Co-ingestion of traditional Japanese barley mixed rice (*Mugi gohan*) with yam paste in healthy Japanese adults decreases postprandial glucose and insulin secretion in a randomized crossover trial

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Running title: Barley rice with yam reduces blood glucose and insulin

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ABSTRACT

Background and Objectives: Barley mixed rice, "*Mugi gohan*," is traditionally eaten with yam paste in Japan. Both ingredients contain dietary fiber and reportedly reduce postprandial hyperglycemia. However, evidence supporting the benefits of combining barley mixed rice with yam paste is limited. In this study, we evaluated whether ingesting a combination of barley mixed rice and yam paste affected postprandial blood glucose concentration and insulin secretion. **Methods and Study Design:** This study followed an open-label, randomized controlled crossover design, following the unified protocol of the Japanese Association for the Study of Glycemic Index. Fourteen healthy subjects each consumed four different test meals: white rice only, white rice with yam paste, barley mixed rice, and barley mixed rice with yam paste. We measured their postprandial blood glucose and insulin concentrations after every meal, and we calculated the area under curve for glucose and insulin. **Results:** Participants had significantly reduced area under curve for glucose and insulin after eating barley mixed rice with yam paste compared to when they ate white rice only. Participants had similar area under curve for glucose and insulin after eating barley mixed rice only, or eating white rice with yam paste. Participants had lower blood glucose concentrations 15 min after eating barley mixed rice only, whilst eating white rice with yam paste did not maintain lower blood glucose after 15 min. **Conclusions:** Eating barley mixed rice with yam paste decreases postprandial blood glucose concentrations and reduces insulin secretion.

Key Words: barley, yam, glycemic index, glucose, insulin

INTRODUCTION

Both worldwide and in Japan, changes in personal behaviors and social environments have contributed to the rapidly increasing prevalence of type 2 diabetes mellitus. Japanese individuals are at a higher risk of impaired glucose tolerance (IGT) because their insulin secretion capacity is lower than that of Europeans and North Americans.[1,2] A randomized controlled trial, which enrolled 1,429 participants with diabetes, showed that acarbose, an α-glucosidase inhibitor, reduced the incidence of type 2 diabetes mellitus and cardiovascular mortality in participants with IGT.[3] A prospective cohort study examining cause-specific mortality in a cohort of 25,364 individuals in the United States (U.S.) showed that high fasting blood glucose was associated with a mortality risk that was related to cardiovascular diseases and high postprandial blood glucose concentrations.[4,5] A U.S. prospective cohort study including 42,898 older adults showed that participants who consumed a greater proportion of whole grain cereals had a lower risk of type 2 diabetes.[6] These results indicate that type 2 diabetes, especially postprandial hyperglycemia, can be managed using dietary interventions. Managing type 2 diabetes is important for preventing macrovascular disease.

`The glycemic index (GI) is an indicator of the expected blood glucose response after a meal. The intake of low-GI foods is associated with lower rates of type 2 diabetes, obesity, and cardiovascular disease.[7-10] Kong et al[7] conducted a 6-month dietary intervention study on 104 obese adolescents and found that following a low-GI diet reduced the body mass index (BMI) and abdominal circumference. Liu et al[8] conducted a prospective cohort study among 75,521 U.S. women and found a negative relationship between a regular low-GI diet and coronary heart disease. Additionally, a cross-sectional study among 1,354 Japanese women found a positive relationship between GI and BMI, which suggested that a high-GI diet is a risk factor for metabolic syndrome.[9] Furthermore, a prospective cohort study among 64,633 Japanese showed that the intake of low-GI foods decreased the risk of type 2 diabetes mellitus.1[0] The GI of certain foods thus influences postprandial blood glucose, which is strongly related to noncommunicable, especially cardiovascular, disease.

Stickiness is a popular food texture in Japan (e.g., fermented soybeans "*natto*," seaweeds, okra), and sticky foods are known as functional foods because they often contain polypeptides and polyglycolides.[11,12] Taniguchi et al[11] reported that simultaneous intake of "*natto*," okra, and yam decreased postprandial blood glucose concentrations. These sticky foods are often eaten with rice. Barley, mixed with rice is popularly referred to as "*Mugi gohan*" and is frequently eaten with yam paste. Barley is a low-GI food containing β-glucan, which is a water-soluble dietary fiber. The GI of refined boiled barley is 35.[13] Although some studies have investigated the association between postprandial blood glucose and barley mixed rice, few studies have reported the GI of barley mixed rice.[14-16] Maeda et al[14] reported a GI of 54 for barley mixed rice but they did not specify the ratio of barley to rice used in their pilot study.[14] They also used high amylose rice, which is not usually consumed.[14] The GI of barley mixed rice has thus not been accurately determined.

Barley mixed rice has, however, been shown to have a glucose lowering effect in healthy individuals. Fukuhara et al[15] reported that white rice mixed with 50% barley lowered postprandial blood glucose among 18 healthy participants.[15] Furthermore, Sato et al[16] reported that refined barley (100%) lowered postprandial blood glucose among six healthy participants. Although both studies reported a significant reduction of postprandial blood glucose associated with eating barley mixed rice as opposed to eating white rice only; neither of these studies mentioned the GI of the cereals.[15,16] In both studies, the barley mixed rice also included a higher percentage of barley than what is normally consumed (10–30%). It is this likely that these studies may have overestimated the effect of common barley mixed rice in lowering the postprandial glucose response. Yam, a popular traditional sticky Japanese food, has a high concentration of dietary fiber and mucin, and has a low GI of 35.[17] To the best of our knowledge, no study has investigated the postprandial glucose response after the simultaneous intake of barley mixed rice and yam paste.

Therefore, we conducted an open-label, randomized, crossover study in healthy participants to examine differences in postprandial elevation of blood glucose concentrations and plasma insulin after ingesting white rice, barley mixed rice, white rice with yam paste, and barley mixed rice with yam paste.

MATERIALS AND METHODS

Study design and assignment

This study was an open-label, randomized controlled crossover study that was conducted in accordance with the CONSORT statement.[18] Using the method described by Jenkins and colleagues,[19] this study followed a unified protocol of the Japanese Association for the Study of Glycemic Index (JASGI), which incorporates white rice as a standard dietary substitute for glucose (http://www.gikenkyukai.com/protocol.html, in Japanese). Briefly, the participants were asked to consume white rice (i.e., the control diet) twice on different days. If the increased area under the curve (iAUC) showed >25% variation, the participants were asked to consume another meal of white rice. If the iAUC still showed >25% variation, the participants were excluded from the study. The iAUC is the definite integral of the curve that describes the change in blood glucose concentrations as a function of time. The GI is calculated as the sum of the area above baseline. To calculate the GI values of the various meals, we set the GI value of white rice to 100, to serve as the baseline value. For ease of comparison with international studies that normally use sugar as a control (GI=100, $\text{GI}_{\text{white rice}}$), we also set the GI value of white rice to 80 ($\text{GI}_{\text{glucose}}$). The test was performed using a crossover design with a wash-out period of 4 days or more. The random function in a spreadsheet (Microsoft Excel 2014) was used to randomize the order of test meal consumption by participants (1 and 2=white rice; 3=barley mixed rice; 4=white rice with yam paste; and 5=barley mixed rice with yam paste). We could not mask the meals because they clearly differed in appearance and texture. However, participants were not directly informed of the ingredients of the test meals. There was no change in study procedures after the clinical trial registration.

Test site and ethical approval

This study was conducted at the University of Yamanashi, Yamanashi, Japan in accordance with the Declaration of Helsinki and was approved by the ethics committee of the Faculty of Life and Environmental Sciences, University of Yamanashi, Yamanashi, Japan (approval number: 2016-4). After the ethics committee approved the study and before participants were recruited, this clinical trial was registered in the University hospital Medical Information Network (UMIN) Clinical Trial Registry (CTR) (registration number: UMIN000023860, Title: Effects of rice with barley and tororo on the GI and blood concentrations of insulin and glucagon).

Participants

Participants were recruited at the University of Yamanashi during September and October 2016. The inclusion criteria were as follows: (i) students of University of Yamanashi aged between 20 and 49 years with BMI ≤25 kg/m^2; (ii) no history of metabolic disease (diabetes mellitus, hypertension, dyslipidemia, hyperuricemia); (iii) no diagnosis of IGT in the past year; (iv) no severe infection, recent surgery, severe diseases (e.g., cancer), or injury; (v) not taking any hypoglycemic medicine; (vi) no long-term use of health foods that could affect this trial (e.g. dietary supplements); (vii) non-smoker; (xiii) no excessive alcohol consumption; (ix) no history of food allergy to ingredients (barley, white rice, grated yam paste) used in this study; (x) not pregnant or planning to conceive; and (xi) deemed eligible by physicians, public health nurses, or representatives of this study. The tests were rescheduled if participants were menstruating on the test day. Participants whose blood glucose iAUC varied ≥25% for the third intake of the standard diet were eliminated from the GI calculation but were included in other analyses.

Intervention (test meals and schedule)

The participants were instructed to consume an energy-adjusted diet on the day before testing (2,464 kJ, protein:fat:carbohydrate=13:19:68) between 7:00 p.m. and 8:00 p.m. and were asked to refrain from eating and drinking anything except water after 8:00 p.m. On the test day, the participant's body weight, blood pressure, height (the time of entry), and fasting blood glucose was measured at 8:00 a.m. Then, the participants consumed the test meals at 9:00 a.m. The white rice in the test meal was packed cooked rice (Sato No Gohan, Sato Foods Co., Ltd., Niigata, Japan). The rolled barley (Oshimugi EX, Hakubaku Co., Ltd., Chuo, Japan) and the raw grated yam paste (grated yam paste with soup stock, Yoshinoya Co., Ltd., Tokyo, Japan) were provided by the company. The ratios of each meal were as follows: (i) barley mixed rice (rice:barley=16:5); (ii) barley mixed rice with yam paste (rice:barley:grated yam paste=16:5:8); and (iii) white rice with yam paste (rice:grated yam paste=16:8). Thereafter, each meal was adjusted to contain 50 g of sugar (Table 1). During meal consumption, participants were instructed to drink 100 mL of water (Natural mineral water, Suntory Holdings Ltd., Osaka, Japan) and to chew each mouthful 30 times and consume the meal within 5 to 10 mins. Blood glucose concentrations were measured at baseline (0 mins) and at 15, 30, 45, 60, 90, and 120 mins after the meal. A self-administered blood glucose measuring device (Glutest NEOα; Sanwa Kagaku Kenkyusho Co., Ltd., Nagoya, Japan) was used. Using heparinized micro-hematocrit capillary tubes (Thermo Fisher Scientific Inc., MA, USA), approximately 100 μL blood was collected just before the meal and at 15, 30, 60, and 120 mins after the meal to measure plasma insulin concentrations. The blood samples were placed in 1.5 mL tubes and stored at −80°C after adding 1 μL of a 200 μL solution of one tablet of Complete Mini Protease Inhibitor (Roche Diagnostics, Basel, Switzerland) that had been prepared in advance. The plasma insulin concentrations were later measured using a Mercodia Ultrasensitive Insulin ELISA kit (Mercodia AB, Uppsala, Sweden). The participants were instructed to rest in a sitting position during the test period and were not allowed to drink or eat during the test. Except for β-glucan, nutrients were measured by Japan Food Research Laboratories. β-glucan was measured using a β-glucan Assay Kit (Mixed Linkage) (Neogen, MI, USA).

Outcomes

The primary endpoints were blood glucose concentrations for each measurement point and the area under the curve for glucose ($AUC_{glucose}$) and insulin ($AUC_{insulin}$) after the test meal. All participants' data were analyzed in an intention-to-treat analysis. The secondary endpoints were GI and iAUCglucose in accordance with the JASGI protocol.

Statistical analysis

Statistical analysis was performed using R version 4.1.3 (R Foundation for Statistical Computing, Vienna, Austria; https://www.R-project.org/). In statistical tests, $p<0.05$ was considered significant.

Blood glucose and insulin: Blood glucose and plasma insulin were shown as mean ± standard deviation (SD). Statistical analysis was performed using the paired Student's t-test for each measurement point and AUC to compare each test meal with the control meal (white rice).

The interaction between barley and yam: Multiple regression analysis was used to examine the influence of barley and yam on $AUC_{glucose}$ and $AUC_{insulin}$. The outcome variables were $AUC_{glucose}$ and $AUC_{insulin}$, with the independent variables: barley consumption (0=white rice and white rice with yam paste, 1=barley mixed rice and barley mixed rice with yam paste), yam consumption (0=white rice and barley mixed rice, 1=white rice with yam paste and barley rice with yam paste), and the interaction between barley intake and yam intake. The results are presented as multiple regression coefficients (R) and standard errors (SE).

RESULTS

Participant inclusion and characteristics

In total, 16 individuals gave informed consent after an explanation of the study. Two participants withdrew for personal reasons, one before and one after the study began. Two of the 14 participants showed >25% variation in $iAUC_{glucose}$ after three white rice meals. Following the protocol of the JASGI, 12 participants were included in the GI analysis, and 14 were included in the main analysis (Figure 1). For insulin analysis, there were five missing data points because of an insufficient plasma sample. The analyses were conducted with the remaining 275 measurement points.

Comparison of postprandial blood glucose and $AUC_{glucose}$

The results for each measurement point and $AUC_{glucose}$ are shown in Figure 2 (a, b). Barley mixed rice significantly lowered blood glucose at 15 min, and tended to lower the $AUC_{glucose}$ when compared to white rice. Barley mixed rice with yam paste significantly lowered the $AUC_{glucose}$ and blood glucose at 45, 60, and 90 min when compared to white rice. Participants had similar blood glucose after eating white rice only and white rice with yam paste meals.

Comparison of postprandial elevation of plasma insulin and $AUC_{insulin}$

The results for each measurement point and $AUC_{insulin}$ are shown in Figure 2 (c, d). Barley mixed rice and yam paste significantly lowered the $AUC_{insulin}$ and blood glucose at 0, 15, 30, 60, and 120 min when compared to the white rice. Blood glucose was similar after eating the barley mixed rice and white rice with yam paste

Interaction between barley and yam

The interactions between the $AUC_{glucose}$ and $AUC_{insulin}$ of barley rice with yam are shown in Table 3. No significant effect was observed for barley and yam. Additionally, no interaction was observed for either $AUC_{glucose}$ or $AUC_{insulin}$.

GI index

The GI glucose of white rice with yam paste, barley mixed rice, and barley mixed rice with yam paste was 78.5±37.3, 57.0±35.1, and 66.0±28.7, respectively (Table 4). According to the criteria of the University of Sydney (https://www.glycemicindex.com/index.php), white rice with yam paste is classified as a high-GI food, and barley mixed rice and barley mixed rice with yam paste are classified as moderate-GI foods. Additionally, $iAUC_{glucose}$ of barley mixed rice and barley mixed rice with yam were significantly lower than white rice only (Student's paired t-test, $p<0.05$).

Adverse events

No participants experienced any adverse events.

DISCUSSION

In this study, we compared the postprandial blood glucose and insulin for barley mixed rice and yam paste. We found that barley mixed rice with yam paste lowered blood glucose concentration and insulin. The postprandial elevation of blood glucose and GI were lower for barley mixed rice and yam than for glucose or white rice.[13-17] To the best of our knowledge, ours is the first study to evaluate the postprandial blood glucose response after ingesting a meal of barley mixed rice and yam paste, which contains the functional ingredients of dietary fiber and mucin.

In our study, barley mixed rice was classified as a moderate-GI food and had a slight lowering effect on postprandial blood glucose. Considering that the β-glucan content of this test food was lower than that in other studies, this result was reasonable.[13-16] Moreover, barley mixed rice with yam paste had a significant lowering effect on blood glucose and insulin, while white rice and yam paste did not affect blood glucose concentrations. Because barley is rich in β-glucan, which is a soluble fiber, β-glucan may be the contributing ingredient for lowering blood glucose. Yam paste contains mucin, dietary fiber, and uncooked raw starch, which are difficult to digest. The dietary fiber content of yam paste is less than 1%, which is considerably lower than that of barley. The low dietary fiber content of yam paste may explain why postprandial blood glucose concentrations did not lower significantly after eating yam paste and white rice.

Interestingly, our results indicated that a combination of barley mixed rice and yam paste had a strong effect on insulin reduction compared to barley mixed rice only and yam with white rice. Considering the results of the multiple regression analysis, this could be an additive effect, rather than a synergistic effect between barley and yam paste (Table 3). As excessive insulin secretion leads to obesity and is associated with metabolic syndrome and type 2 diabetes, reduced insulin secretion may contribute to the prevention of obesity and related disease.[20] However, the inconsistency between postprandial blood glucose and insulin results may be due to the fact that our participants were healthy individuals.

The mechanism underlying low insulin secretion with barley rice with yam paste is unclear. One hypothesis is that insufficient mastication would delay digestion and absorption, subsequently reducing insulin secretion. Barley mixed rice only and barley mixed rice with yam paste have different textures and viscosity; thus, barley mixed rice with yam paste requires less chewing than barley rice only. If barley is not properly chewed, it flows into the stomach and duodenum in a granular state, requiring more time for solubilization by gastric acid and digestion with digestive enzymes such as α-amylase. Our hypothesis is supported by the findings of Kawano et al.[21] who reported that the texture of yam paste is often combined with other foods to improve digestibility. Therefore, it is quite possible that the number of chews and the intensity of chewing were altered by the test meal, even though we instructed participants not to change the number of chews. Additionally, Read et al.[22] compared postprandial blood glucose between swallowing with and without chewing of four different foods.[22] Not chewing the foods resulted in lower postprandial glucose concentrations than those when participants chewed their food,[22] further supporting our hypothesis that chewability and texture may influence postprandial blood glucose concentrations. Similarly, higher postprandial blood glucose concentrations have also been recorded after eating barley porridge than after eating barley kernels.[23] These studies suggest that, depending on food ingredients, less mastication affects the postprandial blood glucose and insulin secretion by delaying digestion. Generally, blood glucose and insulin change are interrelated; however, we found that participants had lower postprandial insulin concentrations after eating a meal of barley mixed rice with yam paste, but insulin concentrations did not decrease after eating barley mixed rice only, or yam with white rice. It has been reported that insulin secretion is stimulated by chewing food and breaking down complex carbohydrates into simpler glucose molecules that stimulate taste cells and receptors in the tongue, releasing more insulin independent of blood glucose concentrations.[24] This mechanism may partially explain why the postprandial insulin response was reduced after consuming, the more easily digestible, barley mixed rice and yam paste. Additionally, in our study, the participants were healthy, and the concentration of blood glucose during fasting and postprandial periods was within the physiological range. Therefore, consuming barley rice alone may be sufficient to reduce postprandial blood glucose, and adding yam paste did not provide any additional benefits. Adding yam paste to barley mixed rice may induce lower rates of insulin secretion, which generally contributes to reduced obesity;[25] therefore, consuming barley mixed rice and yam paste may reduce obesity risk more than consuming barley mixed rice only. We suggest that future studies should investigate the repeatability of our study. Additionally, the lack of effect of white rice with yam on postprandial insulin may be caused by low dietary fiber content and inclusion of healthy participants. In this study, the yam paste was diluted with soup stock by the product company. Therefore, the dietary fiber content was lower than in previous studies.[11] Moreover, postprandial glucose and insulin concentrations may not have increased significantly after the control meal because participants did not have IGT. Therefore, it seems reasonable that white rice with yam paste did not lower the glucose and insulin concentrations of participants in our study.

Recently, many domestic and international studies have reported that the intake of whole grains is associated with reduced body weight and reduced early mortality risk.[26,27] Generally, whole grains in Japan comprise mixed millets and brown rice. Barley is an important food that has drawn global attention as a functional grain. However, barley hulls are removed by refining in Japan; thus, barley is not a whole grain. Nevertheless, barley fiber, such as β-glucan, remains within the endosperm cell walls and, therefore, the health benefits of barley remain even after refining. The soluble fiber in barley accounts for 60% of the total fiber content, which shows a good balance between water-soluble and insoluble fibers. The barley rice used in this study is superior to other grains because the outer hull removal makes the grain easy to eat even for those who prefer white rice. In addition, barley rice with yam paste has only 0.9 g β-glucan, and the amount was lower than reported in other studies.[14–16,28,29] Therefore, simultaneous ingestion of barley and yam paste is strongly recommended. Thus, we hope that this study inspires future studies to investigate the consumption of food combinations, such as bread or other cereal with highly viscous soup, as the source and main ingredient, with some Japanese foods, such as "*natto*" or seaweed.

Although a similar mechanism is expected in the general population, it is difficult to generalize our results because the participants in this study were healthy and young. Therefore, future studies should include a greater variety of participants, such as those aged 40 to 60 years, patients with type 2 diabetes mellitus, and individuals with obesity and/or IGT. Moreover, the effect of the test meal on blood glucose and insulin concentration needs to be investigated over a 3-hour period. In our study, blood glucose and insulin did not decrease to a steady state within 2 hours. Moreover, habitual intake of barley and grated yam paste should be studied in a prospective cohort study. Lastly, we would like to mention the limitations of this study. Firstly, this was an open-label study because it was difficult to blind the test meals owing to the differences in appearance and texture. Secondly, the experiment was conducted using a feasible sample size; therefore, the sample size used in this study may not have been adequate. Finally, there are five missing data points for insulin. We disregarded the missing data based on a previous report; however, this gap may have weakened our conclusion.[30]

In conclusion, the postprandial blood glucose was slightly lower after a meal of barley mixed rice compared to that of white rice. Furthermore, the postprandial blood glucose and insulin concentrations were lower after a meal of barley mixed rice with yam paste than in white rice alone in healthy Japanese individuals.

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CONFLICT OF INTEREST AND FUNDING DISCLOSURE

TM and CK are employees of Hakubaku Co., Ltd. The authors declare that they have no conflicts of interest.

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REFERENCES

1. Welch S, Gebhart SS, Bergman RN, Phillips LS. Minimal model analysis of intravenous glucose tolerance test-derived insulin sensitivity in diabetic subjects. J Clin Endocrinol Metab. 1990;71:1508-18. doi: 10.1210/jcem-71-6-1508.
2. Taniguchi A, Nakai Y, Fukushima M, Kawamura H, Imura H, Nagata I, Tokuyama K, Pathogenic factors responsible for glucose intolerance in patients with NIDDM. Diabetes. 1992;41:1540-6. doi: 10.2337/diab.41.12.1540.

3. Chiasson JL, Josse RG, Gomis R, Hanefeld M, Karasik A, Laakso M, STOP-NIDDM Trial Research Group. Acarbose treatment and the risk of cardiovascular disease and hypertension in patients with impaired glucose tolerance: the STOP-NIDDM trial. JAMA. 2003;290:486-94. doi: 10.1001/jama.290.4.486.
4. DECODE study Group, Group, Diabetes EE. Glucose tolerance and mortality: comparison of WHO and American Diabetes Association diagnostic criteria. The DECODE study group. European Diabetes Epidemiology Group. Diabetes Epidemiology: Collaborative analysis Of Diagnostic criteria in Europe. Lancet. 1999;354:617-21. doi: 10.1016/S0140-6736(98)12131-1.
5. DECODE Study Group, the European Diabetes Epidemiology Group. Glucose tolerance and cardiovascular mortality: Comparison of fasting and 2-hour diagnostic criteria. Arch Intern Med. 2001;161:397-405. doi: 10.1001/archinte.161.3.397.
6. Fung TT, Hu FB, Pereira MA, Liu S, Stampfer MJ, Colditz GA, Willett WC, Whole-grain intake and the risk of type 2 diabetes: A prospective study in men. Am J Clin Nutr. 2002;76:535-40. doi: 10.1093/ajcn/76.3.535.
7. Kong APS, Choi KC, Chan RSM, Lok K, Ozaki R, Li AM et al. A randomized controlled trial to investigate the impact of a low glycemic index (GI) diet on body mass index in obese adolescents. BMC Public Health. 2014;14:180. doi: 10.1186/1471-2458-14-180.
8. Liu S, Willett WC, Stampfer MJ, Hu FB, Franz M, Sampson L, Hennekens CH, Manson JE, A prospective study of dietary glycemic load, carbohydrate intake, and risk of coronary heart disease in US women. Am J Clin Nutr. 2000;71:1455-61. doi: 10.1093/ajcn/71.6.1455.
9. Murakami K, Sasaki S, Takahashi Y, Okubo H, Hosoi Y, Horiguchi H, Oguma E, Kayama F, Dietary glycemic index and load in relation to metabolic risk factors in Japanese female farmers with traditional dietary habits. Am J Clin Nutr. 2006;83:1161-9. doi: 10.1093/ajcn/83.5.1161.
10. Oba S, Nanri A, Kurotani K, Goto A, Kato M, Mizoue, Noda M, Inoue M, Tsugane S, Japan Public Health Center-based Prospective Study Group, Dietary glycemic index, glycemic load and incidence of type 2 diabetes in Japanese men and women: the Japan Public Health Center-based Prospective Study. Nutr J. 2013;12:165. doi: 10.1186/1475-2891-12-165.
11. Taniguchi A, Yamanaka-Okumura H, Nishida Y, Yamamoto H, Taketani Y, Takeda E. Natto and viscous vegetables in a Japanese style meal suppress postprandial glucose and insulin responses. Asia Pac J Clin Nutr. 2008;17:663-8.
12. Taniguchi-Fukatsu A, Yamanaka-Okumura H, Naniwa-Kuroki Y, Nishida Y, Yamamoto H, Taketani Y, Takeda E, Natto and viscous vegetables in a Japanese-style breakfast improved insulin sensitivity, lipid metabolism and oxidative stress in overweight subjects with impaired glucose tolerance. Br J Nutr. 2012;107:1184-91. doi: 10.1017/S0007114511004156.
13. Henry CJK, Lightowler HJ, Strik CM, Renton H, Hails S. Glycaemic index and glycaemic load values of commercially available products in the UK. Br J Nutr. 2005;94:922-30. doi: 10.1079/bjn20051594.

14. Maeda A, Nabiki J, Shibachi M, Murata Y, Ogawa T, Inada H, Haranou A, Haranou Y. Effect of low GI rice rich in amylase mixed with barley on blood glucose, insulin and incretin responses and its clinical significance. Jnl Jpns Soc Clin Nutr. 2012;34:2-7. (In Japanese)
15. Fukuhara I, Ikenaga T, Noguchi H, Kohashi C, Konagai S, Zenbutsu K, Tomita S, Kohda N. Effect of cooked rice with β-glucan enriched barley on postprandial glucose reponse and its second-meal effect. Jpn Parmacol Ther. 2013;41:789-95. (In Japanese)
16. Sato J, Osawa I, Hattori Y, Oshida Y, Sato Y. Effects of dietary fiber on carbohydrate metabolism -a study in healthy subjects and diabetic patients-. Nagoya J Health, Physical Fitness, Sports. 1990;13:75-8.
17. Perry T, Mann J, Mehalski K, Gayya C, Wilson J, Thompson C. Glycaemic index of New Zealand foods. N Z Med J. 2000;113:140-2.
18. Schulz KF, Altman DG, Moher D, CONSORT Group. CONSORT 2010 statement: updated guidelines for reporting parallel group randomised trials. BMJ. 2010;340:c332. doi: 10.1136/bmj.c332.
19. Jenkins DJ, Wolever TM, Taylor RH, Barker H, Fielden H, Baldwin JM, Bowling AC, Newman HC, Jenkins AL, Goff DV, Glycemic index of foods: a physiological basis for carbohydrate exchange. Am J Clin Nutr. 1981;34:362-6. doi: 10.1093/ajcn/34.3.362.
20. Caceres M, Teran CG, Rodriguez S, Medina M. Prevalence of insulin resistance and its association with metabolic syndrome criteria among Bolivian children and adolescents with obesity. BMC Pediatr. 2008;8:31. doi: 10.1186/1471-2431-8-31.
21. Kawano A, Hosoda C, Takahashi T, Ogoshi H. Physical properties and swallowing characteristics of a mixed gel-sol food based on grated yam. Jnl Home Econ Jpn. 2006;57:13-20. Available from:https://cir.nii.ac.jp/crid/1390282681308916736 (In Japanese)
22. Read NW, Welch IM, Austen CJ, Barnish C, Bartlett CE, Baxter AJ et al. Swallowing food without chewing; a simple way to reduce postprandial glycaemia. Br J Nutr. 1986;55:43-7. doi: 10.1079/bjn19860008.
23. Nilsson AC, Ostman EM, Granfeldt Y, Björck IME. Effect of cereal test breakfasts differing in glycemic index and content of indigestible carbohydrates on daylong glucose tolerance in healthy subjects. Am J Clin Nutr. 2008;87:645-54. doi: 10.1093/ajcn/87.3.645.
24. Madhu V, Shirali A, Pawaskar PN, Madi D, Chowta N, Ramapuram JT. Mastication frequency and postprandial blood sugar levels in normoglycaemic and dysglycaemic individuals: A cross- sectional comparative study. J Clin Diagn Res. 2016;10:OC06-8. doi: 10.7860/JCDR/2016/18855.8082.
25. Ludwig DS, Ebbeling CB. The carbohydrate-insulin model of obesity: Beyond “calories in, calories out”. JAMA Intern Med. 2018;178:1098-103. doi: 10.1001/jamainternmed.2018.2933.
26. Aune D, Keum N, Giovannucci E, Fadnes LT, Boffetta P, Greenwood DC, Tonstad S, Vatten LJ, Riboli E, Norat T. Whole grain consumption and risk of cardiovascular disease, cancer, and all cause and cause specific mortality: Systematic review and dose-response meta-analysis of prospective studies. BMJ. 2016;353:i2716. doi: 10.1136/bmj.i2716.

27. Mozaffarian D, Kumanyika SK, Lemaitre RN, Olson JL, Burke GL, Siscovick DS. Cereal. fruit, and vegetable fiber intake and the risk of cardiovascular disease in elderly individuals. JAMA. 2003;289:1659-66. doi: 10.1001/jama.289.13.1659.
28. Matsuoka T, Tsuchida A, Yamaji A, Kurosawa C, Shinohara M, Takayama I et al. Consumption of a meal containing refined barley flour bread is associated with a lower postprandial blood glucose concentration after a second meal compared with one containing refined wheat flour bread in healthy Japanese: A randomized control trial. Nutrition. 2020;72:110637. doi: 10.1016/j.nut.2019.110637.
29. Osonoi T, Matsuoka T, Ofuchi K, Katoh M, Kobayashi T, Mochizuki K. Effects of barley intake on glycemic control in Japanese patients with type 2 diabetes mellitus undergoing antidiabetic therapy: a prospective study. Diabetol Int. 2022;13:387-95. doi: 10.1007/s13340-021-00552-z.
30. Jakobsen JC, Gluud C, Wetterslev J, Winkel P. When and how should multiple imputation be used for handling missing data in randomised clinical trials - a practical guide with flowcharts. BMC Med Res Methodol. 2017;17:162. doi: 10.1186/s12874-017-0442-1.

Table 1. Ingredients and nutrients of each test meal (per serving)†

	WR	BR	WR yam	BR yam
Contents				
White rice (g)	150	117	128	103
Barley‡ (g)	-	37	-	32
Yam§ (g)	-	-	64	52
Total weight (g)	150	154	192	187
Nutrients				
Energy (kJ)	879	912	907	929
Protein (g)	2.9	3.2	3.9	4.0
Fat (g)	0.0	0.0	0.1	0.4
Carbohydrate (g)	48.5	51.6	50.7	52.0
Sugars (g)	48.5	50.0	50.0	50.0
Dietary fiber (g)	0.3	1.8	0.9	2.1
β-glucan (g)	-	1.0	-	0.9

WR: white rice (Control meal); BR: barley mixed rice; WR yam: white rice with yam; BR yam: barley mixed rice with yam.
†Measured by Japan Food Research Laboratories except for β-glucan.
‡Pared and pressed barley.
§Grated yam paste with flavor.

Table 2. Baseline characteristics of the participants (n=14)

	n (%) or Mean±SD
Men (%)	1 (6.7%)
Age (years)	22.5±1.5
BMI (kg/m^2)	18.9±1.1
Maximum blood pressure (mmHg)	103±4
Minimum blood pressure (mmHg)	71±3
Fasting blood glucose (mmol/L)	4.5±0.3

SD: standard deviation; BMI: body mass index.

Table 3. Results of multiple regression analyses to assess the interaction between barley and yam (n=14)†

Variable	$AUC_{glucose}$			$AUC_{insulin}$		
	R	SE	*p*	*R*	SE	*p*
Barley (1: Barley mixed rice, 0: White rice)	−880	537	0.11	−754	820	0.36
Yam (1: with yam, 0: without yam)	−399	537	0.46	−472	820	0.57
Interaction term (Barley, Yam)	273	759	0.72	−605	1060	0.60

R: multiple regression coefficient; SE: standard error.
†The area under curve for glucose (AUCglucose) or area under curve for insulin (AUCinsulin) was used as the outcome. Barley consumption, yam consumption, and the interaction terms of barley and yam were used as independent variables. Interaction term was calculated as the multiplication of barley (0 or 1) and yam (0 or 1).

Table 4. Test food glycemic index (GI) and the results of $iAUC_{glucose}$ (n=12)†

Test food	$GI_{white\ rice}$	$GI_{glucose}$	$iAUC_{glucose}$ (mmol/L*min)	
	Mean±SD	Mean±SD	Mean±SD	*p* value‡
White rice (WR)	100 (ref)	80 (ref)	226±90	Ref
WR with yam	98.1±46.6	78.5±37.3	197±65	0.34
Barley mixed rice (BR)	71.2±43.9	57.0±35.1	144±80	0.04
BR with yam	82.5±35.9	66.0±28.7	171±72	0.04

ref: reference; SD: standard deviation; iAUC: increased area under the curve; GI: glycemic index; WR: white rice; BR: barley mixed rice.
†Twelve subjects followed the criteria of the unified protocol of the Japanese Association for the Study of the Glycemic Index.
‡*p* value derived using student's paired t test.

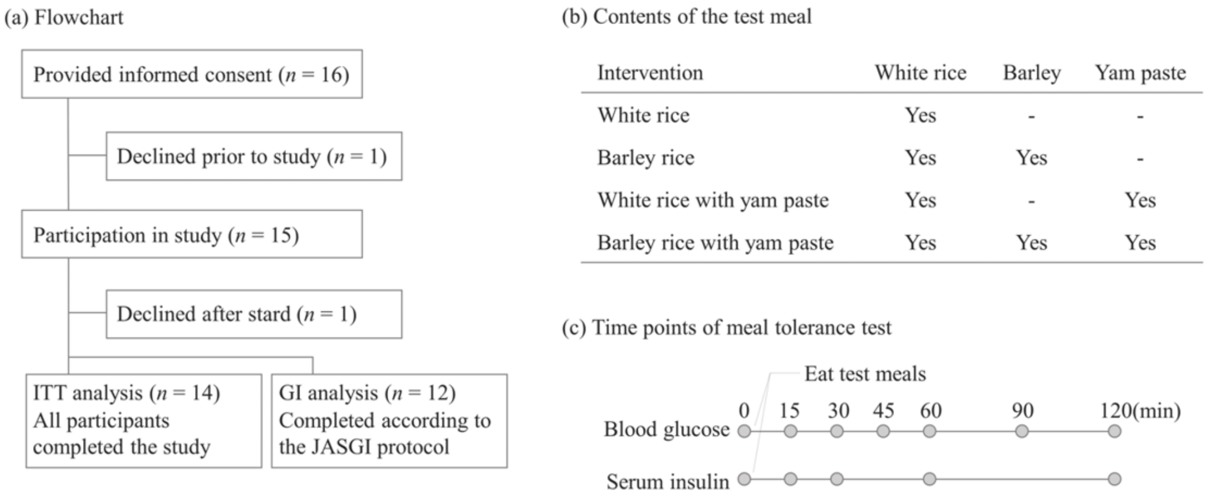

Figure 1. Flowchart of participant recruitment and study design. (a) Flowchart of participant recruitment. (b) Contents of the test meal. (c) Time points of meal tolerance tests. (JASGI: Japanese Association for the Study of Glycemic Index).

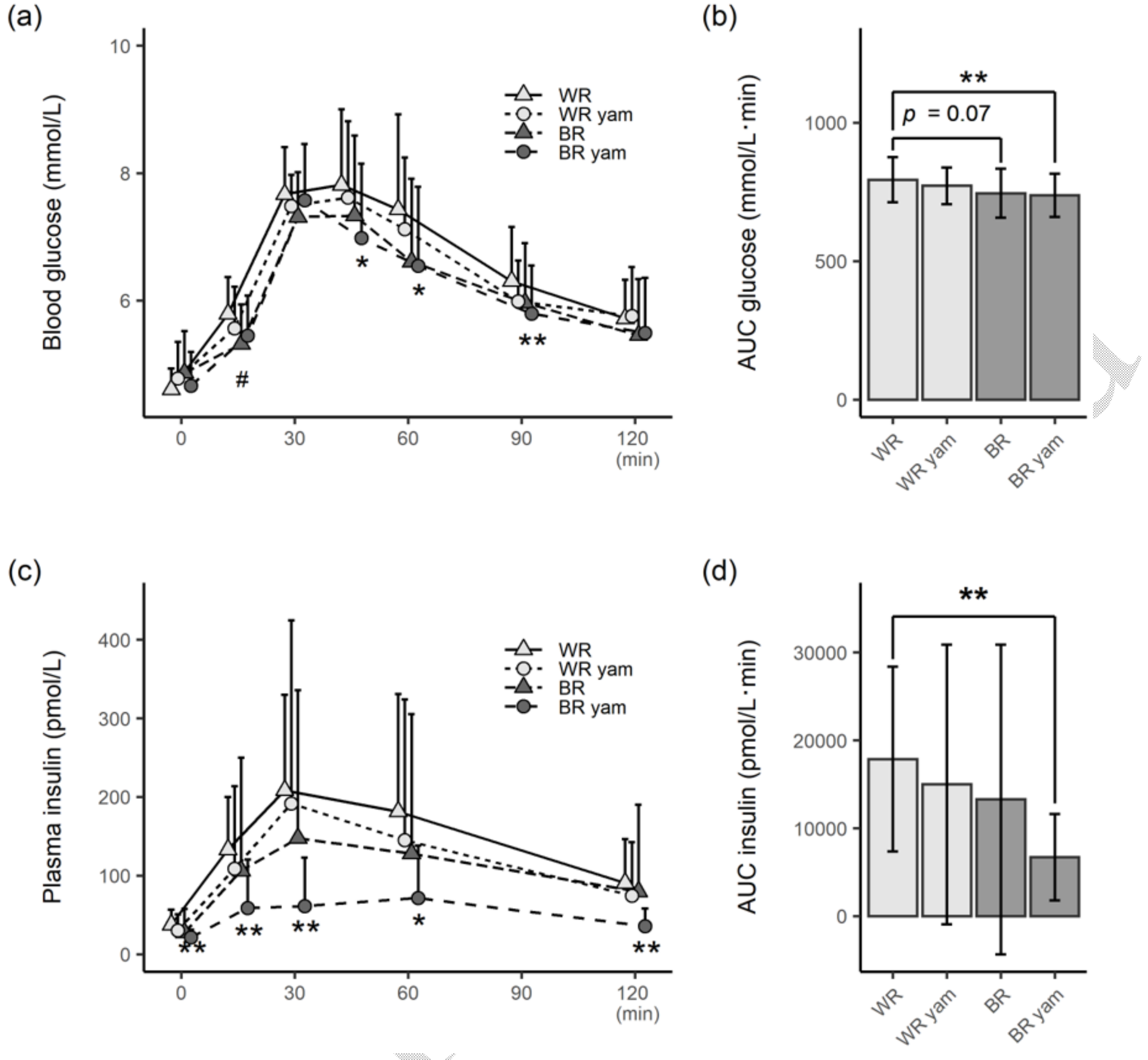

Figure 2. Results of the meal tolerance test (n=14). (a) Blood glucose concentrations (b) Area under curve for glucose ($AUC_{glucose}$) (c) Plasma insulin concentrations (d) Area under curve for insulin ($AUC_{insulin}$). $^{*}p$<0.05; $^{**}p$<0.01 (barley mixed rice with yam vs. white rice), $^{\#}p$<0.05 (barley mixed rice vs. white rice). WR: white rice, BR: barley mixed rice.