ORIGINAL

Effects of the intake of *Undaria pinnatifida* (Wakame) and its *sporophylls* (Mekabu) on postprandial glucose and insulin metabolism

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Abstract : Long-term suppression of postprandial glucose concentration is an important dietary strategy for the prevention and treatment of type 2 diabetes. Because previous reports have suggested that seaweed may exert anti-diabetic effects in animals, the effects of Wakame or Mekabu intake with 200 g white rice, 50 g boiled soybeans, 60 g potatoes, and 40 g broccoli on postprandial glucose, insulin and free fatty acid levels were investigated in healthy subjects. Plasma glucose levels at 30 min and glucose area under the curve (AUC) at 0-30 min after the Mekabu meal were significantly lower than that after the control meal. Plasma glucose and glucose AUC were not different between the Wakame and control meals. Postprandial serum insulin and its AUC and free fatty acid concentration were not different among the three meals. In addition, fullness, satisfaction, and wellness scores were not different among the three meals. Thus, consumption of 70 g Mekabu with a white rice-based breakfast reduces postprandial glucose concentration. J. Med. Invest. 61 : 291-297, August, 2014

INTRODUCTION

Type 2 diabetes (T2D) is a concerning epidemic and is increasing worldwide (1-4). The increase in the prevalence of T2D has become an important public health problem as it is the leading causes of blindness, renal failure, lower limb amputation, coronary heart disease, and stroke (5). Diet plays a major role in preventing and managing hyperglycemia and T2D (6-8). Epidemiologic studies have demonstrated that the glycemic index (GI) of the diet may

be an important factor in preventing type 2 diabetes (9, 10). Therefore, the quality of carbohydrate ingested may be of extreme importance in determining postprandial blood glucose, because of its influence on gastrointestinal transit time and the rate of nutrient absorption and ultimately the long-term risk of diabetes (11).

Marine algae can be divided into two groups, namely microalgae and macroalgae (seaweed). Seaweeds are rich in vitamins, minerals, dietary fiber, proteins, polysaccharides, and various functional polyphenols. Seaweeds are divided into three main classes : green (chlorophytes), red (rhodophytes), and brown (phaeophytes). Brown seaweeds contain several bioactive compounds such as omega-3 polyunsaturated fatty acids, polyphenols, polysaccharides, fucosterol, and fucoxanthin. Algal polyphenols

have several biological activities, including anti-inflammatory, hepatoprotective, anti-tumor, anti-hypertensive, and HIV-1 reverse transcriptase activities as well as anti-diabetic activity based on the inhibition of α-glucosidase (12). Among them, Undaria pinnatifida (Wakame) and Laminaria japonica (Konbu) are the most popular edible seaweeds in Japan. Undaria pinnatifida, commonly known as Wakame in Japan, is a species of brown seaweed containing valuable bioactive organic compounds including fucoxanthin, a carotenoid, which has numerous functional properties. Mekabu is the sporophylls of Wakame and is more viscous than Wakame itself and is also a traditional food in Japan.

White rice is an indispensable staple food in Japan, although it is a high GI food. Therefore, this study was conducted to determine how Wakame or Mekabu intake along with 200 g white rice, 50 g boiled soybeans, 60 g potatoes, and 40 g broccoli may affect postprandial glucose, insulin, free fatty acids, fullness, satisfaction, and wellness scores in healthy subjects.

MATERIALS AND METHODS

Subjects

Twelve healthy subjects (eight men and four women, aged 25.4 ± 1.3 years) with normal Body Mass Index (BMI) participated in this study. In all subjects, fasting plasma glucose concentrations were lower than 92 mg/dl and serum insulin concentrations were within the normal range for healthy subjects (Table 1). Written informed consent was obtained from each subject before enrollment, and the study was approved by the Ethics Committee of the Faculty of Medicine, Tokushima University, Tokushima, Japan.

Protocol

This randomized, crossover study was conducted on three different days separated by weekly intervals. The day before each test day, each subject consumed a standardized dinner at 20 : 00 h and was asked to standardize their exercise and refrain from consuming alcohol. After an overnight fast, venous blood samples were drawn before (0 min) and after (30, 45, 60, 90, 120, and 180 min) the test meal for the analysis of glucose, insulin, free fatty acid (FFA), triacylglyceride (TG), and others. We outsourced the blood test to the SRL. A visual analogue scale (VAS), 100 mm in length with words

Table 1   Characteristics of the subjects

		n = 12
Age	(years)	25.4 ± 1.3
Male/Female		8/4
BMI	(kg/m²)	22.4 ± 0.8
Fasting plasma glucose	(mg/dl)	90.2 ± 1.2
HbA1c	(%)	4.6 ± 0.1
Fasting serum insulin	(μU/ml)	6.38 ± 0.72
Triacylcerol	(mg/dl)	94.5 ± 12.4
Free fatty acid	(mEq/l)	0.38 ± 0.04
Total cholesterol	(mg/dl)	161 ± 7.5
HDL-cholesterol	(mg/dl)	51.4 ± 2.8
Urea nitrogen	(mg/dl)	9.8 ± 0.5
Creatinine	(mg/dl)	0.73 ± 0.04
AST	(IU/l)	21.2 ± 2.9
ALT	(IU/l)	27.8 ± 8.1

(means ± SEM)

expressing the most positive and negative rating anchored to each end was used to assess the subjects' satiety after the test meals at each timepoint. Subjects did not discuss or compare their rating with each other and could not refer to their previous rating when marking VAS.

Test meal

The test meal was designed to resemble a typical Japanese breakfast (13). The effects of Wakame and Mekabu on postprandial glucose and lipid metabolism were compared between three breakfasts consisting of 200 g white rice, 50 g boiled soybeans, 60 g potatoes, and 40 g broccoli (control meal), with Wakame (Wakame meal) or Mekabu (Mekabu meal) (Table 2). The Wakame and Mekabu meals were nutritionally identical but differed in viscosity. Meals were freshly prepared using a microwave oven with a fixed preparation method and cooking time. The reference food was 200 g of aseptically packaged Satou Rice. This quantity of white rice is the recommended serving for the Japanese population.

Laboratory analysis

Blood samples were centrifuged at 3,500 × g for 10 min and serum and plasma samples were stored at -80°C until use. Plasma glucose concentration was measured with a glucose oxidase-based autoanalyzer. The serum insulin concentration was measured by a standard radioimmunoassay. The serum FFA and TG were both measured using enzymatic

Table 2   Energy and composition of the test meals

		Control meal	Wakame meal	Mekabu meal
White rice	(g)	200	200	200
Boiled soybeans	(g)	50	50	50
Potatoes	(g)	60	60	60
Broccoli	(g)	40	40	40
Sea weed	(g)	-	70	70
Water	(ml)	200	200	200
Energy	(kcal)	455.0	466.0	463.0
Protein	(g)	15.3	16.7	16.0
Fat	(g)	5.6	5.7	6.0
Carbohydrate	(g)	87.5	91.5	90.0
Fiber	(g)	6.6	9.1	9.0

methods. The area under the curve (AUC) for glucose and insulin was calculated and the area below the baseline was excluded from the calculation.

Visual analogue scores (VAS)

Visual analogue scale (VAS), 100 mm in length with words anchored at each end, expressing the most positive and the most negative rating, were used to assess fullness, satisfaction and wellness of the test meals at the same time points. Subjects did not discuss or compare their rating with each other and could not refer to their previous rating when marking the VAS.

Statistical analysis

Data are shown as mean ± SEM. Statistical differences were determined by one-way ANOVA with Fisher's protected least significant difference as a posthoc test to compare the three test meals. Statistical analyses were performed using Stat View 5.0 (SAS Institute, Inc., Cary, NC, USA). The results were considered significant at $p < 0.05$.

RESULTS

Effects of Wakame and Mekabu intake on postprandial glucose, insulin, and FFA levels

Plasma glucose levels increased after each meal, reaching a peak value at 30 min after consumption of the control and the Wakame meal. Plasma glucose levels at 30 min after the Mekabu meal were significantly lower than that after the control meal. No differences were observed between the control meal and Wakame meal (Figure 1(A)). In the early postprandial stage (0-30 min), plasma glucose AUCs for the Mekabu meal were significantly lower than those for the control meal ($p < 0.05$). At 0-60, 0-120, and 0-180 min, plasma glucose AUCs tended to be lower for the Mekabu meal compared with those for the control meal, although this observation was not statistically significant (Figure 1(B)). Serum
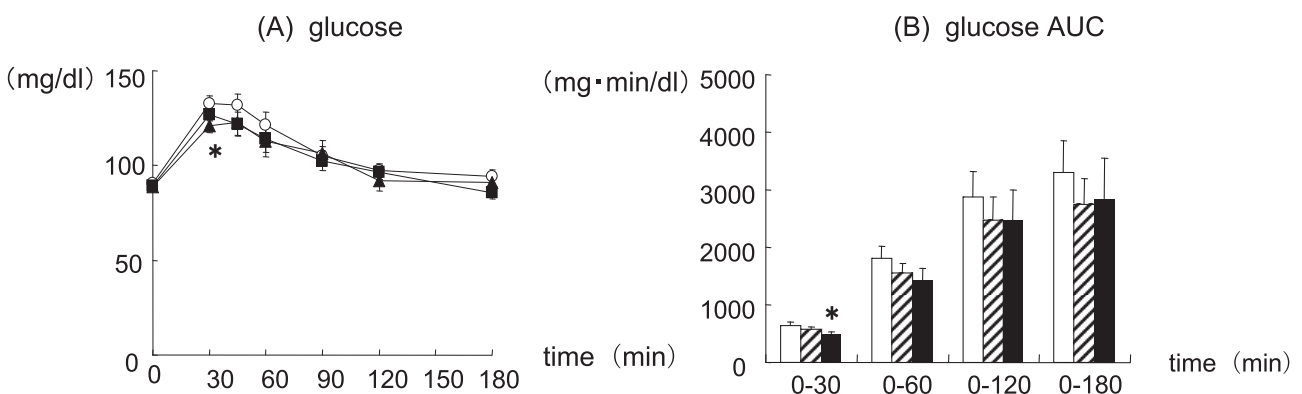

Figure 1   Effects of Wakame and Mekabu intake on postprandial glucose levels (A), AUC for glucose (B)
Values are means ± SEM. (A) ○ : Control meal, ■ : Wakame meal, ▲ : Mekabu meal
(B) ☐ : Control meal, ▨ : Wakame meal, ■ : Mekabu meal   * ; p < 0.05 vs Control

insulin levels increased after each meal, reaching a peak value at 45 min after the control and Wakame meals and at 60 min after the Mekabu meal. Serum insulin levels at 30-120 min and serum insulin AUCs at 0-30, 0-60, 0-120, and 0-180 min were not different among the three meals (Figure 2(A), 2(B)). Serum FFA levels diminished to the same extent after each of the three meals. Serum TG and C-reactive protein concentrations were not affected by any of the meals (Figure 3).

Effects of Wakame and Mekabu intake on postprandial fullness, satisfaction and wellness

Fullness, satisfaction, and wellness scores increased and showed peak levels at 30 min after each meal and gradually decreased until 180 min. The scores at each timepoint were not different among the three meals (Figure 4).
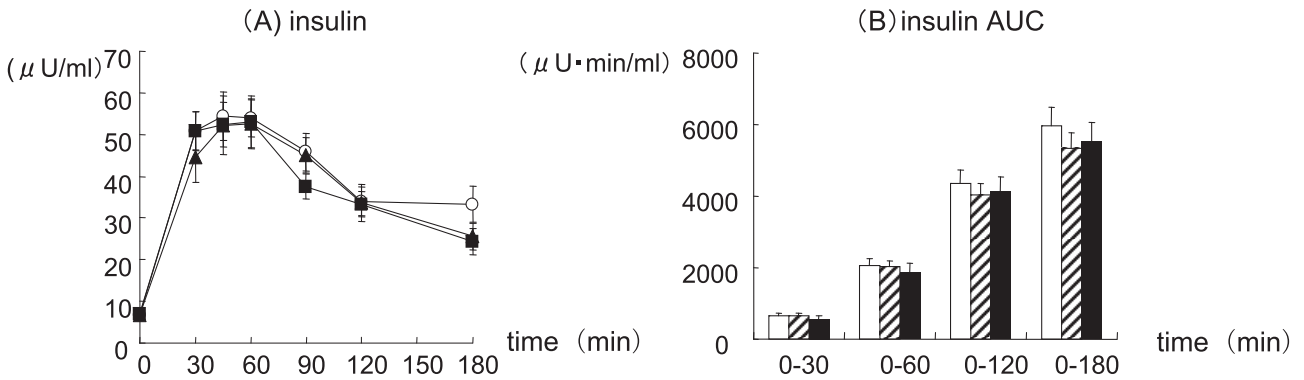

Figure 2   Effects of Wakame and Mekabu intake on postprandial insulin levels (A), AUC for insulin (B)
Values are means±SEM. (A) ○: Control meal, ■: Wakame meal, ▲: Mekabu meal
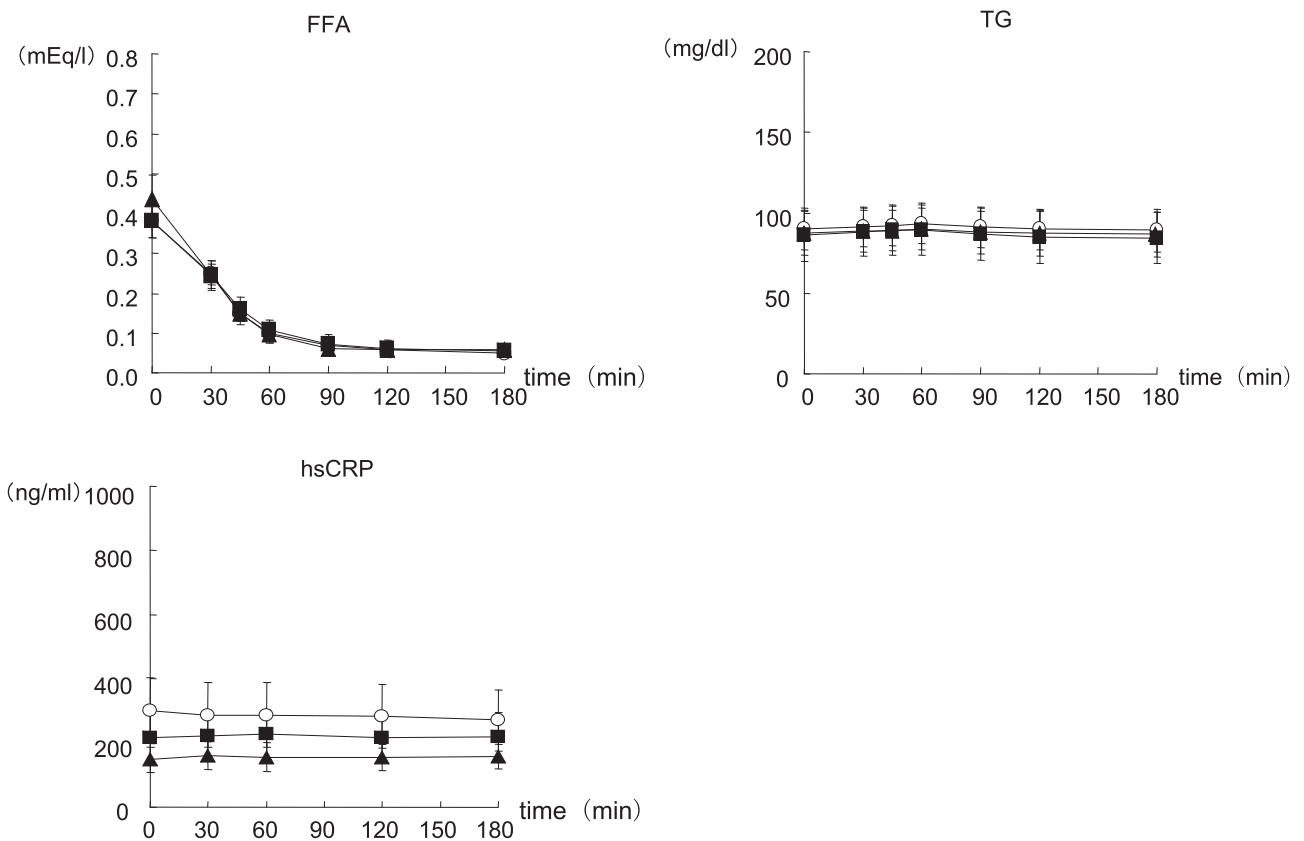(B) □: Control meal, ▨: Wakame meal, ■: Mekabu meal   *; p< 0.05 vs Control

Figure 3   Effects of Control, Wakame and Mekabu intake on postprandial free fatty acid (FFA) levels, triacylglycerol (TG) levels, high-sensitive C-reactive protein (hsCRP)
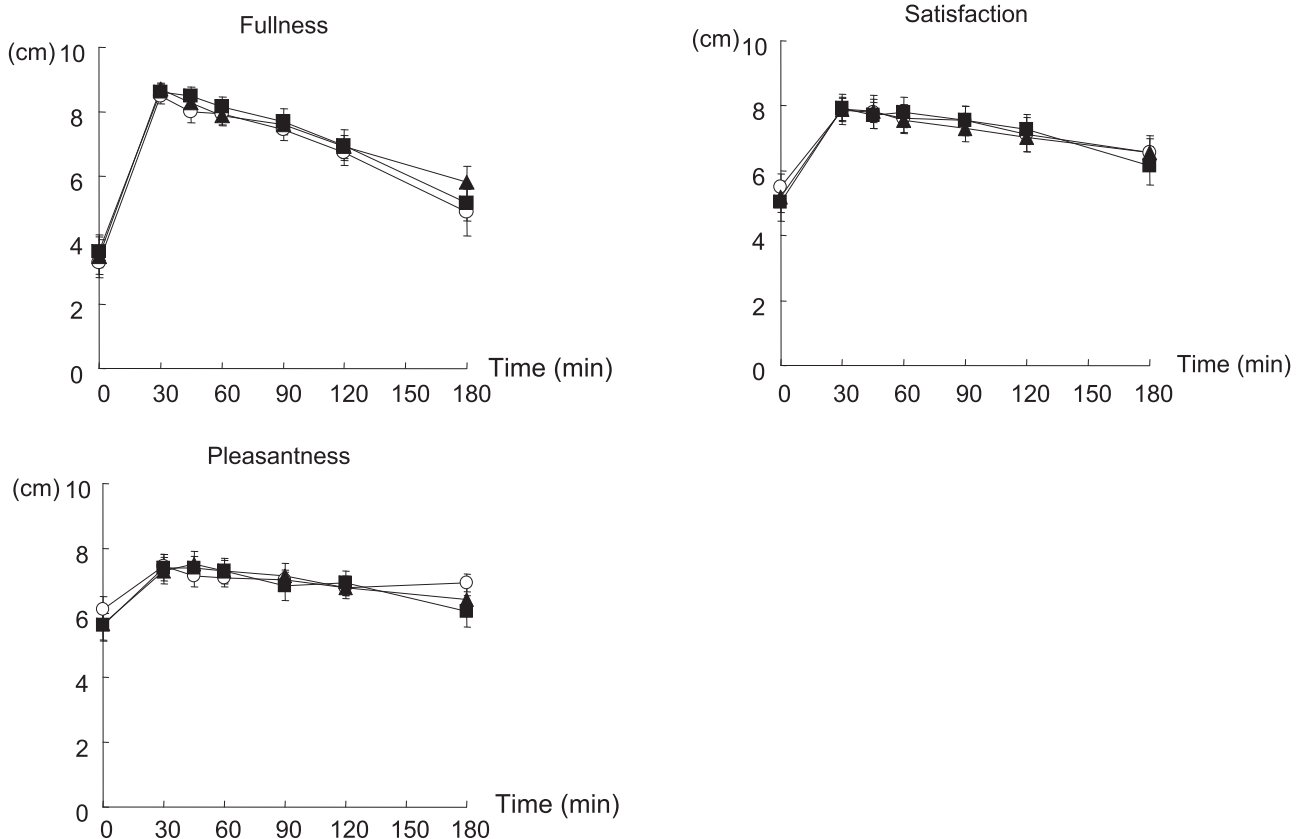Values are means±SEM. ○: Control meal, ■: Wakame meal, ▲: Mekabu meal

Figure 4   Time course of Control, Wakame and Mekabu intake on postprandial Fullness, Satisfaction, Pleasntness
Values are means±SEM. ○ : Control meal, ■ : Wakame meal, ▲ : Mekabu meal

DISCUSSION

The present study demonstrated that intake of 70 g Mekabu combined with 200 g white rice, 50 g boiled soybeans, 60 g potatoes, and 40 g broccoli improved the postprandial blood glucose profile in healthy young subjects. Hence seaweeds are considered to be a rich source of bioactive metabolites.

In Southeast Asian countries, some seaweeds containing fucoxanthin are often used as a food source. Fucoxanthin is a marine carotenoid found in edible brown seaweeds such as Undaria pinnatifida and Hijikia fusiformis. By including 0.2% fucoxanthin in the diet, body weight gain was significantly attenuated compared with control mice, although there was no significant difference in food intake. In addition, blood glucose and plasma insulin concentration were decreased by fucoxanthin supplementation in mice (14). These findings indicate the functionality of fucoxanthin-rich brown algae as an anti-obesity and anti-diabetic functional food (15).

Seaweeds are naturally viscous foods ; Mekabu is more viscous than Wakame. Soluble viscous fibers generally have a greater effect on carbohydrate metabolism in the small intestine by delaying gastric emptying, although a slower rate of absorption may also play a role (16, 17). For example, the prolonged satiety after a viscous meal, as assessed by a VAS, may reflect delayed gastric emptying. Soluble viscous fiber plays an important role in controlling postprandial glycemic and insulin responses and satiety, which are attributable to its effect of slowing gastric emptying and intestinal nutrient absorption (18, 19). Recent results from the prospective EPIC-Netherlands cohort revealed that diets high in GI, glycemic load, and starch and low in fiber were associated with an increased diabetes risk (20). In a meta-analysis of randomized controlled trials, diets with a lower GI were associated with a modest improvement in HbA1c in individuals with diabetes (21).

Lifestyle modification could reduce the risk of diabetes by 30%-67%, and this reduction surprisingly remains even after removing the parameter of lifestyle modification (22, 23). Lifestyle modification can decrease the risk of developing diabetes by approximately 58% in subjects with impaired glucose tolerance. Postprandial hyperglycemia is not only

associated with impaired glucose tolerance but also with hyperlipidemia and oxidative stress, both of which increase the risk of cardiovascular disease (24, 25). Moreover, as higher insulin secretion occurs in the morning, resulting in lower insulin sensitivity in the afternoon (26, 27), continuous Mekabu intake as a part of breakfast may potentiate its effect. In our preliminary study, suppression of postprandial blood glucose concentration was observed after ingestion of 70 g Mekabu or more but not 40 g Mekabu or less. Seaweeds make an important contribution to the daily diet in Japan, and Porphyra spp. (nori) is the most important nutritional seaweed, traditionally used to prepare sushi. Some Japanese may have carbohydrate-active enzymes from marine bacteria in their gut (28).

Therefore, it is concluded from the present study that consumption of 70 g Mekabu or more combined with 200 g white rice, 50 g boiled soybeans, 60 g potatoes, and 40 g broccoli reduces postprandial blood glucose level and favorably alters the risk for noncommunicable diseases including diabetes.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

ACKNOWLEDGMENTS

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