associated with a greater glycaemic response than occurs when comparable amounts of native starch are consumed in raw foods or cooked foods eaten cold or at room temperature [12–14]. However, we believe this may be the first demonstration of this effect in people with diabetes, who experienced a more marked glycaemic response than that observed in normoglycaemic individuals.

The findings of this study are complementary to recent work showing that fine milling of whole grains is associated with greater postprandial blood glucose than when more intact whole grains are consumed [5, 6]. Starch gelatinisation and milling are applied widely to carbohydrate-containing foods and contribute to the more rapid and complete digestion of starch. This is likely due to increased exposure of starch to the action of salivary and pancreatic amylases [15].

This study is limited by the fact that it describes only the immediate consequences of processing whole grains. However, the striking effects of heating and milling on postprandial blood glucose, an accepted determinant of overall glycaemic control and cardiovascular risk [16], suggest that these results warrant incorporation into nutrition recommendations and in dietary counselling. Current nutrition recommendations support the use of whole grains as an appropriate source of dietary carbohydrate for people with diabetes. This study indicates that breakfast cereals will have a reduced glycaemic response if they contain largely intact whole grains, and if consumed as a ‘muesli type’ product or soaked overnight rather than as hot, cooked porridge. The extent to which milling of whole-grain wheat influences glycaemic response suggests that the recommendations for patients with diabetes to choose whole grains over refined grains need to be reconsidered. Definitions for whole-grain foods [17, 18], especially for foods with health claims related to diabetes and glucose control, should factor in the impact of grain milling.

Acknowledgements We thank the study participants.

Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Funding This study was funded by a contestable grant from the Baking Industry Research Trust of New Zealand and the Riddet Centre of Research Excellence. These funders were not involved in designing the study, conducting the study, analysing the data, or interpreting the results.

JIM was supported by the Healthier Lives National Science Challenge. ANR was supported by a National Heart Foundation Research Fellowship. LTM was supported by a Royal Society of New Zealand Rutherford Discovery Fellowship.

Authors' relationships and activities The authors declare that there are no relationships or activities that might bias, or be perceived to bias, their work.

Contribution statement LTM was the principal investigator and together with PS was responsible for the initial study concept and design. JM, IO, TLP and ANR contributed to study concept and design. IO and PS designed the test-meals. MME, EM, CR, ANR, TLP, PS and IO conducted the trial which was managed by ANR. JJH analysed data. MME wrote the first draft. All authors read, revised critically and approved the final manuscript. LTM is the guarantor of this work and, as such, had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

References

1. Evert AB, Dennison M, Gardner CD, Garvey WT, Lau KHK, MacLeod J et al (2019) Nutrition Therapy for Adults With Diabetes or Prediabetes: A Consensus Report. Diabetes Care 42(5):731–754. https://doi.org/10.2337/dci19-0014
2. American Diabetes Assocation (2019) Lifestyle Management: Standards of Medical Care in Diabetes. Diabetes Care 42(Suppl 1):S46–S60
3. Reynolds A, Mann J, Cummings J, Winter N, Mete E, Te Morenga L (2019) Carbohydrate quality and human health: a series of systematic reviews and meta-analyses. Lancet 393(10170):434–445. https://doi.org/10.1016/S0140-6736(18)31809-9
4. Reynolds AN, Akerman AP, Mann J (2020) Dietary fibre and whole grains in diabetes management: Systematic review and meta-analyses. PLoS Med 17(3):e1003053. https://doi.org/10.1371/journal.pmed.1003053
5. Reynolds AN, Mann J, Elbalshy M, Mete E, Robinson C, Oey I et al (2020) Wholegrain Particle Size Influences Postprandial Glycemia in Type 2 Diabetes: A Randomized Crossover Study Comparing Four Wholegrain Breads. Diabetes Care 43(2):476–479. https://doi.org/10.2337/dc19-1466
6. Åberg S, Mann J, Neumann S, Ross AB, Reynolds AN (2020) Wholegrain processing and glycaemic control in type 2 diabetes: a randomised crossover trial. Diabetes Care 43(8):1717–1723
7. Mann J, Truswell S (2017) Essentials of human nutrition. Oxford University Press
8. Wee MSM, Henry CJ (2020) Reducing the glycemic impact of carbohydrates on foods and meals: Strategies for the food industry and consumers with special focus on Asia. Compr Rev Food Sci Food Saf 19(2):670–702. https://doi.org/10.1111/1541-4337.12525
9. Cleveland LE, Moshfegh AJ, Albertson AM, Goldman JD (2000) Dietary intake of whole grains. J Am Coll Nutr 19(Suppl 3):331S–338S
10. International Organization for Standardization (2010) Food products - Determination of the glycaemic index (GI) and recommendation for food classification. ISO 26642:2010
11. Matthews J, Altman DG, Campbell M, Royston P (1990) Analysis of serial measurements in medical research. BMJ 300(6719):230–235. https://doi.org/10.1136/bmj.300.6719.230
12. Collings P, Williams C, MacDonald I (1981) Effects of cooking on serum glucose and insulin responses to starch. BMJ 282(6269):1032. https://doi.org/10.1136/bmj.282.6269.1032
13. Bornet F, Fontvieille A-M, Rizkalla S, Colonna P, Blayo A, Mercier C et al (1989) Insulin and glycemic responses in healthy humans to native starches processed in different ways: correlation with in vitro alpha-amylase hydrolysis. Am J Clin Nutr 50(2):315–323. https://doi.org/10.1093/ajcn/50.2.315
14. Jung EY, Suh HJ, Hong WS, Kim DG, Hong YH, Hong IS et al (2009) Uncooked rice of relatively low gelatinization degree resulted in lower metabolic glucose and insulin responses compared with cooked rice in female college students. Nutr Res 29(7):457–461. https://doi.org/10.1016/j.nutres.2009.07.002
15. Snow P, O'Dea K (1981) Factors affecting the rate of hydrolysis of starch in food. Am J Clin Nutr 34(12):2721–2727. https://doi.org/10.1093/ajcn/34.12.2721
16. Bonora E, Muggeo M (2001) Postprandial blood glucose as a risk factor for cardiovascular disease in Type II diabetes: the epidemiological evidence. Diabetologia 44(12):2107–2114. https://doi.org/10.1007/s001250100020
17. Food Standards Australia New Zealand (2015) Food Standards Code: Standard 2.1.1 Cereal and cereal products. Commonwealth of Australia Gazette
18. Ross AB, van der Kamp JW, King R, Le KA, Mejborn H, Seal CJ et al (2017) Perspective: A Definition for Whole-Grain Food Products-Recommendations from the Healthgrain Forum. Adv Nutr 8(4):525–531. https://doi.org/10.3945/an.116.014001