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Effect of dietary fiber-enriched brown rice crackers on suppressing elevation of blood glucose level

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ABSTRACT

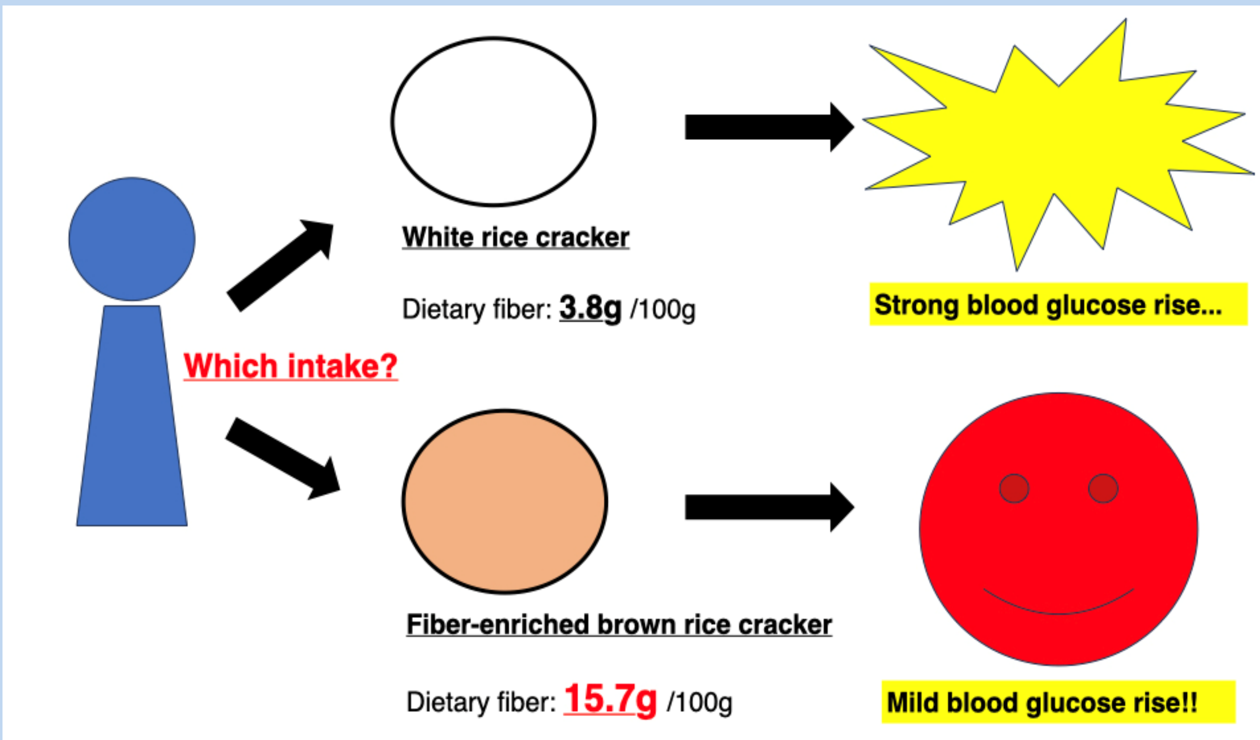
Background: Rice crackers are composed of carbohydrates refined from rice and enjoyed as a snack in Japan. Most rice crackers are crafted from white rice, and the potential postprandial blood glucose rise following their consumption may pose a clinical concern. Brown rice contains more dietary fiber than white rice and has been reported to suppress elevations of blood glucose. Dietary fiber-enhanced brown rice crackers have a significantly higher dietary fiber content than regular brown rice crackers and can be expected to suppress blood glucose elevations more reliably.

Methods: We conducted a crossover trial in humans using white rice crackers and dietary fiber-enhanced brown rice crackers to investigate the effect of dietary fiber-enhanced brown rice crackers on postprandial blood glucose elevations. Participants ingested the 100 g rice crackers with 200 mL water for 10 min, and blood was collected from the fingertip at 7 time points: baseline, and at 15, 30, 45, 60, 90, and 120 min after ingestion of the rice cracker. The primary outcome measure was the blood glucose levels, and the secondary outcome measure was the incremental area under curve of blood glucose.

Results: Glucose levels and incremental areas under curve at 60 min and 120 min after intake were significantly lower with dietary fiber-enhanced brown rice crackers than with white rice crackers. Incremental area under curves at 60 min and 120 min after intake of rice crackers were also significantly lower in dietary fiber-enhanced brown rice crackers than white rice crackers.

Conclusions: Ingesting dietary fiber-enhanced brown rice crackers instead of white rice crackers could be useful for achieving better glycemic control.

Keywords: Brown rice crackers, Dietary fiber, Postprandial blood glucose



INTRODUCTION

It is well-known that carbohydrate intake contributes to postprandial hyperglycemia in individuals undergoing diabetic dietary therapy. This manifestation is also described in American Diabetes Association (ADA) guidelines [1]. Rice crackers (Senbei), a representative snack in Japan, are made from rice and have a high carbohydrate content, which can result in increasing blood glucose levels after meals. In Japanese clinical practice, it has also been observed that snacking on rice crackers can lead to an elevation in postprandial blood glucose levels, posing challenges in maintaining optimal blood glucose control. Brown rice is rice that has only the rice husk removed, but the bran and germ remain intact. On the other hand, white rice is made by removing the chaff, bran, and germ from rice seeds. Therefore, brown rice is rich in bran and germ nutrients that white rice does not have. Especially compared to white rice, it contains more vitamin B, minerals such as calcium and magnesium, dietary fiber and protein. It has been reported that brown rice suppresses a postprandial rise in blood glucose levels compared to white rice [2-4]. It was estimated that replacing 50 grams of white rice (just one third of a typical daily serving) with the same amount of brown rice would lower the risk of type 2 diabetes by 16% [5]. Switching from WR-C to BR-C is also thought to suppress an elevation of blood glucose, but there is only one report supporting this [6], and heat-moisture treated BR-C were used in this previous study. It was reported that dietary fiber can suppress postprandial rises in blood glucose [7]. It can be supposed that if the dietary fiber content of BR-C were further increased, a cracker with a stronger effect would be produced.

Dietary fiber-enriched F-BR-C has a higher dietary fiber content than the typical BR-C (13.0g/100g vs. 2.0g/100g). We hypothesized that this F-BR-C could better suppress postprandial blood glucose levels compared to WR-C.

This study aimed to verify whether elevations of blood glucose can be suppressed after ingesting F-BR-C in comparison with ingesting WR-C in humans.

MATERIALS AND METHODS

Study participants: Study details were disclosed to potential participants before their enrollment, and investigators obtained written informed consent after it was determined that those individuals could independently decide to participate. Those individuals then underwent screening by medical interview to check for exclusion criteria, somatometry, and laboratory testing. All participants were male although not by design. Inclusion criteria were: (i) a fasting blood glucose level < 126 mg/dL; and (ii) screening test results judged to be appropriate for this study by the investigator. Exclusion criteria were : (i) diabetes with fasting glucose levels ≧ 126 mg/dL and HbA1c of ≧ 6.5%; (ii) a history of a severe disease (e.g. liver, kidney, heart, or blood diseases) judged to be inappropriate for this study; (iii) presence of gastrointestinal diseases judged to be inappropriate for this study; (iv) food allergy related to rice or other grains; and (v) rejection from participation in this study by the principal investigator. We calculated the sample size for the primary analysis based on differences observed in our previous study [6]. Assuming a similar effect size, power calculations showed that a sample size of 11 individuals would be sufficient to reach a power of 80% at a significance level of 0.05. 2 participants didn't meet inclusion criteria and 9 healthy men were recruited from 11 applicants who were employees of Kuriyama-Beika Co., Ltd. (Niigata, Japan. URL: https://www.befco.jp/). Nine people were randomly and sequentially assigned using random number tables to one of two groups (4 or 5 participants/ group). Background characteristics are shown in Table 1.

Table 1. Demographics of study participants

Demographic	n=9
Age (years)	51.3 ± 5.5
Height (m)	1.73 ± 0.07
Body weight (kg)	75.3 ± 8.9
BMI (kg/m^2)	25.1 ± 1.6

Values are expressed as means ± standard error of the mean (SEM). BMI: body mass index. There were 9 participants, all males. The average BMI was over 25, and many were obese.

Rice cracker preparation: WR-C and F-BR-C were prepared specially for the experiment at Kuriyama-Beika Co., Ltd. Nutrient analysis of rice crackers was conducted by Kuriyama-Beika Co., Ltd.

Study design: We conducted single-blind, single ingestion crossover trials. The study protocol was approved by the Research Ethics Review Committee of the Niigata University on May 14, 2020 (Approval Number: 2020-0002) and conformed to the Principles of the Declaration of Helsinki and the Ethical Guidelines for Life Science and Medical Research Involving Human Subjects issued by the Ministry of Health, Labor and Welfare, Japan. The study lasted from January to March 2020 and was registered as UMIN000040410 in the UMIN Clinical Trials Registry, Japan.

Two-treatment, single administration, two-period crossover trials were performed, trials 1 and 2. In trial 1, subjects in group A ingested WR-C and those in group B ingested F-BR-C. In trial 2, subjects in group A ingested F-BR-C, and subjects in group B ingested WR-C. Trial 1 and 2 were conducted 7 days apart, but both groups underwent testing on the same day. On the test days, participants ingested 100 g

rice crackers with 200 mL water for 10 min [5]. The intake of rice crackers was adjusted to provide an approximate sugar intake of 75g, equivalent to the amount of glucose (a type of carbohydrate) consumed during a 75g OGTT. The test diet did not distinguish crackers by appearance or taste. Blood was collected from the fingertip at 7 time points: baseline, and at 15, 30, 45, 60, 90, and 120 min after ingestion of the rice cracker [7]. Blood glucose was measured using Glutest Neo Alpha (Sanwa Kagaku Kenkyusyo Co, Ltd., Aichi, Japan. URL: https://www.skk-net.com/en/index.html). Participants were instructed by the principal investigator and assistants to conform to the following during the study period: (i) avoid an irregular lifestyle, including overeating and poor sleep; (ii) do not change their lifestyle habits, including diet, sleep, and exercise; (iii) do not donate blood; and (iv) do not begin to consume new health foods. Participants were prohibited from eating and drinking anything except water from 20:00 on the day before testing and given only water and the test food during the 120 minutes of testing [8].

The primary outcome measure was the blood glucose levels, and the secondary outcome measure was the IAUC of blood glucose. Efficacy analysis was performed on data from all participants who completed the study.

Statistical Analysis: Data are shown as the mean ± SEM and were analyzed by two-way repeated analysis of variance. For comparison of groups at each time point, paired t-test was used, and p-values were corrected by the Bonferroni method. SPSS® software (IBM Ltd., Chicago, IL, USA) was used for the statistical analysis. A value of $P < 0.05$ was considered statistically significant.

RESULTS

Rice crackers: Nutrient and non-nutrient compositions of WR-C and F-BR-C are shown in Table 2. Total energies were also approximately equal for WR-C and F-BR-C. Carbohydrate levels were similar in both crackers, but sugar levels were lower in F-BR-C than in WR-C. Dietary fiber content was clearly greater in F-BR-C than in WR-C (15.7 g vs. 3.8 g). As for the breakdown of dietary fiber, WR-C was composed exclusively of low-molecular-weight water-soluble dietary fiber, and F-BR-C increased the amount of both water-soluble and insoluble dietary fibers compared to WR-C. The amount of GABA is comparable in both crackers, but oryzanol and total ferulic acid were higher in F-BR-C than in WR-C.

Table 2. Pre-visit dietary intake

	WR-C	F-BR-C
Energy （kcal/100g）	378	368
Water (g/100g)	2.6	2.8
Ash (g/100g)	2.3	2.4
Fat (g/100g)	1.0	4.0
Protein (g/100g)	7.7	9.3
Carbohydrate (g/100g)	86.4	81.5
Sugars (g/100g)	82.6	65.8
Dietary fiber (g/100g)	3.8	15.7
Insoluble dietary fiber (g/100g)	<0.5	6.9
High molecular weight water-soluble dietary fiber (g/100g)	<0.5	1.3
Low molecular weight water-soluble dietary fiber (g/100g)	3.8	7.5
Salt (g/100g)	1.77	1.15
Free GABA (mg/100g)	3	4
Oryzanol (mg/100g)	0.7	21.8
Total ferric acid (mg/100g)	11	33
Ferric acid (mg/100g)	<0.5	<0.5
Polyphenol (mg/100g)	0.14	0.17

Values are expressed as means ± standard error of the mean (SEM). GABA: gamma-aminobutylic acid, WR-C: white rice crackers, F-BR-C: brown rice crackers with increased dietary fiber. Dietary fiber is measured according to AOAC2011.25 method.

Glucose levels and incremental areas under the curve of glucose (IAUC): Glucose levels at 60 min and 120 min after intake of rice crackers were significantly lower with F-BR-C than WR-C (Table 3). In F-BR-C, blood glucose elevation was suppressed by 30 points at 60 minutes and 21 points at 120 minutes as the extent of suppression of this elevation compared to WR-C.

Based on this data, profiles illustrating changes from baseline were obtained, as depicted in Figure 1. Changes in blood glucose at 60 min and 120 min after intake of rice crackers were also significantly lower in F-BR-C than WR-C. IAUCs at 60 min and 120 min after intake of rice crackers were also significantly lower in F-BR-C than WR-C (Table 3).

Table 3. Postprandial glucose and incremental areas under the curve for glucose

a)

Glucose (mg/dL)	**Baseline**	**15**	**30**	**45**	**60**	**90**	**120 min**
WR-C	104 ± 10	118 ± 27	154 ± 23	183 ± 39	201 ± 26	178 ± 50	155 ± 41
F-BR-C	103 ± 11	119 ± 22	157 ± 29	180 ± 47	171 ± 36*	168 ± 45	134 ± 37*

b)

IAUC (min.mg/dL)	**Baseline**	**15**	**30**	**45**	**60**	**90**	**120 min**
WR-C	0 ± 0	133 ± 137	623 ± 379	1579 ± 672	2891 ± 980	5451± 1810	7313 ±2804
F-BR-C	0 ± 0	127 ± 137	1666 ± 1145	2635 ± 1442	3710±1741*	5688±2423	7115±3192*

(a) Postprandial glucose and (b) incremental areas under the curve for glucose after intake of test food. WR-C: white rice crackers. F-BR-C: brown rice cracker with increased dietary fiber. Values are expressed as means ± standard error of the mean (SEM). Significant difference comparison: *p<0.05 vs. WR-C (paired t-test and p-values were corrected by the Bonferroni method).

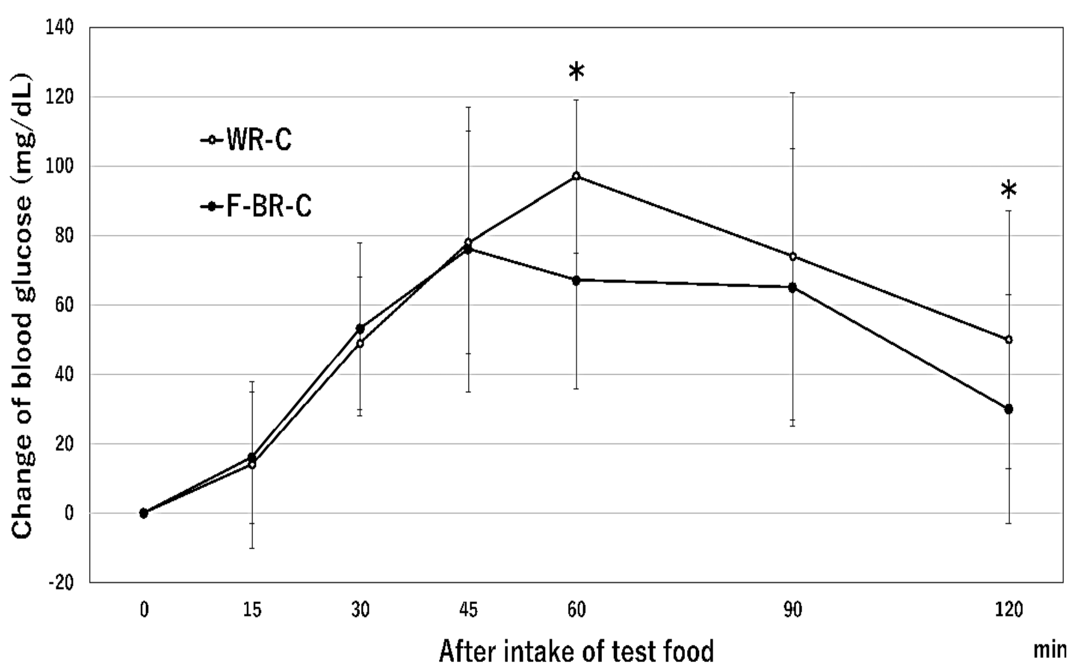


Figure 1. Time courses of changes in postprandial blood glucose levels. WR-C: white rice cracker. F-BR-C: brown rice cracker with increased dietary fiber. Time-courses of changes in blood glucose levels after intake of white rice crackers (WR-C, empty circle), and brown rice crackers (F-BR-C, solid square). Values are expressed as means ± standard error of the mean (SEM). Significant difference comparison: *p<0.05 vs. WR-C (paired t-test and p-values were corrected by the Bonferroni method).

DISCUSSION

Brown rice contains many nutrients with potential health benefits, such as dietary fiber (contains resistant starch), polyphenols, amino acids, and vitamins. Resistant starch, a type of starch that remains undigested in the body and is abundant in brown rice, shares a similar function with dietary fiber. It has garnered scientific interest for its potential to reduce the risk of type 2 diabetes [9-10]. Resistant starch can be measured as dietary fiber using the AOAC2011.25 method, and in our study, dietary fiber was measured by this method.

Dietary fiber contributes to the suppression of blood glucose elevation [11]. In retrospective studies that investigated the relationship between dietary fiber intake and the risk of developing diabetes, the higher dietary fiber intake group was lower incidence of type 2 diabetes mellitus compared to the lower dietary fiber intake group [12-13]. The previous study also found that those who ate vegetables or cereal had a lower risk of developing type 2 diabetes, however no association was found between fruits and the risk of developing type 2 diabetes [12]. This study also included a meta-analysis of 18 studies, and increasing cereal fiber reduced the risk of developing diabetes, although no association was found between fruits and vegetables and the risk of developing diabetes. In another study, high dietary fiber intake from cereals reduced the risk of developing diabetes, but no association was observed with dietary fiber from fruits and vegetables [14]. Among dietary fibers, it is suggested that the intake of dietary fiber derived from grains is effective in reducing the risk of developing type 2 diabetes. In a crossover study conducted with different dietary fiber intakes, high fiber diets suppressed increases in blood glucose, HbA1c and insulin levels compared to low fiber diets [15].

Dietary fiber is classically divided into insoluble and soluble. Of all dietary fibers, soluble dietary fiber, in particular, has the effect of slowing down the absorption of carbohydrates and suppressing the rise of blood glucose levels [16-17].In a meta-analysis that examined the risk of developing type 2 diabetes with insoluble and soluble dietary fiber, there was an association between insoluble dietary fiber and grain-derived dietary fiber with the risk of developing type 2 diabetes, but there was no association between intake soluble dietary fiber and the onset of type 2 diabetes mellitus [12]. However, the number of studies is small, and further research is needed to clarify the differences in association between soluble and insoluble dietary fiber and diabetes risk. Insoluble fiber is found in grains and vegetables, while soluble fiber is found in fruits, vegetables, and bread [18]. In our study, F-BR-C increased both insoluble and soluble dietary fibers compared to WR-C. Although it is unknown whether the insoluble dietary fiber or the soluble fiber was strongly involved, it is possible that the dietary fiber containing resistant starch influenced the blood glucose elevation suppression effect.

The mechanisms by which dietary fiber suppresses blood glucose rise are as follows [19]: 1) Oral: Increases satiety by prolonging food retention time in the oral cavity, 2) Stomach: Increases stomach expansion and satiety via the vagus nerve [20], and prolonging nutrient absorption. 3) Small intestine: Activating peristalsis in the small intestine, prolonging nutrient absorption, secretion of gastrointestinal hormones (incretins) [21-22], 4) Large intestine: Shortening the retention time of food in the intestine, promoting defecation, and changing the intestinal flora [21].

Gamma amino butyric acid (GABA) is a type of amino acid that has been reported to have the effect of lowering blood glucose levels [23]. Reducing production of the neurotransmitter GABA in the liver could normalize blood glucose levels, decrease appetite, and lead to weight loss [24]. In our study, there was no difference in GABA content between WR-C and F-BR-C.

Ferulic acid is a type of polyphenol with high antioxidant effect that was reported to improve lipid and glucose homeostasis [25]. γ-Oryzanol is a component of brown rice that was shown to decrease blood glucose by promoting β-cell neogenesis and regeneration [26]. In our study, total ferulic acid and Oryzanol were higher in F-BR-C than in WR-C. It is possible that ferulic acid and Oryzanol, like dietary fiber, also contributed to the suppression of blood glucose elevation. However, since ferulic acid in brown rice has a high ratio of cross-linking with arabinoxylan, ferulic acid may not function in the gastrointestinal tract with a single administration [27]. In addition, since the concentration of ferulic acid in blood was not measured, it is unknown whether ferulic acid had an effect.

In evaluating the taste of the F-BR-C, the consumers expressed that it was a food that could be enjoyed between meals daily. However, ingestion of foods with increased dietary fiber may cause problems such as a feeling of abdominal fullness. Several study participants complained of abdominal distension immediately after ingesting the test meal, but this spontaneously subsided. No other adverse events occurred.

This study is the first to report the effect of F-BR-C on blood glucose elevations compared with WR-C in a human trial. The use of dietary F-BR-C might be a guidepost to maintain good blood glucose levels while enjoying moderate snacks. As limitations of this study, participants were limited to men, and the number of participants was small. It is not clear whether F-BR-C are more effective than BR-C in suppressing blood glucose elevation, because no group established to ingest BR-C not enriched with dietary fiber. In addition, since the number of sugars was less in F-BR-C, it is possible that F-BR-C caused a lower blood glucose increase than in WR-C. It is also unclear which component of F-BR-C exerted its efficacy. As a measurement item, only the blood glucose level was evaluated, but it is necessary to investigate changes in the insulin level after ingestion. Furthermore, it is considered important to evaluate body weight and HbA1c under long-term intake conditions. Intestinal flora and incretin hormone measurements may also be required.

It is hoped that by substituting current between-meal snacks with these F-BR-C options, individuals with diabetes and those at risk of diabetes can enjoy snacks to some extent while working towards controlling their blood glucose levels.

CONCLUSION

In conclusion, when F-BR-C were ingested, there was a significant difference in the extent of blood glucose increase 60 and 120 minutes after ingestion compared to ingestion of WR-C. It was suggested that ingesting F-BR-C instead of WR-C could be a useful means to achieve good glycemic control. Regarding the effect of suppressing blood glucose elevation by dietary F-BR-C, it is possible that the active ingredients such as ferulic acid, γ-oryzanol, and the enhanced dietary fiber are involved.

Abbreviations: WR-C: white rice crackers, BR-C: brown rice crackers, F-BR-C: Dietary fiber-enriched BR-C, HbA1c: hemoglobin A1c, UMIN: University Hospital Medical Information Network, OGTT: oral glucose tolerance tests, IAUC: incremental area under curve, SEM: standard error of the mean, GABA: Gamma-Amino Butyric Acid.

Author's Contributions: Hirohito Sone and Kenichi Watanabe: designed and supervised the project; revised the manuscript. Hiroshi Suzuki: performed the experiments; analyzed data; wrote the manuscript. Izumi Ikeda, Yasunaga Takeda, Mariko Hatta, Chika Horikawa, Efrem D'Avila Ferreira, Wu Sijia, Khin Laymon: analyzed data. All authors have read and approved the final manuscript.

Competing Interests: No author has any conflict of interest, except that we received the rice crackers for free from Kuriyama Beika Co., Ltd. No authors received research funding from Kuriyama Beika Co., Ltd.

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