Original Article

Riceberry rice puddings: rice-based low glycemic dysphagia diets

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Background and Objectives: Swallowing difficulty and diabetes mellitus are common in the elderly. However, texture-modified foods suitable for blood sugar control are scarce. This study was aimed to identify texture, glycemic indices (GIs) and postprandial responses of original and high-fiber Riceberry rice puddings. **Methods and Study Design:** International Dysphagia Diet Standard Initiative (IDDSI)'s methods were used to determine texture. *In vitro* digestion was performed for estimating glycemic indices. A randomized cross-over controlled trial was conducted in twelve healthy volunteers. Original pudding, high-fiber pudding and white bread containing 40 g carbohydrate each were assigned in random sequence with twelve-day wash-out intervals. Plasma glucose concentrations were measured at 0, 15, 30, 60, 90, 120, 150, and 180 min after food intake. Individual GIs of puddings were calculated. **Results:** Original and high-fiber puddings were classified as IDDSI level 3 (liquidized) and 4 (pureed), respectively. The *in vitro* estimated GIs were 51 for original and 48 for high-fiber puddings. Clinical trial showed rapid kinetics (peaked at 30 min) but lower postprandial responses of both puddings, compared to white bread (peaked at 60 min). The adjusted GIs for original and high-fiber puddings were not significantly different (at 41±7.60 and 36±6.40, respectively). **Conclusions:** Addition of fiber to the original pudding changed physical properties but not significantly reduced the GI. Original and high-fiber Riceberry rice puddings could be low-GI dysphagia diets, which may be useful for step-wise swallowing practice from IDDSI level 3 to 4 for those who also required blood sugar control.

Key Words: glycemic index, dysphagia, rice, postprandial glucose response, texture-modified diet

INTRODUCTION

In 2017, over 425 million people were diagnosed with Diabetes Mellitus (DM) worldwide. By 2045, the incidence will reach 629 million.[1] High blood sugar is associated with cardiovascular disease, stroke, kidney damage, blindness, and limb ulcers.[2] Monitoring glycemic indices of foods is recommended to control blood sugar.[3] Glycemic index (GI) is postprandial glycemic response after consuming a test food in comparison with that of an equal carbohydrate amount from the standard reference (white bread or glucose solution).[4] GI values of food are classified as low (GI <55), medium (GI 55–69) or high (GI ≥70).[5] Low-GI foods indicated lower or slower rise of plasma glucose after meal.[6,7] Low-GI diets help control fasting plasma glucose, hemoglobin A1C (HbA1C), and reduce diseases' risk.[8,9]

Though various low GI foods were developed, their applications in elderly are limited. Due to teeth loss and swallowing difficulty, many elders cannot consume regular textured food and are at risk of malnutrition.[10,11] Dysphagia (swallowing difficulty) is common in elderly, patients with neurological disorders, and head and neck cancer.[10] Dysphagia diets are classified by International Dysphagia Diet Standardization Initiative (IDDSI).[12] Hyperglycemia is a co-morbidity.[13] Nevertheless, low-GI dysphagia diets are scarce. Since rice is a staple food for Asians, rice-based texture-modified diets are necessary. Riceberry rice is a deep purple variety from Thailand.[14] It is originated from a natural cross between Jai Hom Nin (non-glutinous black rice) and the fragrant Khao Dawk Mali 105 (Thai Jasmine rice).[14] Riceberry rice is gluten-free and rich in minerals and antioxidants; thus, it is mostly eaten as whole grain. Interestingly, an *in vitro* study found slower digestibility and lower estimated glycemic index of Riceberry rice than that of Jasmin rice.[14] Since steamed Riceberry rice is difficult-to-swallow for dysphagic elderly, original and high-fiber Riceberry rice puddings have been developed. Nevertheless, IDDSI

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classifications and glycemic indices of these puddings were unknown. This study was aimed to identify texture and glycemic indices of original and high-fiber Riceberry rice puddings using IDDSI tests, in vitro digestion and a randomized cross-over trial.

METHODS

Materials

Original and the high fiber Riceberry rice puddings were obtained from Vichwai Group, Co. Ltd., Thailand. Sugar (sucrose) was from Mitr phol sugar Corporation, Ltd. (Bangkok, Thailand) and isomaltulose was from DPO International (Bangkok, Thailand). White bread was a product of President Bakery Public Company, Ltd. (Bangkok, Thailand).

Tris-maleate buffer (pH 6.9) was prepared from potassium hydroxide pellets, calcium chloride dihydrate and Tris (hydroxymethyl) aminomethane (Merck KGaA (Darmstadt, Germany) and maleic acid (Sigma-Aldrich (Missouri, US). Hydrochloric Acid-Potassium Chloride (KCl-HCl) buffer (pH1.5) was made from potassium chloride and hydrochloric acid which were products of Merck KGaA (Darmstadt, Germany). Pepsin and α-amylase were purchased from Sigma-Aldrich (Missouri, US). Ethanol was a product of RCI Labscan (Bangkok, Thailand). Glucose oxidase–peroxidase kit (GOPOD) was purchased from Megazyme (Wicklow, Ireland).

Texture classification according to IDDSI

IDDSI standard tests including flow test, fork pressure, fork drip, spoon pressure, spoon tilt, chopstick and finger test were performed three times each using 10 cm syringe (BD^{TM} catalogue no. 301604), 4 mm-spike fork, regular spoon and chopsticks.[12,15]

In vitro digestion

Starch hydrolysis of 100 mg pudding were performed. Hydrolysis index (HI) and estimated glycemic index (eGI) were calculated as described.[16,17]

Briefly, 100 mg pudding was weighed into a 50 mL-screw capped test tube. Ten mL HCl–KCl buffer (pH=1.5) was added, followed by addition of 0.2 mL HCl–KCl buffer (pH=1.5) containing 57.9 µmol pepsin. Each sample was incubated at 40°C for 60 min in a shaking water bath (WNE22 with shaking device: Memmert, Germany). After that, each sample was added with 9 mL of 0.1 M tris–maleate buffer (pH 6.9) and 1 mL of α-amylase. The samples were further incubated at 37 °C in a shaking water bath and they were removed from the water bath after 0, 20, 30, 60, 90 and 120 min of incubation. The α-amylase was inactivated immediately by placing the tubes on ice. All tubes were centrifuged at 3,816 g at 25°C for 10 min. Then, 1 mL supernatant was taken and mixed with 500 µL of 100% ethanol to create sample mixture. Glucose concentration was measured by using glucose oxidase–peroxidase (GOPOD) kit. Three mL of GOPOD was added to a brown bottle together with 100 µL of sample mixture and then incubated in a water bath at 40°C for 20 min. The 250 µL of sample was taken in a 96-well-plate to measure the absorbance with micro plate reader (Synergy HT, Bio-tekInstrumrnts Winooski, Vermont, USA) at 510 nm. Each analysis was performed in triplicates.

Hydrolysis curves were built (disregarding the value at time 0), and the area below the hydrolysis curves was calculated (AHC). The Hydrolysis Index (HI) for each sample was calculated by using the following equation[17]

$$HI = \frac{\text{Glucose AHC}_{(0\text{-}2h)}\text{ (test pudding}}{\text{Glucose AHC}_{(0\text{-}2h)}\text{ (sugar)}} \times 100$$

Estimated GI (eGI) was calculated by the following equation: [17]

$$GI = (0.862 \times HI) + 8.198$$

Clinical trials

This study has been registered in Thai Clinical Trials Registry (TCTR20181231001). The full protocol can be accessed at http://www.clinicaltrials.in.th/index.php?tp=regtrals&menu=trialsearch&smenu=fulltext&task=search&task2=view1&id=4302.

Ethical approval

This study was approved by Central Institutional Review Board of Mahidol University (MU-CIRB) with the COA. No. MU-CIRB 2018/100.0805). The study was conducted according to Declaration of Helsinki and International Conference on Harmonisation-Guideline for Good Clinical Practice (ICH-GCP). Informed consent from each participant was obtained prior to data collection. Their privacy rights were maintained.

Design, blinding and random allocation

This was a randomized cross-over clinical trial. Randomization by minimization method was used to assign participants into three groups evenly to ensure statistically similar mean values of sex, age, body mass index (BMI), and blood biochemical data. Each group received different sequences of original, high-fiber rice puddings, and white bread (Table 1). A researcher performed random allocation. Both original and high-fiber puddings had similar physical properties and packaging. Each pudding was labelled as No.1 or No.2 to conceal the actual identities. All participants, laboratory, and statistical analysers were blinded from the assignments.

Table 1. Order of Interventions in each randomly allocated group

No.	Sequence of interventions		
	1	2	3
Group 1 (n=4)	White Bread	Original pudding	High fiber rice pudding
Group 2 (n=4)	High fiber rice pudding	White Bread	Original pudding
Group 3 (n=4)	Original pudding	High fiber rice pudding	White Bread

ND = not detectable

Sample size

Effect size was calculated from a previous study. [18] The effect size was 0.816 from incremental area under the curve (AUCi) of blood glucose after intakes of white bread (357±29), stew (315±49) and pudding (275±45). Using G-power 3.1.9.2, the required sample size to achieve the power of 0.9 for repeated measures ANOVA of three groups and three measurements with Bonferroni correction (level of significance (αBon) = α /M = 0.05/ 2 = 0.025) at this effect size was 9 participants. A previous report detailing GI method suggested 10 subjects.[4] Finally, to account for 20% drop-out, twelve participants were recruited.

Participants

Inclusion criteria were age between 18-60 years, no family history of diabetes and with fasting plasma glucose (FPG) ≤100 mg/dL,[19] having body mass index (BMI) <30 mg/m^2, no systemic diseases, normal blood biochemical parameters including triglyceride, liver function (AST, ALT), kidney function (BUN, creatinine), and total cholesterol to HDL-C ratio <5 for male and <4.5 for female,[20] no gastrointestinal malfunctions, no hemorrhagic disorders or the use of anti-coagulants. Exclusion criteria were pregnancy or unable to refrain from smoking and drinking throughout the study.

Intervention

The participants ingested 300 g of each pudding (high-fiber and original), and 80 g white bread containing 40 g of available carbohydrate equally as recommended (25-50 g of available carbohydrate).[4] White bread was the reference food.[21] Original pudding was made of Riceberry rice powder, sucrose, purple sweet potato powder, gelling, coloring and flavoring agents. High-fiber pudding contained similar ingredients except sucrose was replaced by isomaltulose, modified starch and Fibersol, and digestion-resistant maltodextrin. White bread was made of wheat flour, sucrose, margarine, egg, yeast, milk powder, and salt. Table 2 showed nutrient contents of puddings and white bread.

Study procedure

The study was conducted at Institute of Nutrition, Mahidol University. The foods were provided to all participants separated by 12 days wash-out periods. After overnight fasting, participants consumed each food within 15 min. Venous blood samples were collected in sodium fluoride tube at 0, 15, 30, 60, 90, 120, 150, and 180 min after the start of meal ingestion. Subjects sat in a relaxed environment and blood pressures were measured every one hour.

Monitoring

Dietary intake and activities were monitored by using food record and International Physical Activity Questionnaire.[22,23] Three-day-food record included two weekdays and one weekend day during the washout periods. Energy and nutrient intakes were analyzed by using the INMUCAL-Nutrient V.3. Habitual physical activity was divided into three categories - high, moderate, and low based on Total MET-minute-week.[22] Rigorous exercise, heavy meals, and late sleeping were avoided before test days. Alcohol drinking, smoking, and the use of dietary supplements affecting blood sugar were refrained throughout the study. Adverse events were monitored throughout the study by using subject diaries.

Outcome

The primary outcomes were postprandial glucose responses and GI values of the original and high-fiber rice puddings. Plasma glucose concentrations were measured by using enzymatic hexokinase method.[24,25] Line plots between glucose concentration and time for each food were created for each participant. Area under the curve incremental (AUCi) were calculated over a 180 min period.[4] AUCi included only the values above fasting concentrations.[26] Individual GIs for each food were calculated as following:

$$GI = \frac{\text{Glucose } AUC_{(0\text{-}3h)} \text{ (test pudding)}}{\text{Glucose } AUC_{(0\text{-}3h)} \text{ (bread)}} \times 100$$

Table 2. Nutrient contents per 100 g of original and high fiber Riceberry rice pudding

	Original pudding	High fiber pudding	White bread
Total energy (kcal)	98.0	109.0	270
Energy from fat (kcal)	31.0	30.0	41.7
Total fat (g)	3.4	3.3	5.2
Saturated fat (g)	0.7	0.6	3.13
Cholesterol (mg)	2.1	1.9	ND
Protein (g)	3.8	3.6	10.4
Total carbohydrate (g)	13.0	16.3	45.8
Dietary fiber (g)	0.8	3.8	4.1
Sugar (g)	8.2	5.4	6.25
Vitamin B-1 (mg)	0.6	0.5	0.19
Vitamin B-2 (mg)	1.1	1.0	0.14
Vitamin B-6 (mg)	0.9	0.7	ND
Vitamin B-12 (µg)	0.7	0.4	ND
Sodium (mg)	24.0	23.0	458.3
Calcium (mg)	85.0	79.0	33.3
Iron (mg)	0.1	0.1	0.63

ND: not detectable.

Glycemic index of white bread was approximately 62–75, compared to 100 for glucose solution.[27,28] Thus, the obtained GI values were further divided by 1.4 as recommended.[27-28]

Statistical analyses

Baseline characteristics were summarized as mean±SD. Statistical tests were selected based on normality of data (tested by using D'Agostino-Pearson Omnibus normality test). Baseline characteristics were compared among groups by using Kruskal-Wallis test. The average plasma glucose levels at each time point were compared among foods by using Repeated measures ANOVA followed by Tukey's tests. Baseline glucose levels and AUCi among test foods were compared by using Friedman test followed by Dunn's test. Dietary intakes and physical activity categories were compared between the washout periods by using Wilcoxon signed rank test and Chi-square test, respectively. All statistical tests were performed by using two-tailed test. Bonferroni correction was applied when multiple comparisons was performed. *P*-value < 0.05 was considered statistically significant. Graph Pad Prism V.7 was used for graphing and statistical analysis

RESULTS

Texture classification according to IDDSI

Original and high-fiber Riceberry rice puddings showed texture properties of IDDSI level 3 (liquidised) and level 4 (pureed), respectively (Figure 1 and Table 3).

In vitro digestion

As shown in Figure 2, AUCi of the original pudding, the high-fiber rice pudding and sucrose were 360.8 ± 8.03, 285.2 ±26.8, and 1744±0.00 respectively. HI of original pudding was 21, while HI of the high-fiber pudding was 16. The estimated GIs of the original and high-fiber rice puddings were 51 and 48, respectively.

Clinical trial

The duration of this study was from August 2018 to December 2018. Consolidated Standards of Reporting Trials (CONSORT) diagram was shown in Figure 3. Nineteen participants were screened but five people were excluded. Finally, twelve participants (three male and nine female) were randomly assigned into three groups evenly. The sample size of 12 participants was adequate as indicated by post-hoc power of 0.99 for repeated measures ANOVA with Bonferroni correction of AUCi data.

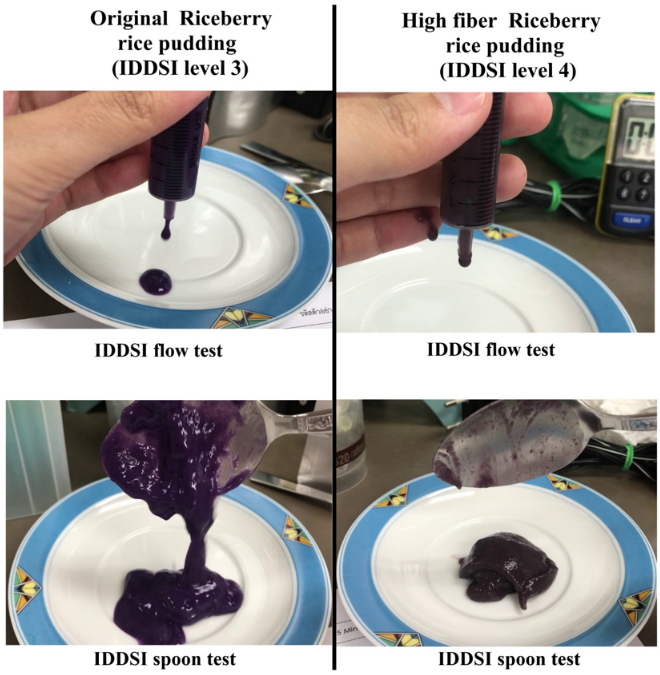
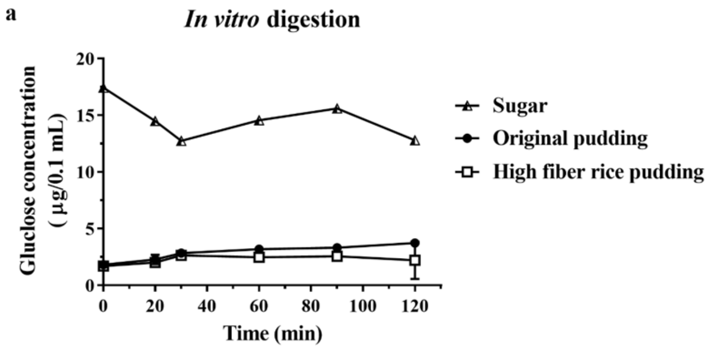


Figure 1. Texture classification according to IDDSI. Flow test showed over 8 mL of original pudding (upper right) and 10 mL of high fiber puddings remained in syringe (upper left). Spoon tilt showed easy pouring and spreading of original pudding (lower left), while full spoon of high fiber pudding plopped off and hold a shape (lower right). Original and high-fiber puddings were level 3 and 4, respectively.

Table 3. Result of IDDSI's tests for texture classification

	Original rice pudding	High-fiber rice pudding
1. IDDS flow test	>8 mL remained in 10 mL syringe after 10 s	10 mL remained in 10 mL syringe after 10 s
2. Fork pressure test	No clear patterns of fork prongs on the surface	Prongs of a fork leave a clear pattern on the surface
3. Fork drip test	Drip slowly in dollops through prongs of a fork	Sample sits in a mound above the fork and did not flow through the prongs
4. Spoon tilt test	Easily poured from spoon and spread out on the plate	Full spoonful plop off the spoon and hold shape on a Plate
5. Chopstick test	Cannot hold it by chopsticks	Cannot hold it by chopsticks
6. Finger test	Cannot be held by finger but slides smoothly between thumbs and finger leaving a coating	Can be held by finger, slides smoothly between thumbs and finger leaving noticeable residue
Summary	Level 3 (liquidized)	Level 4 (puree)



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Samples	Original pudding	High fiber pudding	Sucrose
Glucose AHC (mean ± SD)	360.8 ± 8.03	285.2 ± 26.81	1744 ± 0.00
HI	21	16	
eGI	51	48	

Figure 2. *In vitro* starch hydrolysis of puddings and estimated glycemic index. (a) Line plots showed mean±SD of glucose concentration (Microgram/0.1 mL) at 0, 20, 30, 60, 90, and 120 min after the digestion of the original pudding, the high fiber rice pudding and sucrose as specified, measured by glucose oxidase–peroxidase assay. (b) Table showed means±SD of area under hydrolysis curve (AHC) of each product, hydrolysis indices (HI), and estimated glycemic indices of puddings.

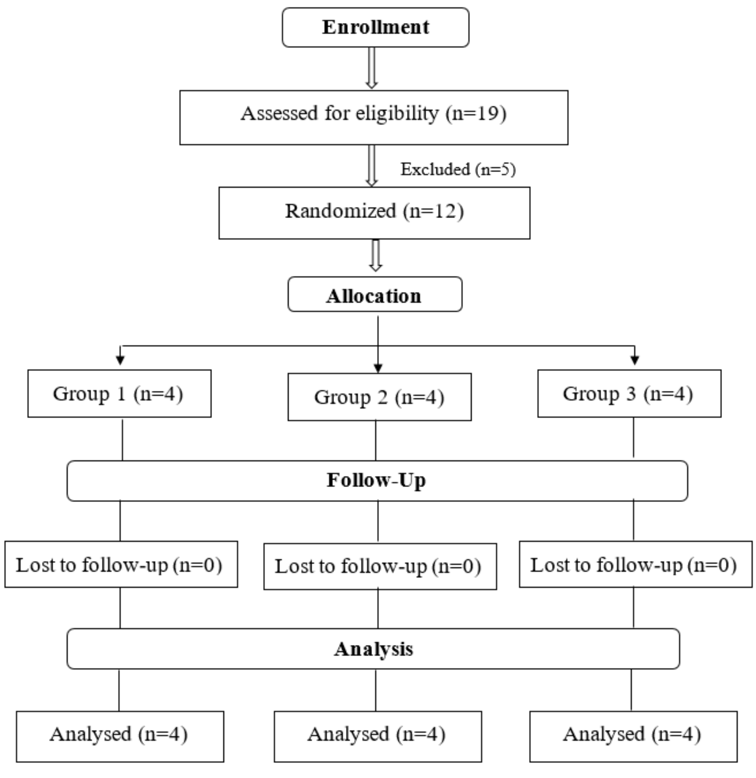

Figure 3. The diagram depicts number of recruited volunteer and actual number of participants included in data analysis.

As shown in Table 4, the participants were 12 adults aged 22-46 years. Mean BMI was 24.2±4.1. kg/m^2. Baseline biochemical data were normal. Table 5 showed no differences in sex, age, BMI, and biochemical data among the randomized groups. Figure 4a showed no differences in baseline glucose among the test days. Plasma glucose concentrations rapidly rose and peaked at 30 min after puddings were consumed, compared to 60 min peak for white bread (Figure 4b). While postprandial glucose concentrations of puddings declined rapidly, those of white bread continuously remained high. The average maximum glucose concentrations (Cmax) of high-fiber, original rice puddings, and white bread were 95.3, 103.6, and 105.4 mg/dL, respectively. Table 6 showed that the average AUCi of glucose for both original pudding (mean±SE: 3412±1367, 95% CI: 402, 6421) and high-fiber pudding (mean±SE: 3401±1424, 95% CI: 267, 6536) were significantly lower than bread (mean±SE: 5351±1415, 95% CI: 2237, 8465). However, there were no significant difference in AUCi between both puddings.

Table 4. Baseline characteristics all participants

Characteristics	N	Mean±SD	Reference range
Demographic data			
Male: Female	3: 9		
Age (years)		32±8.4	
Anthropometry data			
BMI, kg/m^2		24.2±4.1	
Biochemical data			
FPG, mg/dL		80 ±7.1	<100
Triglyceride, mg/dL		88±29	<150
Total cholesterol, mg/dL		199±29.5	<200
HDL-C, mg/dL		57±10.3	>55
Direct LDL, mg/dL		141±26.5	<130
Total cholesterol: HDL-C ratio		4±0.5	
Male		3.7±0.15	<5.0
Female		3.4±0.64	<4.5
BUN, mg/dL		10±2.9	6-20
Creatinine, mg/dL		0.73±0.12	0.51-0.95
Total bilirubin, mg/dL		0.6±0.23	0.2-1.2
AST, U/L		23±11.1	0-32
ALT, U/L		18±8.8	0-33

BMI: Body mass index; FPG: Fasting plasma glucose; HDL-C: High density lipoprotein cholesterol; Direct LDL: Direct low-density lipoprotein cholesterol; BUN: Blood urea nitrogen; AST: Aspartate transaminase; ALT: Alanine transaminase; U/L: unit per litre

Table 5. Comparison of baseline characteristics among randomly allocated groups

Characteristic	Group 1 (n=4)	Group 2 (n=4)	Group 3 (n=4)	*p*-value†
Sociodemographic data				
Male: Female (n)	1:3	1:3	1:3	
Age (years) ‡	32±7.13	32±9.98	31±10.42	0.89
Anthropometry data ‡				
BMI, kg/m^2	24.5±5.26	24.6±3.93	23.3±4.83	0.94
Biochemical data ‡				
FPG, mg/dL	79±7.3	79±9.8	81±6.8	0.95
Triglyceride, mg/dL	87±16.3	100±36.2	77±37.8	0.55
Total cholesterol, mg/dL	205±41.8	213±20.9	180±22.3	0.14
HDL-C, mg/dL	59±10.6	59±16.2	54±5.4	0.94
Direct LDL, mg/dL	146±34.0	154±22.9	124±21.4	0.83
Total cholesterol: HDL-C ratio	3.5±0.39	3.8±0.83	3.4±0.49	0.63
BUN, mg/dL	12±2.6	11±3.8	9±2.1	0.28
Creatinine, mg/dL	0.72±0.08	0.75±0.2	0.71±0.08	>0.99
Total bilirubin, mg/dL	0.5±0.20	0.5±0.13	0.7±0.36	0.53
AST, U/L	23±12.1	20±5.4	26±17.7	0.99
ALT, U/L	15±9.1	18±10.0	20±10.3	0.63

BMI: Body mass index; FPG: Fasting plasma glucose; HDL-C: High density lipoprotein cholesterol; Direct LDL: Direct low-density lipoprotein cholesterol; BUN: Blood urea nitrogen; AST: Aspartate transaminase; ALT: Alanine transaminase; U/L: unit per litre

The average GIs were 41±7.6 for the original and 36 ± 6.4 for high-fiber puddings, which was not significantly different (p>0.05).

Figure 5 showed no differences in energy, carbohydrate, fiber and protein intakes, and physical activity between the washout periods (p>0.05). The findings suggested consistent lifestyle. Throughout the study no adverse events were observed.

DISCUSSION

Dysphagia is found in 15-22% of community dwelling individuals and 40-60% of nursing home residents over the age of 50 years.[29] Although dysphagic people are also at risk of hyperglycemia, low GI texture-modified diets are scarce. Here, we reported that original and high-fiber Riceberry rice puddings had low GI (at 41±7.6 and 36±6.4) and can be classified as IDDSI level 3 and 4 dysphagia diets, respectively. Meanwhile, a previous study reported medium GI of Riceberry rice grain (at 62).[30] Consistently, rice pudding (weaning food for infants) made from white rice have GI of 59±6,[31] while the average GI of white rice grain was 73± 4.31. These findings suggested that texture modified food (e.g. pudding) may have lower GI than regular food. Future parallel studies comparing GIs of food with various textures made from similar rice varieties are required to test such hypothesis.

The key mechanism of low glycemic indices in the rice puddings may be rapid kinetics (both absorption and distribution). Although the sugar content of original pudding (8.2 g) was higher than those of high-fiber one (5.4 g), glucose responses of both puddings were similar with peaked at 30 min. Thus, free sugar unlikely contributed to the swift kinetics. Instead, textural and biochemical properties may better explain. First, food with solid-matrix

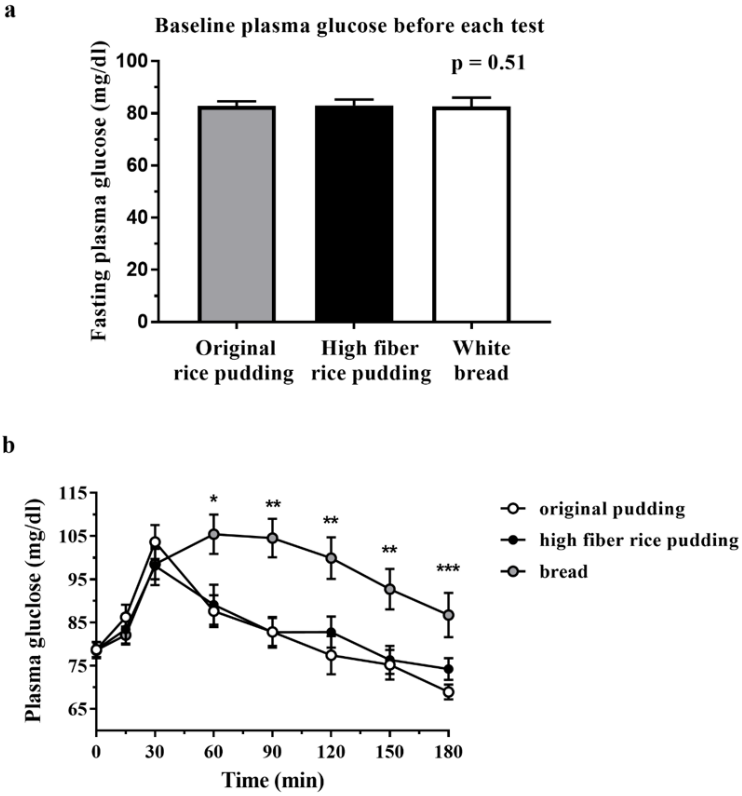

Figure 4. Postprandial glucose response after intake of puddings. (a) Bar graph showed mean±SD of plasma glucose concentration (mg/dL) in all participants (n=10) at baseline before consuming the original pudding, the high fiber rice pudding, and bread as specified (n=10), $p>0.05$, Friedman test. (b) Mean±SE plasma glucose concentration (mg/dL) in all participants (n=10) at baseline, 15, 30, 60, 90, 120, 150, and 180 after consumption of the original pudding, the high fiber rice pudding, and white bread as specified. (*) means $p<0.05$, ** means $p<0.01$, ***means $p<0.001$, Repeated measure ANOVA followed by Tukey's multiple comparison tests).

Table 6. Area under curve incremental (AUCi)† and glycemic index (GI)‡ values of puddings in each individual and the average

Subject No.	AUC Ori	AUC HF	AUC Bread	GI Ori	GI HF
1	2113	680	3645	41	13
2	892.5	769	815	78	67
3	1313	1450	6556	14	16
4	360.7	255	2031	13	9
5	1725	454	1404	88	23
6	3510	4680	5723	44	58
7	1475	1200	4380	24	20
8	1447	345	3038	34	17
9	12195	14693	15563	56	67
10	470	1178	2023	17	42
11	949	2205	4215	16	37
12	14490	12533	14820	70	60
Mean±SE§	3412±1367*	3401±1424**	5351±1415	41±7.64	36±6.43

HF; high-fiber rice pudding.
†AUCi was area under curve of plasma glucose and time; ‡GI was calculated from ratios of AUCi between that of pudding and bread divided by conversion factor of 1.4; §$p=0.45$ for GI comparison, paired t-test.
*$p<0.01$, **$p<0.001$, compared with bread, Friedman test followed by Dunn's multiple comparison test Ori, original rice pudding.

(e.g. bread, cooked rice grain) must undergo continuous comminution and extrusion, absorbing saliva and coalescing into a bolus (semi-solids to glutinous-liquids with rheological properties) prior to swallowing.[32] In contrast, semisolid (e.g. pudding) or liquid food already has rheological properties and does not require much chewing and comminution. It exists as emulsion droplets or dispersed particles which easily flow through the mouth and trigger swallowing.[32] Thus, the oral processing time of puddings are likely to be shorter than that of white bread leading to earlier rise of postprandial glucose. Second, the lower peaks and rapid glucose declines after the peaks in both puddings suggested rapid tissue distribution of glucose. Since whole grain of Riceberry rice (including bran) is the main ingredients (over 30% dry weight) in both puddings, the rice bran might contribute to the rapid glucose uptake in tissues. In fact, bran cereal was shown to have low GI due to rapid glucose uptake.[26] Also, Riceberry bran was shown to reduce blood glucose in diabetic rats through stimulation of insulin.[33] Roles of texture and

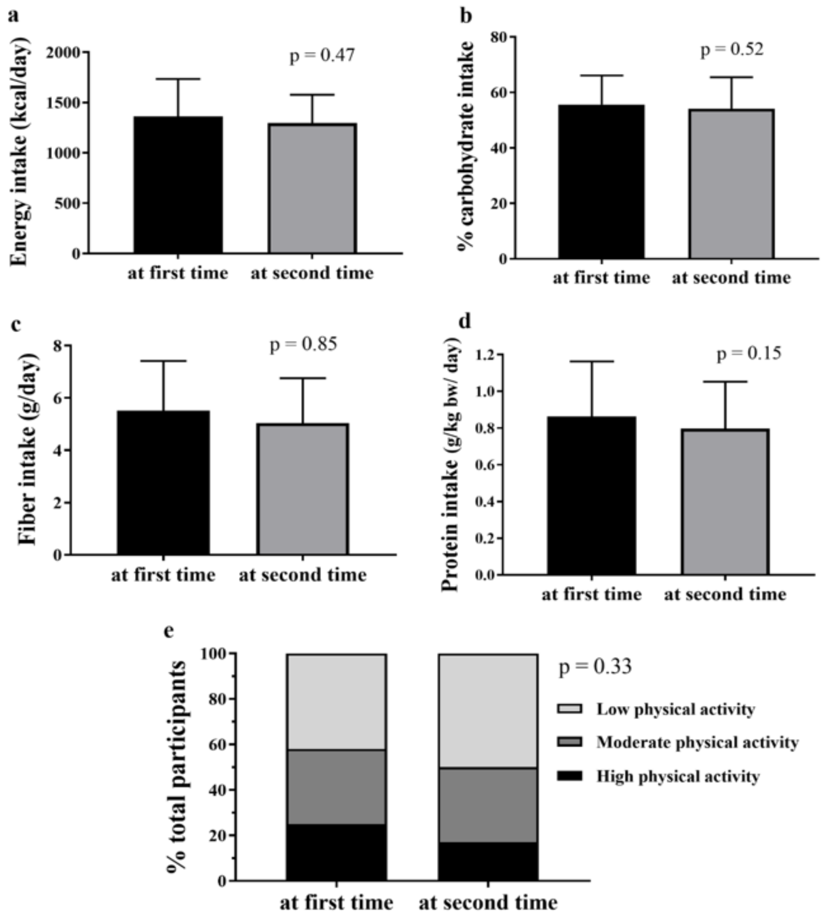

Figure 5. Monitoring of usual dietary intake and physical activity. Bar graph showed comparison of mean ± SD of energy intake (kcal/day) (a), carbohydrate intake (%) (b), fiber intake (g/day) (c), and protein intake (g/kg body weight/ day) (d) between the 1st and 2nd washout periods, $p > 0.05$, Wilcoxon signed rank test. Stacked bar showed comparison of the percentage of participants with low, moderate, and high physical activity habit between the first and the second washout periods (e) $p > 0.05$, chi-square test.

functional compounds in rice products on glycemic index warrants further studies.

The strengths of this research were the randomized crossover design and the matched characteristics of participants which reduced within-subject variability and selection bias. Nevertheless, there were some limitations. First, meals on the night before GI measurement were not standardized as suggested.[34] Nevertheless, baseline glucose levels of all test days were not different and the residual effects of previous meal should be minimal. Second, large variations of glucose response among individuals were observed, consistent with a recent study.[27] Future metabolomics studies are necessary to identify patterns of the responders and non-responders to low GI diet.[35]

Original and high-fiber Riceberry rice puddings could be low-GI dysphagia foods, which may be useful for stepwise swallowing practice from IDDSI level 3 to level 4 for those who also require blood sugar control. Long-term effect of the puddings warrants further studies in prediabetic and diabetic individuals with dysphagia.

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AUTHOR DISCLOSURES

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