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Original Artcle

Effects of choice of staple food and the addition of dietary fiber on changes in postprandial blood glucose level

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Abstract

***Objective*:** Foods with a low glycemic index (GI) produce a slow elevation of postprandial blood glucose level, and postprandial hyperglycemia can be suppressed by eating foods in the appropriate order (*e.g.*, eating vegetables before steamed rice). This study was conducted to assess the effects of choice of staple food (carbohydrates) and the addition of dietary fiber on changes in postprandial blood glucose level, with the aim to develop a method of reducing glycation stress.

***Methods*:** Nine staple foods [steamed rice, handmade udon (wheat noodles), boiled udon, bread, sekihan (steamed glutinous rice with red beans), buckwheat noodles, pasta, brown rice, rice cakes) and 2 side dishes (soft boiled eggs, vegetable salad) were used as test foods. Written consent to participate in the study was obtained from 19 healthy male or female subjects (age 30.3 ± 12.0 years). On the day of experimentation, fasting blood glucose levels were measured, and each test food was then eaten for breakfast over a period of 10 minutes. Blood glucose levels were measured using a glucose meter for self monitoring at 15, 30, 45, 60, 90, and 120 minutes after the start of food ingestion. Glycation stress was quantified in terms of blood glucose elevation and area under the curve of blood glucose elevation (AUC). Data obtained were statistically analyzed using Tukey's multiple comparison test. This study was conducted after approval by the Doshisha University Ethics Committee for Scientific Research Involving Human Subjects.

***Results*:** In the subjects exhibiting a blood glucose elevation of AUC ≥ 5,000 after eating steamed rice, the postprandial blood glucose levels observed after taking each of the 9 staple foods were compared. The maximum blood glucose level change tended to be lower for pasta than for brown rice ($p = 0.049$), lower for bread ($p = 0.060$) and pasta ($p = 0.060$) than for steamed rice, and lower for bread ($p = 0.050$) than for brown rice. The AUC was lower for bread and pasta than for steamed rice, and lower for pasta than for sekihan. Both the maximum blood glucose level change ($p = 0.029$) and AUC ($p = 0.029$) were lower for wheat-derived staple foods than for rice-derived staple foods. In the dietary fiber addition test, the maximum blood glucose level change was lower by 12 mg/dL for udon supplemented with dietary fiber than for handmade udon ($p = 0.049$), with no significant difference found in AUC.

***Conclusions*:** Changes in postprandial blood glucose level differed depending on the choice of staple food; the addition of dietary fiber may mitigate blood glucose elevation after meals and lessen glycation stress.

***KEY WORDS*:** glycemic index, post-prandial hyperglycemia, glycation stress, dietary fiber, resistant dextrin

Introduction

The phenomenon in which reducing sugars such as glucose bind to protein non-enzymatically to form glycoproteins is known as glycation. Glycation stress refers to a form of stress on the body caused by a load of reducing sugar or aldehyde [1,2]. As an aging risk factor, glycation stress can serve as a promoter of skin aging, and cause of diabetic complications, and other conditions. Available methods of glycation stress reduction include the suppression of hyperglycemia, the suppression of glycation reactions, and the degradation and excretion of glycation reaction products.

Published reports on the suppression of hyperglycemia showed that choosing foods with a focus on carbohydrate counting is suitable for dietary therapy for diabetes mellitus [3], foods with a low glycemic index (GI) are unlikely to elevate blood glucose levels [4], and postprandial hyperglycemia can be suppressed by eating vegetables first [5,6]. Meanwhile, many functional foods containing indigestible dextrin are commercially available as food items for people who are likely to have elevated blood glucose levels. However, the stresses of being subjected to extreme limitations on carbohydrate intake other than dietary fiber, the lack of freedom of choosing favorite staple foods, and the obligation to take all vegetables in advance of other foods reduce the pleasure of meals.

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We previously assessed the effects of eating grapefruit on postprandial blood glucose levels, showing that taking fruits containing dietary fiber in advance suppresses blood glucose level elevations which occur after taking a staple food [7]. In the present study, we assessed the effects of choice of staple food and the addition of dietary fiber to staple foods on changes in postprandial blood glucose levels, with the aim to develop a method of reducing glycation stress from the viewpoint of suppression of hyperglycemia.

Methods

Subjects

Subjects were recruited from among those with relevance to the Department of Anti-Aging Medicine, Doshisha University Faculty of Life and Medical Sciences. The subject inclusion criteria comprised healthy persons aged 20 years or older who did not meet any of the following exclusion criteria: those with food or drug allergy, pregnant or lactating women, patients under treatment with medication or follow-up, patients with the diagnosis of diabetes mellitus, patients with a pronounced cardiopulmonary functional disorder, patients on therapeutic medication for hypertension, persons with a past history of gastrointestinal surgery, and persons suspected of having infectious disease. Other subjects judged by the investigator as being inappropriate for inclusion in the study were also excluded from the study.

The study population comprised 19 subjects with relevance to the Department of Anti-Aging Medicine, Doshisha University Faculty of Life and Medical Sciences (9 males and 10 females, age 30.3 ± 12.0 years, BMI 20.8 ± 2.5). These subjects provided written consent to participate in the study after being given a full explanation of the study.

Protocol for blood glucose test

A blood glucose test was performed according to the unified protocol established by the Japanese Association for the Study of Glycemic Index (JASGI) [8] as shown blow. A glycemic index (GI) evaluation sheet was internationally standardized by Jenkins *et al.* [4]. In Japan, Sugiyama *et al.* conducted a pioneering study based on this method [9]. At the first meeting of the JASGI held in July 2002, it was agreed that the method of Sugiyama *et al.* should be adopted as the unified protocol, and it was recommended that all experiments involved in JASGI joint research on GI should comply with this protocol. The unified research procedures for GI studies are shown below.

1. Subjects

Each group shall consist of 10 subjects at 20-50 years of age, with a BMI ≤ 30, who have not exhibited abnormal glucose tolerance in the past 1 year. Each subject shall not be on any drugs such as antihypertensive agents. Informed consent shall be obtained in advance in accordance with the Declaration of Helsinki. The test shall not take place until 1 day after the test of the previous day. The study shall not be implemented on female subjects during menstruation.

2. Day before the test

Excessive exercise, taking meals after 8:00 p.m, surfeit, overdrinking, and staying up late at night shall be prohibited. If the subject feels ill on the day before the test, or prior to or during the test, the test shall be postponed or terminated.

3. Day of the test

- Breakfast shall be prohibited.
- The test shall be performed (started) at 7:00-9:00 a.m.
- Prior to taking the test food, the blood sampling finger shall be disinfected with alcohol and dried thoroughly. Thereafter, fasting blood glucose shall be measured (1st time) (any finger acceptable).
- Measurement is possible when the fasting blood glucose level is between 70 mg/dL and 110 mg/dL. The reference diet and test food shall be taken over a period of 5-10 minutes, with about 30 chews per mouthful required.
- During measurement, refrain from smoking and activities other than light standing work, sitting work, and the like.
- Blood glucose shall be measured at 15 (2nd time), 30 (3rd time), 45 (4th time), 60 (5th time), 90 (6th time), and 120 minutes (7th time) after the start of taking each test food.

4. Reference diet

Packed steamed rice (Sato No Gohan [Sato Foods Co., Ltd., Niigata, Japan], 100% consisting of Koshihikari, produced in Niigata Prefecture, 147 g) shall be twice tested. If the difference in area under the curve of blood glucose elevation is 25% or less, the two measurements shall be averaged to obtain the reference value. If the difference exceeds 25%, the same test shall be performed 3 more times, and the measurements with a difference of 25% or less shall be averaged to obtain the reference value. Up to about 150 mL of water or hot water will be allowed to be taken along with the test food. The subject shall fast between test food ingestion and the end of the test.

5. Test foods

With a 50 g unified content of carbohydrates (excluding dietary fiber), test foods are chosen from among staple foods: 1) single-ingredient foods, such as spaghetti, buckwheat noodles, udon, rice cakes, rice porridge, and bread, 2) mixed-ingredient foods, such as rice cooked with peas, sekihan, rice cooked with various ingredients, curry and rice, sushi rice, chicken pilaf covered with an omelet, fried rice, bowl of rice topped with fried cutlets, bowl of rice topped with tempura, bowl of rice topped with cooked beef, and cereal + cow's milk. Other test foods with high contents of carbohydrates other than dietary fiber will be allowed to be chosen from among fruits, confectionery, luxury foods, canned foods, and other foods by each study group.

6. Test equipment

Each subject will collect his or her own blood using a simple blood collecting device, and measure glucose levels using a glucose meter for self monitoring (*e.g.*, Glutest Ace, Sanwa Kagaku Kenkyusho Co., Ltd.). In the present study, a different glucose meter for self monitoring (GLUCOCARD MyDia, ARKRAY, Inc., Kyoto) was used instead.

Test foods

The present study comprised two tests: a staple food comparative test and a dietary fiber addition test. Respective test foods are shown below (***Table 1***). Nutrient contents in some of these foods were calculated using the Standard Tables of Food Composition in Japan 2010 [10].

- Staple food comparative test: 9 items (carbohydrates other than dietary fiber: 75 ± 10 g).

Steamed rice, handmade udon/wheat noodles served hot in broth, commercially available udon, bread, sekihan (rice + red beans), buckwheat noodles, pasta, brown rice, rice cakes.

• Dietary fiber addition test: 2 items

Udon (supplemented with dietary fiber) (carbohydrates other than dietary fiber: 74.3 g). Indigestible dextrin was added as the dietary fiber.

Of the foods used in the experiments, handmade udon and udon supplemented with dietary fiber were supplied by Hanamaru, Inc. (Chuo-ku, Tokyo, Japan).

The amount of carbohydrates other than dietary fiber in each test food was set at 75 ± 10 g in order to correspond to the 75 g amount of carbohydrates other than dietary fiber for the 75 g oral glucose tolerance test (OGTT) in common use for diagnosing diabetes mellitus.

Statistical analyses

The 0-minute value was subtracted from the blood glucose level measured over time after eating each test food to obtain Δ blood glucose level; the largest change in the level observed up to 120 minutes after the start of ingestion was considered as the maximum blood glucose level change. Using these parameters, the area under the blood glucose elevation curve (AUC) was calculated. Data obtained were statistically analyzed by the Mann-Whitney U-test for significant differences between 2 groups and Tukey's multiple comparison test among 3 groups or more, using the SPSS statistical analysis software. A two-sided p-value of less than 5% was considered to indicate a significant difference.

Ethical Considerations

The present study was conducted in compliance with the ethical principles of the Declaration of Helsinki (Note of Clarification added at the 2004 World Medical Association General Assembly in Tokyo) and Japan's Act on the Protection of Personal Information, and with reference to the Ministerial Ordinance on Good Clinical Practice (GCP) for Drug (Ordinance of Ministry of Health and Welfare No. 28 of March 27, 1997) and the Ethical Guidelines for Epidemiological Research established by Japan's Ministry of Health, Labour and Welfare, and Ministry of Education, Culture, Sports, Science and Technology. The present study was conducted after examination and approval for the ethics and appropriateness of the study at a meeting of the Doshisha University Ethics Committee for Scientific Research Involving Human Subjects (Application Number: 1228).

Table 1. Staple food consumption and nutrients in test food items

Food items	Staple food Consumption	Energy (kcal)	Protein (g)	Lipids (g)	Carbohydrates (g)	Dietary fiber (g)	Amount of carbohydrates other than dietary fiber (g)
Steamed rice 200 g + furikake (seasoned dried condiments for sprinkling over rice)	200	347	5.6	1.2	75.2	0.6	74.6
Handmade udon (wheat noodles) + soup stock	270	346	8.6	1.1	75.9	2.3	73.6
Commercially available udon + soup stock	330	364	10.2	1.6	74	2.7	71.3
Bread (sandwich loaf)	170	449	15.8	7.5	79.4	3.9	75.5
Sekihan (rice + red beans)	180	340	7.0	0.7	76.3	3.1	73.2
Buckwheat noodles + soup stock	100	371	11.3	2.1	77.4	3.8	73.6
Pasta + Japanese mushrooms	95	401	15.1	2.3-3.0	75.8	2.6	73.2
Brown rice + furikake	210	358	6.5	2.7	75.8	2.9	72.9
Rice cakes + clear soup	140	330	5.7	0.8	74.5	1.1	73.4
Udon supplemented with dietary fiber + soup stock	250	349	7.1	1.5	77.1	2.6	74.5
Steamed rice 200 g + furikake + wakame (seaweed) soup supplemented with dietary fiber	200	347	5.6	1.2	76.16	1.3	74.86

Numerical figures for food items shown in black were calculated using the Standard Tables of Food Composition in Japan 2010 [10].
An indigestible dextrin is blended as dietary fiber.
Numerical figures for food items shown in red were calculated using the nutritional facts indicated on respective labels.

Results

Staple food comparative test

To determine the influence of the choice of staple food (carbohydrates) on postprandial blood glucose level, subjects ate 9 staple food items (steamed rice, handmade udon, commercially available udon, bread, sekihan, buckwheat noodles, pasta, brown rice, rice cakes), and had their blood glucose levels measured.

For all 19 subjects, AUC tended to be lower for pasta than for steamed rice ($p = 0.050$). Three subjects exhibited a slight blood glucose elevation of AUC < 5,000, making a direct comparison difficult; therefore, subclass analysis was performed on 16 subjects in the **group susceptible to blood glucose elevation** of AUC ≥ 5,000. Blood glucose changes and AUC in this group are shown in ***Fig. 1 and 2***, respectively. The maximum blood glucose level change was lower for pasta than for brown rice ($p = 0.049$), and tended to be lower for bread ($p = 0.060$) and pasta ($p = 0.060$) than for steamed rice, and tended to be lower for bread ($p = 0.050$) than for brown rice. The AUC was lower for bread and pasta than for steamed rice, and lower for pasta than for sekihan, and tended to be lower for pasta than for rice cakes.

In the **group susceptible to blood glucose elevation**, blood glucose level changes following ingestion of each of rice-derived staple foods (steamed rice, sekihan, brown rice, rice cakes) and wheat-derived staple foods (handmade udon, commercially available udon, bread, pasta) were compared. Changes in blood glucose level and AUC are shown in ***Fig. 3 and 4***, respectively. Both the maximum blood glucose level change ($p = 0.029$) and AUC ($p = 0.029$) were lower for wheat-derived staple food than for rice-derived staple food.

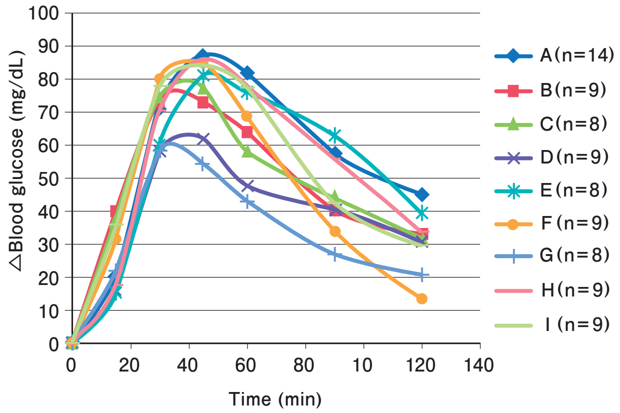

Fig.1. **Blood glucose level changes in subjects who were likely to have elevated blood glucose levels after taking each of 9 staple food items.**

A: steamed rice 200 g, B: handmade udon, C: commercially available udon, D: bread, E: sekihan, F: buckwheat noodles, G: pasta, H: brown rice, I: rice cakes.

For changes in maximum blood glucose level: $p < 0.05$; brown rice vs. pasta, $p < 0.1$; steamed rice vs. bread, steamed rice vs. pasta, brown rice vs. bread; Tukey's multiple comparison test. For changes in maximum blood glucose level: $p < 0.05$; brown rice vs. pasta, $p < 0.1$; steamed rice vs. bread, steamed rice vs. pasta, brown rice vs. bread; Tukey's multiple comparison test.

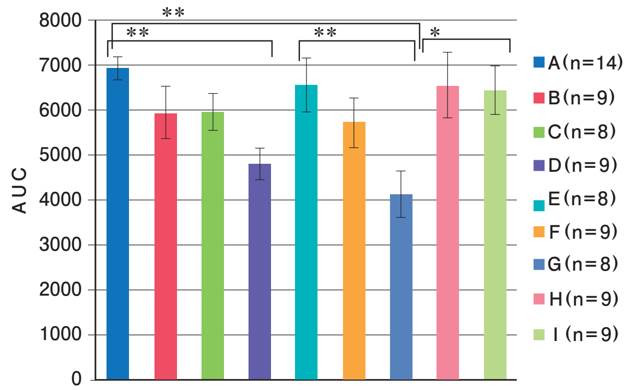

Fig.2. **AUC values from subjects who were likely to have elevated blood glucose levels after taking each of 9 staple food items.**

A: steamed rice 200 g, B: handmade udon, C: commercially available udon, D: bread, E: sekihan, F: buckwheat noodles, G: pasta, H: brown rice, I: rice cakes.

For changes in maximum blood glucose level: $p < 0.05$; brown rice vs. pasta, $p < 0.1$; steamed rice vs. bread, steamed rice vs. pasta, brown rice vs. bread; Tukey's multiple comparison test. $P < 0.05$**, $p < 0.1$*, Tukey's multiple comparison test. Bar indicates standard error mean.

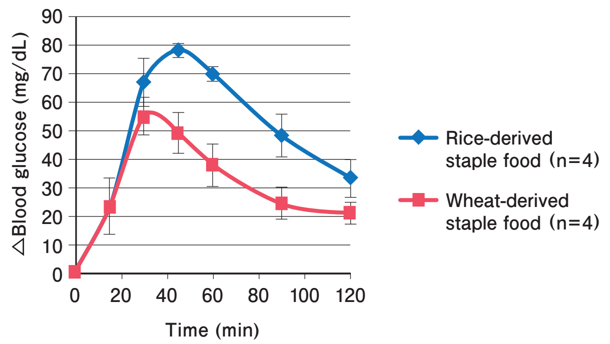

Fig.3. **Blood glucose level changes after ingestion of rice-derived staple food (blue circle) and ingestion of wheat-derived staple food (red square).**

For maximum blood glucose levels: $p < 0.05$; rice-derived staple food vs. wheat-derived staple food; Mann-Whitney U-test. Bar indicates standard error mean.

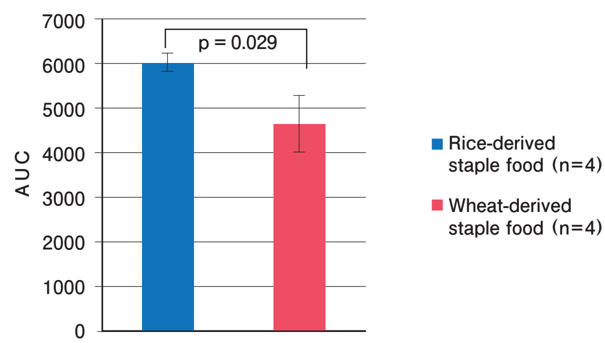

Fig.4. **AUC after ingestion of rice-derived staple food (blue) and ingestion of wheat-derived staple food (red).**

Mann-Whitney U-test. Bar indicates standard error mean.

Dietary fiber addition test

To determine the influence of indigestible dextrin on postprandial blood glucose levels, blood glucose levels were measured after ingesting indigestible dextrin-blended handmade udon (udon supplemented with dietary fiber) alone and both an indigestible dextrin-blended soup and steamed rice.

In the entire study population, no significant difference was found in the maximum blood glucose level change or AUC between handmade udon and udon supplemented with dietary fiber. In the **group susceptible to blood glucose elevation**, the maximum blood glucose level change was lower by 12 mg/dL for udon supplemented with dietary fiber than for handmade udon ($p = 0.049$), with no difference found in AUC (***Fig. 5 and 6***).

In both the entire study population and the **group susceptible to blood glucose elevation**, no significant difference was found in maximum blood glucose level change or AUC between ingestion of steamed rice alone and ingestion of both an indigestible dextrin-blended soup and steamed rice (***Fig.7 and 8***).

Discussion

Staple food comparative test

In the **group susceptible to blood glucose elevation**, the maximum blood glucose level change tended to be lower, and AUC was lower, for bread and pasta than for steamed rice. This was attributed to the difference in nutrients contained therein.

Wheat flour is available in three types classified by source: strong flour from hard wheat grains, general-purpose flour from intermediate wheat grains, and weak flour from soft

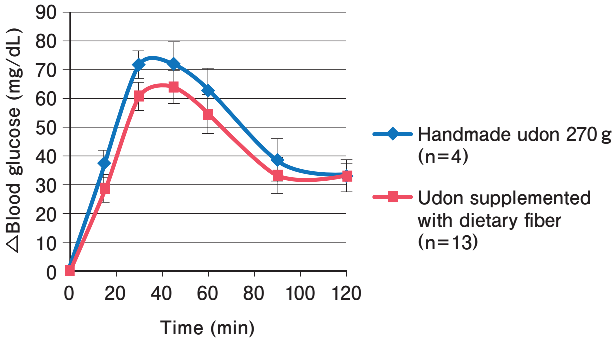

Fig.5. **Blood glucose level changes in subjects who were likely to have elevated blood glucose levels after taking each of handmade udon (wheat noodles; blue) and udon supplemented with dietary fiber (red).**
For changes in maximum blood glucose level: $p < 0.05$; handmade udon vs. udon supplemented with dietary fiber, Mann-Whitney U-test. Bar indicates standard error mean.

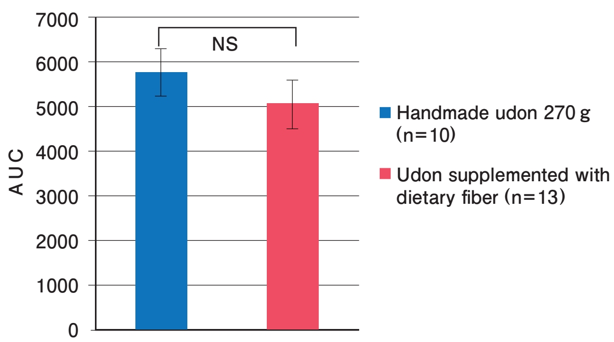

Fig.6. **AUC values in subjects who were likely to have elevated blood glucose levels after taking each of handmade udon (blue) and udon supplemented with dietary fiber (red).**
NS; not significant. Bar indicates standard error mean.

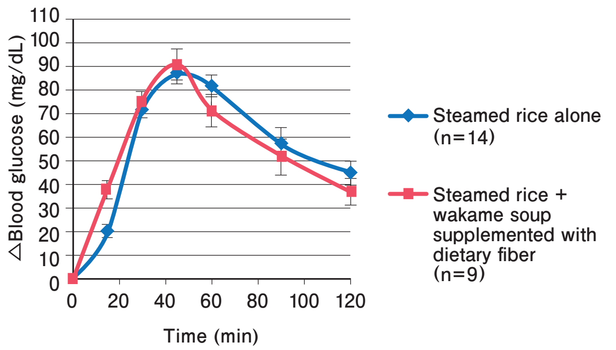

Fig.7. **Blood glucose level changes in subjects who were likely to have elevated blood glucose levels after taking each of steamed rice alone (blue) and steamed rice + wakame (seaweed) soup supplemented with dietary fiber (red).**
An indigestible dextrin is blended as dietary fiber. Regarding the changes in maximum blood glucose level change, no significant difference was found. Bar indicates standard error mean.

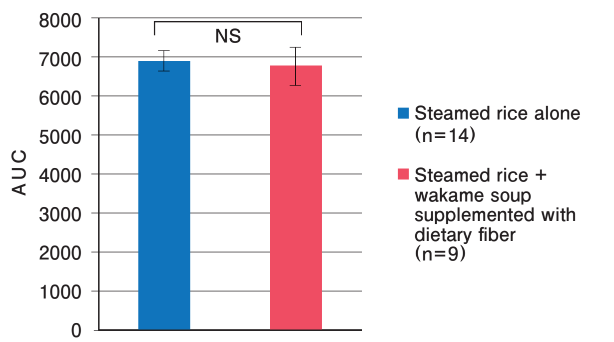

Fig.8. **AUC values in subjects who were likely to have elevated blood glucose levels after taking steamed rice alone (blue) and steamed rice + wakame (seaweed) soup supplemented with dietary fiber (red).**
An indigestible dextrin is blended as dietary fiber. NS; not significant. Bar indicates standard error mean.

wheat grains [11]. These flour types differ in protein content, with higher protein contents in descending order of strong flour, general-purpose flour, and weak flour. Because bread and pasta are produced from strong flour, which has a high protein content, their protein content is nearly 10 g higher than that of steamed rice. Udon is produced from general-purpose flour; its protein content differs from that of steamed rice by approximately 3 g. Because protein acts on cells to secrete glucose-dependent insulinotropic polypeptide (GIP), a promoter of insulin secretion, to promote insulin secretion [12], postprandial hyperglycemia is suppressed when taking carbohydrates other than dietary fiber and protein at one time. Furthermore, bread is supplemented with lipids such as butter and margarine during its production. The lipid content in the bread item used in this experiment was higher by approximately 6 g than that in the steamed rice. Lipids influence gastric smooth muscle movement *via* gastrointestinal tract hormone and the vagus nerve to reduce the gastric emptying rate [13], thus slowing the blood glucose elevation after meals. In the present experiment, the tendency toward smaller maximum blood glucose level changes and lower AUC values in pasta and bread than for steamed rice were attributed to the effects of the proteins in the pasta and bread and the lipids in the bread.

In addition to the protein content, the lower AUC values for wheat-derived staple food compared to rice-derived staple food are attributable to the influence of wheat albumin. Wheat albumin, a water-soluble protein extract from wheat, is composed of multiple proteins [14]. Wheat albumin reportedly possess inhibitory activity against mammalian amylase to delay the digestion of carbohydrates other than dietary fiber *in vivo* [15,16].

Dietary fiber addition test

Indigestible dextrin is known to mitigate blood glucose elevations after meals. A suggested mechanism action is as follows: Indigestible dextrin suppresses the glucose transport related to chorionic disaccharidases such as sucrase-isomaltase complex (disaccharidase-related transport: DRT), thus reducing the absorption of the glucose resulting from membranous digestion of disaccharides from small intestinal mucoepithelial cells [17,18]. Indigestible dextrin has also been suggested to be involved in incretin, a hormone that is secreted from the gastrointestinal tract, and promotes insulin secretion [19-21].

Some studies have found reductions in postprandial blood glucose level with a load of indigestible dextrin [22-24], and other studies found no difference in postprandial blood glucose level between indigestible dextrin load and non-load [25-28]. The udon supplemented with dietary fiber used in that experiment contained 1.0-1.5 g of indigestible dextrin added. In the present study, the above-described effect of indigestible dextrin was obtained when 1.0-1.5 g of indigestible dextrin was added, and this fact is thought to explain the smaller changes in maximum blood glucose level than for handmade udon not supplemented with indigestible dextrin.

A study which compared ingestion of both a miso (bean paste) soup containing 4.4 g of indigestible dextrin as a dietary fiber and 300 g of steamed rice and ingestion of 300 g of steamed rice alone, showed that no significant difference existed between the two groups in the entire study population, and that blood glucose level elevation was suppressed 30 minutes after ingestion in the **group susceptible to blood glucose elevation** [29]. In the present study however, no significant difference was found even in the **group susceptible to blood glucose elevation** when eating an indigestible dextrin-blended soup along with steamed rice. This is attributable to the low indigestible dextrin content in the indigestible dextrin-blended soup. The above-described miso soup contained 4.4 g of dietary fiber, whereas the soup blended with indigestible dextrin used in the present study contained 0.7 g of dietary fiber. This is thought to be the reason that no evidence of effectiveness of indigestible dextrin was obtained in the present study. A blood glucose level elevation suppressing effect might be observed if the amount of indigestible dextrin contained in the blended soup was increased. However, the present study was unavoidably subject to limitations in the evaluation of indigestible dextrin because of the use of commercial food products.

GI value of staple foods and glycation stress

Because GI values are calculated from AUC, foods that produce a sharp elevation and reduction of blood glucose level have low GI values because of their low AUC. The AUC was lower for buckwheat noodles, whereas the maximum blood glucose level change was lower for udon. Because glycation is more likely to proceed at blood glucose levels of 160 mg/dL or more, it is also important to suppress the maximum blood glucose level change in order to suppress glycation stress. For this reason, to suppress glycation stress, it is necessary to choose food items taking into account not only GI value, but also the maximum blood glucose level change.

Conclusion

In the **group susceptible to blood glucose elevation**, a difference was found in both maximum blood glucose level change and AUC depending on the choice of staple food. Hence, it is suggested that postprandial hyperglycemia may be suppressed to lessen glycation stress by taking a staple food and side dishes in combination and by adding dietary fiber to a staple food.

Acknowledgments

A presentation of this study was made at the 13th Scientific Meeting of Japanese Society of Anti-Aging Medicine (Yokohama in June 2013), and it received the Best Poster Award selected by high school students.

Statement of conflict of interest

The authors have no conflicts of interest related to this study to declare.

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