Original Article

Yam paste in glycemic preloads curbs peak glycemia of rice meals in apparent healthy subjects

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Background and Objectives: People with dental problems and dysphagia frequently consume foods in paste form. A strategy is required to mitigate the glycemic responses of these foods. **Methods and Study Design:** The effect of yam paste ingestion on postprandial glycemic responses was assessed using a two-arm study design for yam paste ingestion: (1) as low– and medium–glycemic index food and (2) as preload and coingested food in a rice meal. In a randomized crossover trial, 18 healthy volunteers consumed (1) low-intensity-cooked yam paste; (2) medium-intensity-cooked yam paste; (3) cooked white rice; (4) coingested low-intensity-cooked yam paste with rice; (5) coingested medium-intensity-cooked yam paste with rice; (6) a preload of low-intensity-cooked yam paste before rice; (7) a preload of medium-intensity-cooked yam paste before rice. Postprandial glycemic responses and satiety assessments were conducted for each food approach. The glycemic characteristics of yam paste were manipulated with the preparatory treatment. **Results:** Ingesting a preload of 10 g of yam paste before a rice meal resulted in better glycemic responses for 0–60 min in terms of peak glucose value and positive increments under the curve than co-ingesting yam paste with rice, with no adverse effect on satiety, irrespective of the glycemic index of the yam paste. **Conclusions:** Regarding isocarbohydrates, both low- and medium-glycemic index yam paste preloads curbed the glucose peak value of a rice meal and lowered the glycemic index value of mixed meals in young healthy people.

Key Words: yam paste, preload, starch digestion, glycemic response, satiety

INTRODUCTION

Epidemiological and human intervention studies have indicated that postprandial glycemia is an independent risk factor for type 2 diabetes, cardiovascular disease, some cancers, and all-cause mortality.[1,2] People with prediabetes, diabetes, and obesity must manage their diet for postprandial glycemia because altered glucose homeostasis is associated with the pathogenesis of vascular damage through oxidative stress, inflammation, and endothelial dysfunction.[3]

Yam tubers or rhizomes are a source of dietary carbohydrate in Asia, Africa, and America.[4] Chinese yam (*Dioscorea opposita Thunb.*), rich in potassium, yam polysaccharides, allantoin, and polyphenols, can modulate blood glucose, blood pressure, and blood cholesterol.[5] Cooked fresh yam resulted in a glycemic index (GI) of 52 and an insulinemic index of 64 in Chinese,[6] and among Ghanaians, Australian aboriginals, and New Zealanders, the GIs were 66, 34, and 35, respectively,[7] all of which are lower than GIs of polished rice and white bread. In Asia, yam is usually processed into dehydrated slices or powder. Yam paste, which is made by using boiling water and yam powder, is widely consumed by elderly people as an easily digestible food. Such paste foods made of starchy materials are popular in Asian countries[8] as snacks while traveling or working.

However, extruded foods that need little or no mastication are associated with rapid gastric emptying and increased glycemic and insulin responses.[9,10] Yam paste has an extremely high GI of 110.[11] Considering the potential health benefits of yam, it remains a candidate for novel ways in which the powder might be prepared or ingested with better glycemic characteristics.

Studies have shown that partial substitution of refined rice (having a high GI) with starchy foods, such as potatoes[12] or whole grains,[13] elicits comparable or improved postprandial glycemic responses (GRs). Limited studies have suggested that the ingestion of carbohydrate-rich foods, such as rice,[14] potatoes,[12] and even sugar solution,[15] as a preload may have glycemia attenuating effects. However, the GR of yam paste as a preload is unknown.

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This study investigated the effect of yam paste ingestion on postprandial GRs in a trial consisting of two arms: (1) consumption of yam paste as a food with low and medium GI; and (2) ingestion of yam paste as a preload and coingestion food of a rice meal. We hypothesized that the glycemic characteristics of yam paste would be manipulated with changes in the preparation and ingestion processes with no significant changes in the subjective appetite and with retention of its carbohydrate form.

METHODS

Participant recruitment

A total of 18 healthy volunteers aged 20–27 years were recruited through advertisement and moments. Questionnaires were used to assess whether the respondents had the following exclusion criteria: (1) self-reported digestive diseases (frequent gastrointestinal upset or digestive disorders); (2) diagnosis of metabolic diseases (hypertension, diabetes, impaired glucose tolerance, dyslipidemia, and hyperuricemia); (3) BMI beyond the range of 18.5–24.0 kg/m^2; (4) dependency on alcohol, smoking, medication, or drugs; (5) chronic or acute allergy to yam, rice, or wheat; (6) irregular eating or sleeping pattern; (7) eating disorders (bulimia, anorexia nervosa, and binge eating); (8) unstable weight in the past 3 months; and (9) participation in competitive or endurance sports. Each eligible individual signed a written informed consent form.

Ethics and design

The study was approved by the Ethics Committee of China Agricultural University (ethics number CAUHR-2019001) and registered on the Chinese Clinical Trial Registry as ChiCTR1900023901, with procedures in full compliance with the provisions of the revised Helsinki Declaration of 1983.

In vitro starch digestion experiments were conducted to assess the digestive characteristics of yam paste and to determine the ideal microwave heating duration to prepare it. The human trial applied a randomized self-controlled crossover design and consisted of two groups of studies.

Study 1: Aimed to determine the GI of cooked yam samples, which were used in the subsequent study 2. The test meals included (1) glucose solution reference; (2) low-intensity-cooked yam paste (LY); and (3) medium-intensity-cooked yam paste (MY). Each test food contained 25 g of available carbohydrates (ACs) per serving.

Study 2: Aimed to explore the GR of the mixed meals of yam paste and rice. The test meals included (4) glucose solution; (5) cooked white rice; (6) coingestion of LY with rice (LY+R); (7) coingestion of MY with rice (MY+R); (8) preload of LY before rice (PLY+R); and (9) preload of MY before rice (PMY+R). In each mixed meal, the yam paste (MY or LY) contributed to 10 g of AC, and the rice contributed to 40 g of AC. In the preload treatments, the yam paste was ingested 30 min before rice; in coingestion treatments, the yam paste was ingested simultaneously with rice.

The volunteers were assigned to nine test meals in the morning with at least a 1-week interval in a randomized order. In female participants, the test sessions were not conducted during the 3 days before and after their menstruation to avoid possible confounding of satiety assessment. Participants arrived at the laboratory at 7:50 am after an overnight fast of 12 h and were allowed to rest for 10 min before being served with test meals. They were asked to consume the provided yam paste within 5 min and rice meal within 10 min. The participants were instructed to remain seated and to not discuss anything related to food in test sessions. They were asked to report any discomfort or adverse event during the test session.

Blood glucose was determined using finger prick blood and glucometer (LifeScan Inc., Milpitas, CA, USA) before each test meal and at 15, 30, 45, 60, 90, 120, 150, 180, and 240 min after meal ingestion (Figure 1). Additional blood samples were collected at 15 and 30 min following yam ingestion in preload treatments. Subjective appetite was assessed using the visual analogue scale (VAS)[16,17] and visual meal creator (VIMEC),[18] which recorded the number of prospective edible dumplings at the same time point as glucose tests. After each trial, participants were asked to eat dumplings and record the number of dumplings ingested to assess the subsequent food intake.

In vitro starch digestibility

In vitro carbohydrate digestion was assessed using the modified Englyst method.[19] The mixed enzyme solution used was a supernatant mixture of 1.8 mL of diluted invertase, 3 mL of diluted amyloglucosidase, and 27 mL of diluted porcine pancreatic-amylase at 37℃. Diluted enzyme was prepared through centrifugation of the following mixtures for 10 min (3000 r/min): 0.01 g of invertase (200 U/mg, Biotopped) in 4.0 mL of water, 60 µL amyloglucosidase (260 U/mL, Sigma-Aldrich, St. Louis, MO, USA) in 4.74 mL water, and 3.0 g of porcine pancreatic-amylase (150 U/mg, Sigma-Aldrich) in 20 mL water.

A portion of each test meal (same as in the glucose test) was mashed evenly at a speed of 3000 r/min for 15 s in a Midea High-Performance Blender (Midea Group, Guangdong, China) to simulate the chewing process. Four

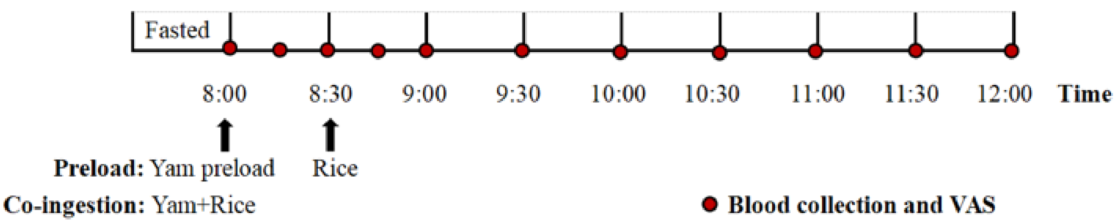

Figure 1. Glycemic response test flow. VAS: visual analogue scale.

grams of mash was mixed with 5 mL of saturated benzoic acid, 5 mL of 0.5 mol/L sodium acetate buffers, and 50 mg of guar gum powder; the pH was modified to 5.2 with 2 mol/L sodium hydroxide. The mixture was immediately incubated in a shaking water bath (37°C, 180 strokes/min) after five small glass balls, and 5 mL of the fresh mixed enzyme solution was added. Then, 95% ethanol was added to stop enzyme activity at 0, 2, 5, 10, 20, 60, and 120 min, respectively. The released glucose was assayed with Synergy HT Microplate reader at a wavelength of 525 nm.

Meal preparation

To prepare the yam paste, 13.76 g of yam powder was dispersed in 100 g of water in a paper cup and then cooked in a microwave oven for 20 s (LY) or 60 s (MY). The preparation procedures were based on sensory tests and the acceptability assessment. The rice and yam paste were cooked just before serving to avoid possible starch retrogradation. The test meal weights were balanced with water.

Yam powder was prepared through dehydration of yam (*Dioscorea opposita Thunb.*) followed by grinding in Henan, China. Polished rice (*Oryza sativa spp. japonica*) used was cultivated in Heilongjiang, China. Table 1 presents the composition of the test meals.

Data processing and statistical analysis

Based on rapidly digestible starch (RDS), slowly digestible starch (SDS) and resistant starch (RS) and hydrolysis index (HI) calculation,[20] *in vitro* carbohydrate digestion results were used to predict the possible GRs. The glycemic response and variability were shown as indicators including the incremental peak (ΔPeak) and low (ΔLow) of glucose concentrations, the positive increments under the curve of GRs (iAUC)[21] and continuous overall net glycemic action (CONGA1) defined as the standard deviation of the glucose differences at every hour throughout the test session.[22]

The results are presented as means (standard errors) unless otherwise stated. A multiple linear regression test was used to confirm the absence of significant effects of confounding factors, such as the time taken for consuming the meal and the hedonic ratings of test meals in all sessions. Data were checked for normal distribution by using Kolmogorov–Smirnov test before the analysis, and the natural logarithmic transformation was used when data were nonnormally distributed. Time-dependent variables (e.g., blood glucose and starch digestibility data) were assessed with a two-way (time × treatment) repeated-measure ANOVA. One-way ANOVA was used to assess the difference between treatments in non–time-dependent variables (e.g., iAUC), and Duncan's multiple range test was used for multiple comparisons with statistical significance set at $p<0.05$. All the statistical analyses were performed using SPSS version 21.0 (SPSS Inc. Chicago, IL, USA).

RESULTS

In vitro starch digestion of yam paste

Considering both sensory acceptance and disparity of starch digestion, 20-s (LY) and 60-s (MY) microwave-cooked yam samples were selected based on several pilot tests. Because the gelatinization temperature of yam starch used in the trial was 85.0°C (determined through the rapid viscosity analyzer test), both the MY and LY samples did not reach full gelatinization status.

The percentage of glucose released from MY was significantly higher than that released from LY at all test time points (Figure 2A), and the hydrolysis index value of MY was higher than that of LY ($p<0.01$) (Figure 2B).

The starch fractions and core temperatures of the yam paste samples are presented in Table 2. The RDS content of MY was higher, whereas the SDS and RS contents were lower, than those of LY due to the extended cooking duration.

Glycemic responses

In total, 18 eligible volunteers (nine men and nine women) completed all test procedures after duplicated oral glucose tolerance test (Figure 3). The baseline characteristics in mean (standard deviation) were as follows: age, 22.6 years; fat mass, 24.7% (6.4%); BMI, 21.7 (1.9) kg/m^2; and basal metabolism rate, 1391.3 (218.3)

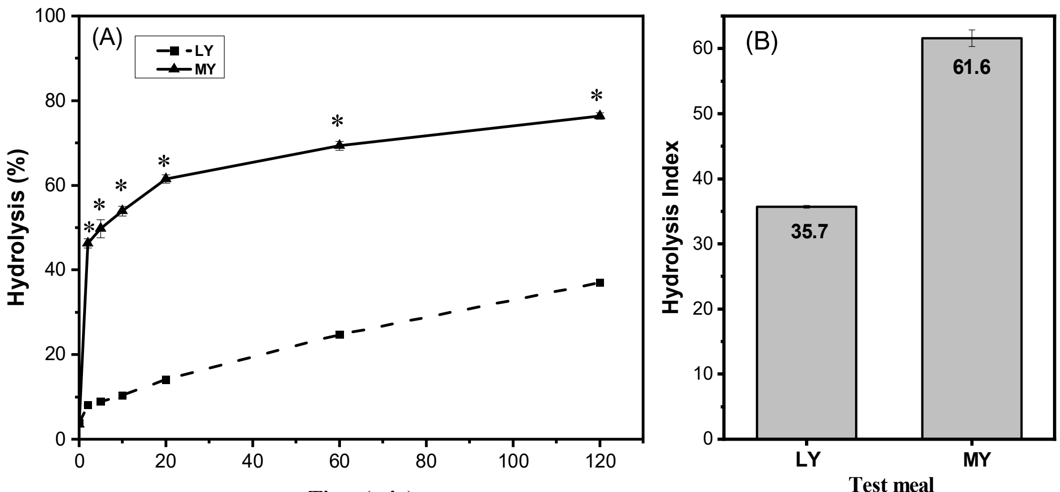

Figure 2. *In vitro* starch digestion of yam pastes with different gelatinization characteristics. LY, low-intensity-cooked yam paste; MY, medium-intensity-cooked yam paste; *LY different from MY ($p<0.05$), vertical bars show the standard errors of six replicates.

Table 1. Nutritional composition of administered test meals (per serving)

Test meals	Rice (g)	Yam (g)	Available CHO (g)	Protein (g)	Fat (g)	Soluble fiber (g)	Insoluble fiber (g)	Weight (g)
G (25 g AC)	-	-	25.0	-	-	-	-	355.56
LY	-	34.4	25.0	3.2	0.3	0.7	0.5	355.56
MY	-	34.4	25.0	3.2	0.3	0.7	0.5	355.56
G (50 g AC)	-	-	50.0	-	-	-	-	
Rice	172.3	-	50.0	6.2	0.5	0.0	0.7	355.56
LY +R	137.8	13.8	50.0	6.3	0.6	0.3	0.8	355.56
MY +R	137.8	13.8	50.0	6.3	0.6	0.3	0.8	355.56
PLY +R	137.8	13.8	50.0	6.3	0.6	0.3	0.8	355.56
PMY +R	137.8	13.8	50.0	6.3	0.6	0.3	0.8	355.56

AC: available carbohydrate; G: glucose; Y: yam; LY: low-intensity-cooked yam paste; MY: medium-intensity-cooked yam paste; PLY: preload LY; PMY: preload MY; R: rice; LY+R: coingestion of LY and rice; MY+R: coingestion of MY and rice; PLY+R: preload LY with rice; PMY+R, preload MY with rice.
The cooked rice weight is shown, and the nutritional composition determinations are based on national standard.

Table 2. Starch fractions and core temperature for yam samples (mean values and standard errors [SE], n=6)

	RDS (g/100 g)		SDS (g/100 g)		RS (g/100 g)		Core temperature (°C)	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
LY	10.1†	0.4	16.6‡	1.2	45.4‡	1.2	46.6†	1.3
MY	44.4‡	1.2	10.7†	1.3	17.0†	0.6	82.5‡	1.4

LY: low-intensity-cooked yam paste; MY: medium-intensity-cooked yam paste; RDS: rapidly digestible starch; SDS: slowly digestible starch; RS: resistant starch.
†‡Significant differences among test meals are represented by different symbols ($p<0.05$).
Vertical bars show the standard errors of six replicates.

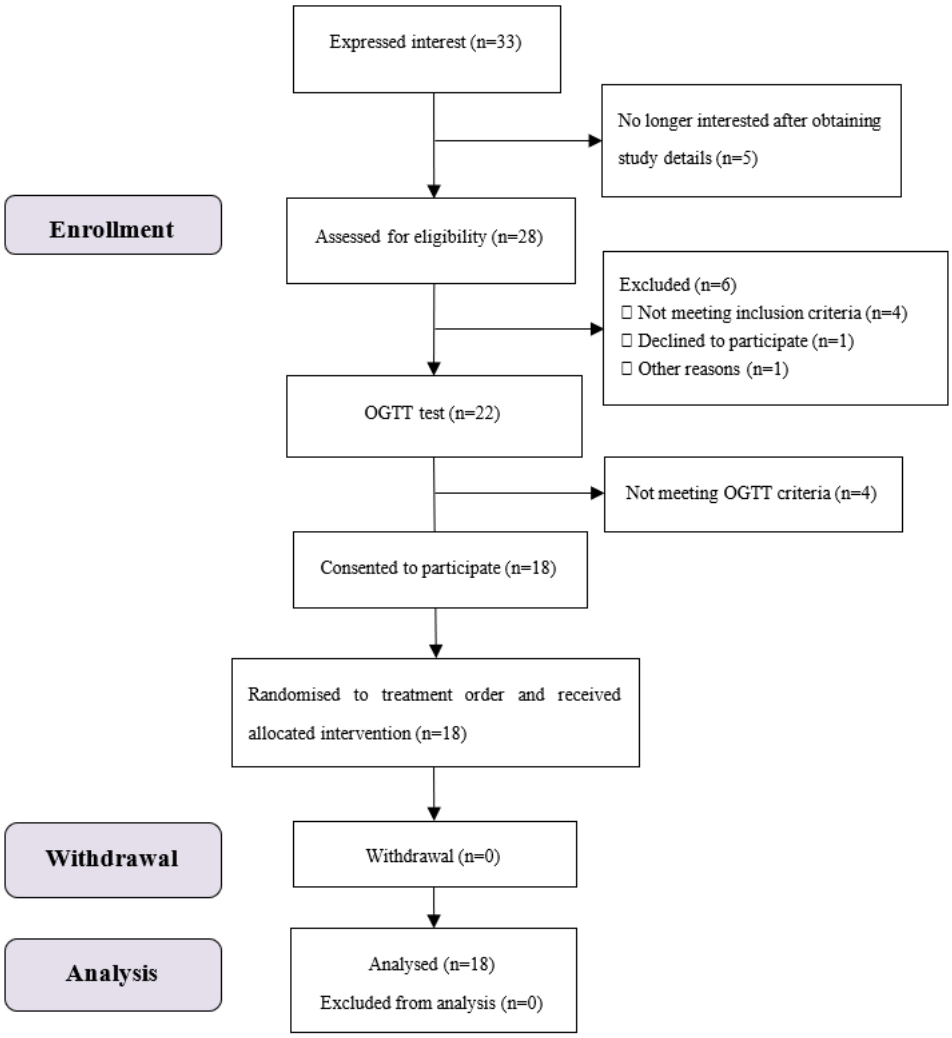

Figure 3. Consolidated standards of reporting trial flow diagram of the study participant selection. OGTT: oral glucose tolerance test.

kcal/day. All 18 volunteers' data were included in the analyses. No adverse event was reported in any test session.

The GRs of yam samples in study 1 are shown in Figure 4. Compared with LY, MY elicited a significantly higher glucose concentration at 15, 30, 45, and 60 min and a lower glucose concentration at 90 and 120 min, as well as a greater magnitude of glycemic excursion. The GI values of MY and LY were 68.4 and 30.6, classified as medium and low GI foods,[23] respectively.

Figure 5 shows the GRs and GI values of test meals in study 2. Two preload treatments elicited significantly

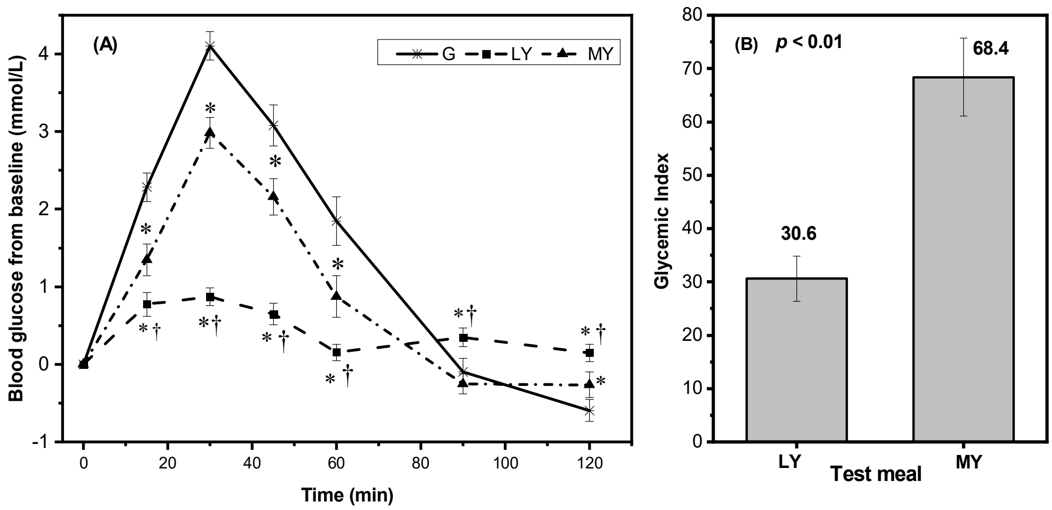

Figure 4. Glycemic responses of yam paste samples (n=18). (A) Blood glucose changes from baseline for yam samples. (B) The GI values of yam samples. Values are shown as the mean value with their standard errors represented by vertical bars. *LY or MY different from G, †LY different from MY (p<0.05). G, glucose; LY, low-intensity-cooked yam paste; MY, medium-intensity-cooked yam paste.

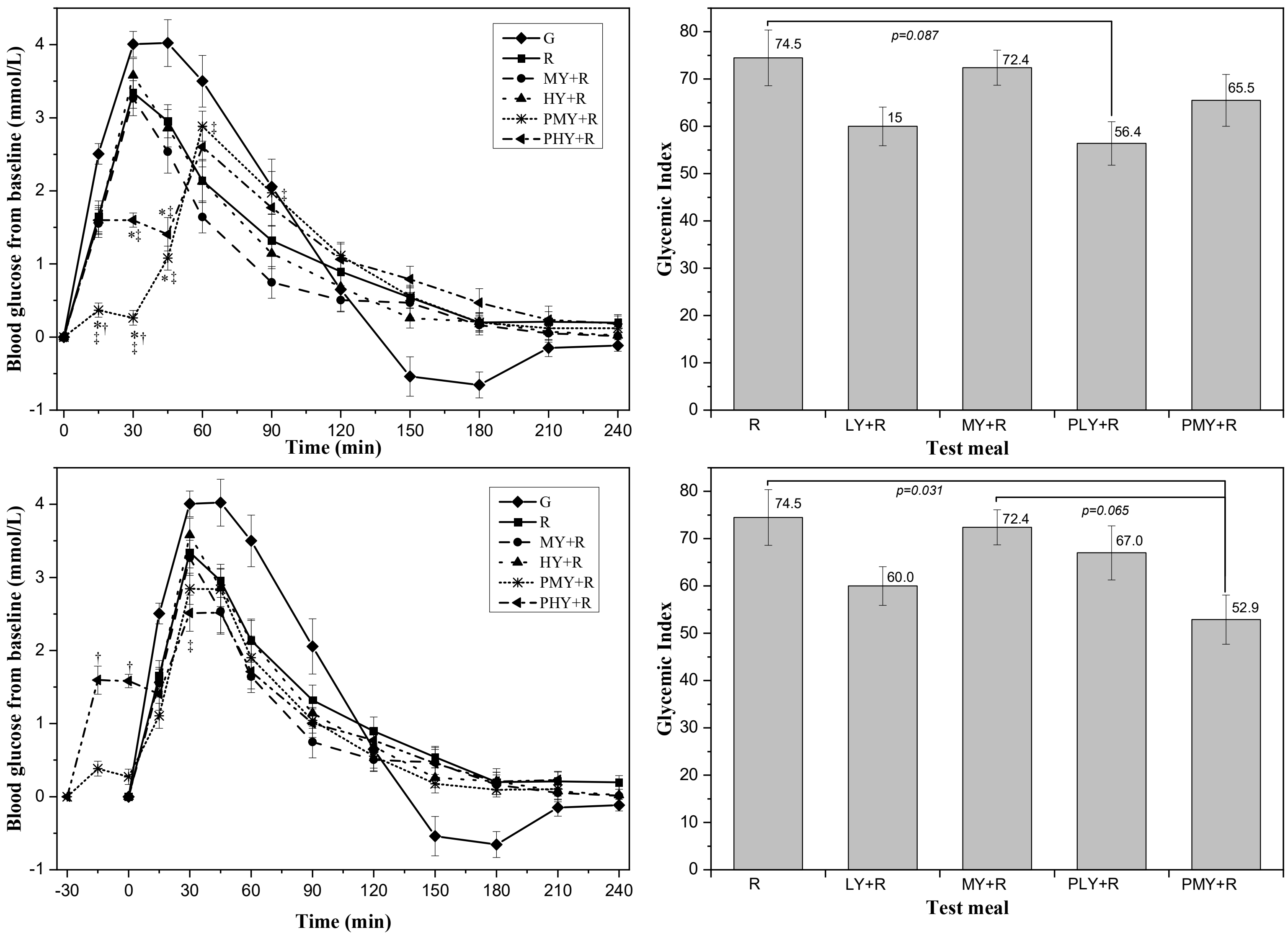

Figure 5. Blood glucose changes from baseline and GI values for mixed test foods (n=18). (A) Defined the start of yam ingestion as time 0. (B) Defined the start of rice ingestion as time 0. G, glucose; R, rice; LY+R, coingestion of low-intensity-cooked yam paste and rice; MY+R, coingestion of medium-intensity-cooked yam paste and rice; PLY+R, preload low-intensity-cooked yam paste with rice; PMY+R, preload medium-intensity-cooked yam paste with rice. Values are shown as the mean value with their standard errors represented by vertical bars. *Test meals different from rice, †LY different from MY, and ‡preload different from coingestion counterparts (p<0.05).

lower glycemic increments than their coingestion counterparts did at 30 and 45 min, along with a delayed peak (Figure 5A). The LY preload had comparable blood glucose levels, except at 15- and 30-min points, compared with the MY preload. No difference was observed between rice control and coingestion treatments of yam samples with different GIs. Figure 5C shows that the MY preload resulted in lower glucose increments than its coingestion counterparts at 30 min. Figure 5 (B) shows that with the LY preload, there is a trend toward a of lower GI value than with R, while, based on Figure 5 (D), the GI value of the MY preload was lower than that for R and that it trended lower with co-ingestion of MY. Both preload meals were classified as medium GI food, whereas the nonpreload rice meal was classified as high GI food. Table 3 shows the glycemic variability indices of the test meals. Both the MY and LY preloads resulted in lower peak values and mitigated GRs in terms of iAUC0-30 and iAUC0-60 compared with their coingestion counterparts and the rice control, and the LY preload further lowered the increments than did the MY preload. The CONGA1 of PLY+R was higher than that of the LY+R and PMY+R. No difference was observed in subsequent blood glucose incremental summation.

Subjective appetite and subsequent food intake

Assessment with VAS (Figure 6A) showed that PLY+R and PMY+R had significantly lower satiety increments at 15 and 30 min compared with rice and their coingestion counterparts. Assessment with VIMEC (Figure 6B) revealed that PLP+R and PMY+R lead to more prospective food intake at 15 and 30 min compared with rice and their coingestion counterparts. However, no significant difference was observed among the test meals in terms of either satiety score during 60–240 min or the subsequent meal intake according to dumpling consumption.

DISCUSSION

In this study, coingestion of yam pastes and rice elicited GRs comparable to the iso-carbohydrate rice reference, whereas yam paste preload mitigated GRs in terms of peak glucose value and iAUC0-60 compared with their coingested counterparts, irrespective of the GI of yam paste.

LY and MY yam paste, as cooked paste foods, had GI values of only 30.6 and 68.4, respectively. In the 2002 version of international GI table, the listed values of yam food were 34 (peeled, sliced, soaked for 2 days, and baked for 15 min), 35 (peeled and boiled), and 66 (cooking treatment not specified).[7] However, these yam foods were not of the same variety as those used in Asian foods (*Dioscorea opposita Thunb.* vs *Dioscorea bulbifera*). The disparity of GI values could also be explained by the difference in processing procedure and variety.[8,11] Minimized processing results in greater retention of RS, which is beneficial to gut microbiota[24] and contributes to improved glycemic characteristics.[25]

Despite difference in the GI values of the two yam paste samples, no significant difference in GRs occurred between LY+R and MY+R. As rice accounted for 80% of the total AC in the test meals, the possible discrepancy between the two yam-paste-containing meals might be attenuated by the large bulk of rice. This was consistent with a previous study that preloaded 15 g AC of potatoes before 35 g of AC of rice meal and showed comparable GRs irrespective of the GI of the potatoes.[12]

Both the preload treatments elicited significantly less glycemic increments at 30 and 45 min, low GI values, and significantly reduced postprandial blood glucose excursion (−0.8 mmol/L and −0.9 mmol/L reduction, respectively) compared with their coingestion counterparts and rice reference. Although individual differences were observed among participants with respect to which preload better suppressed the GI, LY, or MY, it is remarkable that merely 10 g of preload starch could make a difference in postprandial GR of high GI meals. In previous studies, the effective amounts of preload AC were 25 g for kiwifruit and rice[14] and 15 g for potato,[12] apple,[15] and dried apple.[26]

For people with insulin resistance, the carbohydrate preload strategy must be applied prudently because the improved postprandial glycemia should not be at the cost of increased plasma insulin. The insulin response of yam preloads needs to be documented. However, in this study, the 20% substitution of high-GI rice carbohydrate with medium- or low-GI yam paste did not likely elicit an increased insulin response. Reduced glycemic load is usually associated with a lower postprandial GR as well as improved insulin sensitivity.[27] A study reported that a high-GI rice porridge preload results in comparable incremental iAUC at 180 min for plasma insulin, ghrelin, and glucagon concentrations compared with a water-preload reference.[14] The introduction of the yam paste with the same AC, reduced GR, and comparable postprandial insulinemia to a rice meal would increase nutrient density in terms of potassium, phytochemicals, and dietary fiber and thus would be beneficial in metabolic disease prevention and management.[28]

In this study, all test meals presented comparable self-reported satiety. The determinants of satiety usually include energy, carbohydrate, protein, and fat contents and dietary fiber of test meals,[29] and food texture.[30] As the physical form and nutrient contents of LY and MY samples were completely same, the four yam paste-containing meals elicited a similar postprandial satiety. The only difference between LY and MY was the disparity of starch fractions, such as the RDS and RS contents. Food rich in RS content is usually associated with enhanced satiety.[31] However, the interval between yam paste preload and rice meal was 30 min, which might be too short for the RS in LY to elicit an extra surge of incretin concentration, commonly appearing within 30–60 min after food ingestion.[32] In addition, the disparity of RS content between LY and MY samples (6.3 g vs. 2.4 g) might be too small to make a significant difference in acute satiety through the stimulation of the release of gut peptides, such as PYY and GLP-1.[33]

Dumpling (jiaozi) is a well-known and highly enjoyable traditional Asian food made of flour, meat/egg, and vegetables. Compared with the common practice of serving *ad libitum* food of various types and recording the food intake, counting dumplings is an easy and a well-accepted method of measuring food intake for participants. In this study, a good agreement was observed be-

Table 3. Glycemic variability indices for test meals (mean values and standard errors [SE], n=18)

	R		LY+R		MY+R		PLY+R		PMY+R	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
ΔPeak (mmol/L)	3.7†‡	0.2	3.6†‡	0.2	3.8†	0.2	2.8§	0.3	2.9§	0.2
ΔLow (mmol/L)	-0.3†	0.1	-0.4†	0.1	-0.3†	0.1	-0.5†	0.1	-0.4†	0.1
$CONGA_1$	1.6‡	0.1	1.5‡	0.1	1.7†‡	0.1	2.0†	0.1	1.6‡	0.1
$iAUC_{0-30}$	50.0†	3.9	47.8†	3.2	50.8†	3.7	8.1§	1.7	36.1‡	3.0
$iAUC_{0-60}$	135.3†	8.3	122.9†	7.5	136.4†	8.2	48.3§	4.0	88.8‡	5.5
$iAUC_{0-120}$	220.7†	17.4	179.2†‡	12.6	214.9†	15.0	167.7‡	12.9	197.0†‡	15.2
$iAUC_{0-150}$	256.6†	20.2	208.8†	17.4	241.1†	18.0	206.9†	16.1	245.7†	20.6
$iAUC_{0-240}$	275.4†	22.5	222.2†	20.0	255.8†	20.5	219.4†	17.4	268.7†	25.6

R: rice; Y: yam; LY: low-intensity-cooked yam paste; HY: high-intensity-cooked yam paste; PLY: preload low-intensity-cooked yam paste; PMY: preload medium-intensity-cooked yam paste; LY+R: coingestion of low-intensity-cooked yam paste and rice; MY+R: coingestion of medium-intensity-cooked yam paste and rice; PLY+R: preload low-intensity-cooked yam paste with rice; PMY+R, preload medium-intensity-cooked yam paste with rice; $CONGA_1$: continuous overall net glycemic action; iAUC: increments under the curve of GRs.
Values are the mean glycemic characteristics of test meals with their standard errors.
†‡§Significant differences among test meals are represented by different symbols (p<0.05).

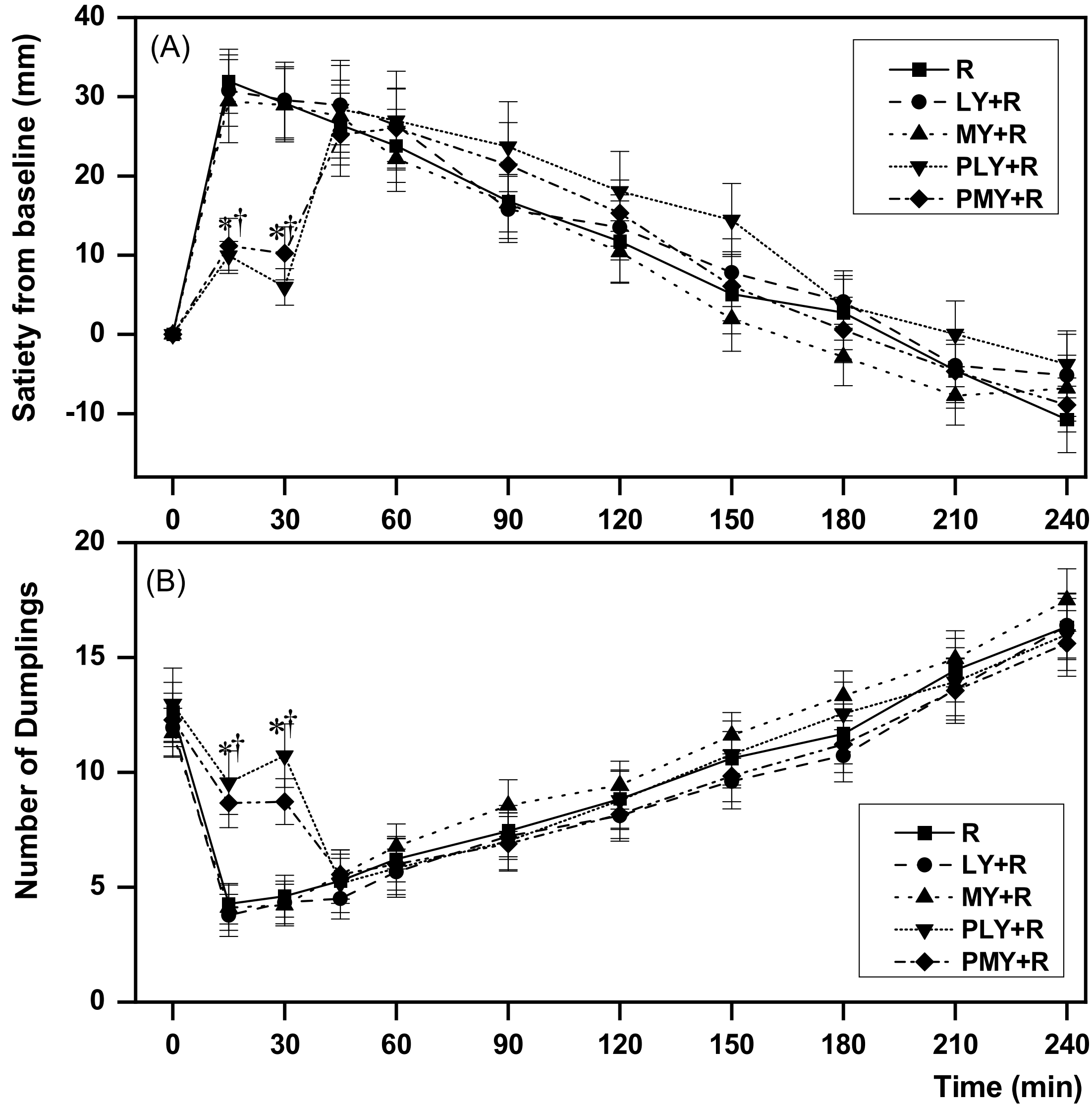

Figure 6. Satiety changes from baseline for test foods assessed using visual analogue scale and VIMEC (n=18). R, rice; LY+R, coingestion of low-intensity-cooked yam paste and rice; MY+R, coingestion of medium-intensity-cooked yam paste and rice; PLY+R, preload low-intensity-cooked yam paste with rice; PMY+R, preload medium-intensity-cooked yam paste with rice. Values are shown as the mean value with their standard errors represented by vertical bars. *Test meals different from rice, and †preload different from coingestion test meals (p<0.05).

tween the number of dumplings expected to be consumed with VIMEC and the actual number of dumplings consumed, which indicated the feasibility of counting dumplings as an innovative assessment of satiety and the subsequent food intake in some Asian cultures.

Ours is a novel study insofar as the impact of paste food ingestion on GRs is concerned. Because people with dental problems and dysphagia frequently consume soft-texture high-GI carbohydrate foods or foods in paste form, this study on the strategy for mitigating the GRs of paste foods is relevant. We successfully reduced the glucose peaks of paste food and mixed meals through (1) yam-paste GI decrement with minimized heating treatment and (2) consumption of paste food as a preload of a high-GI carbohydrate diet.

The present study was conducted as an acute trial in young healthy volunteers. The hypoglycemic effect of yam paste preload is yet to be confirmed in elderly individuals and patients with diabetes in long-term intervention studies. The possible action of phytochemicals and glycan in yam[5] and the patterns of relevant hormones, such as insulin, GLP-1, and GIP, deserve further investigation.

In conclusion, our study found that substitution of 20% isocarbohydrate of rice with low- or medium-GI yam paste increased GRs, whereas yam paste preloads curbed the glucose peak value and lowered the GI value of mixed meals without any adverse effect on satiety in young healthy participants. Given the popularity of paste-form carbohydrate foods in some groups of people and the importance of glycemic homeostasis in the prevention of chronic disease,[34] the consumption manner of these foods must be optimized.

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AUTHOR DISCLOSURES

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REFERENCES

1. Takao T, Suka M, Yanagisawa H, Iwamoto Y. Impact of postprandial hyperglycemia at clinic visits on the incidence of cardiovascular events and all-cause mortality in patients with type 2 diabetes. J Diabetes Investig. 2017;8:600-8.
2. Cavalot F, Pagliarino A, Valle M, Di Martino L, Bonomo K, Massucco P, Anfossi G, Trovati M. Postprandial blood glucose predicts cardiovascular events and all-cause mortality in type 2 diabetes in a 14-year follow-up: lessons from the San Luigi Gonzaga Diabetes Study. Diabetes Care. 2011;34:2237-43.
3. Skrha J, Soupal J, Skrha JJ, Prazny M. Glucose variability, HbA1c and microvascular complications. Rev Endocr Metab Disord. 2016;17:103-10.
4. Shao Y, Mao L, Guan W, Wei X, Yang Y, Xu F, Li Y, Jiang Q. Physicochemical and structural properties of low-amylose Chinese yam (Dioscorea opposita Thunb.) starches. Int J Biol Macromol. 2020;164:427-33.
5. Epping J, Laibach N. An underutilized orphan tuber crop-Chinese yam: a review. Planta. 2020;252:58.
6. Lin MH, Wu MC, Lu S, Lin J. Glycemic index, glycemic load and insulinemic index of Chinese starchy foods. World J Gastroenterol. 2010;16:4973-9.
7. Foster-Powell K, Holt S, Brand-Miller JC. International table of glycemic index and glycemic load values: 2002. Am J Clin Nutr. 2002;76:5-56.
8. Liang X, Fan Z, Wang S. In vitro carbohydrate digestion properties of traditional powder starchy food materials. Journal of China Agricultural University. 2011;16:138-43.
9. Ranawana V, Clegg ME, Shafat A, Henry CJ. Postmastication digestion factors influence glycemic variability in humans. Nutr Res. 2011;31:452-9.
10. Tsuchiya M, Niijima-Yaoita F, Yoneda H, Chiba K, Tsuchiya S, Hagiwara Y et al. Long-term feeding on powdered food causes hyperglycemia and signs of systemic illness in mice. Life Sci. 2014;103:8-14.
11. Dong Y, Fan Z, Liu Y. Starch fractions and glycemic response of roasted and powdered starchy foods. Journal of Chinese Institute of Food Science and Technology. 2016;16: 261-7. (In Chinese)
12. Zhao W, Zhou Y, Yuan Y, Fan Z, Wu Y, Liu A, Lu X. Potato preload mitigated postprandial glycemic excursion in healthy subjects: An acute randomized trial. Nutrients. 2020; 12:2759.
13. Zhu R, Fan Z, Li G, Wu Y, Zhao W, Ye T, Wang L. A comparison between whole grain and pearled oats: acute postprandial glycaemic responses and in vitro carbohydrate digestion in healthy subjects. Eur J Nutr. 2020;59:2345-55.
14. Lubransky A, Monro J, Mishra S, Yu H, Haszard JJ, Venn BJ. Postprandial glycaemic, hormonal and satiety responses to rice and kiwifruit preloads in Chinese adults: A randomised controlled crossover trial. Nutrients. 2018;10: 1110.
15. Lu J, Zhao W, Wang L, Fan Z, Zhu R, Wu Y, Zhou Y. Apple preload halved the postprandial glycaemic response of rice meal in healthy subjects. Nutrients. 2019;11:2912.
16. Flint A, Raben A, Blundell JE, Astrup A. Reproducibility, power and validity of visual analogue scares in assessment of appetite sensations in single test meal studies. Int J Obes Relat Metab Disord. 2000; 24:38-48.
17. Blundell J, de Graaf C, Hulshof T, Jebb S, Livingstone B, Lluch A, Mela D, Salah S, Schuring E, van der Knaap H, Wester-terp M. Appetite control: methodological aspects of the evaluation of foods. Obes Rev. 2010;11:251-70.
18. Holliday A, Batey C, Eves FF, Blannin AK. A novel tool to predict food intake: The Visual Meal Creator. Appetite. 2014;79:68-75.
19. Englyst KN, Englyst HN, Hudson GJ, Cole TJ, Cummings JH. Rapidly available glucose in foods: an in vitro measurement that reflects the glycemic response. Am J Clin Nutr. 1999;69:448-54.
20. Englyst HN, Kingman SM, Cummings JH. Classification and measurement of nutritionally important starch fractions. Eur J Clin Nutr. 1992;46(Suppl 2):S33-S50.
21. Wolever TM. Effect of blood sampling schedule and method of calculating the area under the curve on validity and precision of glycaemic index values. Br J Nutr. 2004;91: 295-301.
22. McDonnell CM, Donath SM, Vidmar SI, Werther GA, Cameron, F.J. A novel approach to continuous glucose analysis utilizing glycemic variation. Diabetes Technol Ther. 2005;7:253-63.
23. Institution BS Food products. Determination of the glycaemic index (GI) and recommendation for food classification. Iso International Standard. 2010.
24. DeMartino P, Cockburn DW. Resistant starch: impact on the gut microbiome and health. Curr Opin Biotechnol. 2020;61: 66-71.
25. Xiong K, Wang J, Kang T, Xu F, Ma A. Effects of resistant starch on glycaemic control: a systematic review and meta-analysis. Br J Nutr. 2021;125:1260-9.
26. Zhao W, Wang L, Fan Z, Lu J, Zhu R, Wu Y, Lu X. Co-ingested vinegar-soaked or preloaded dried apple mitigated acute post-prandial glycemia of rice meal in healthy subjects under equicarbohydrate conditions. Nutr Res. 2020;83:108-18.
27. Lau C, Pedersen O, Faerch K, Carstensen B, Glumer C, Jorgensen T, Tetens I, Borch-Johnsen K. Dietary glycemic index, glycemic load, fiber, simple sugars, and insulin resistance: the Inter99 study. Diabetes Care. 2005;28:1397-403.
28. Bindels LB, Walter J, Ramer-Tait AE. Resistant starches for the management of metabolic diseases. Curr Opin Clin Nutr Metab Care. 2015;18:559-65.
29. Karhunen LJ, Juvonen KR, Huotari A, Purhonen AK, Herzig KH. Effect of protein, fat, carbohydrate and fibre on gastrointestinal peptide release in humans. Regul Pept. 2008; 149:70-8.
30. Stribitcaia E, Evans C, Gibbons C, Blundell J, Sarkar A. Food texture influences on satiety: systematic review and meta-analysis. Sci Rep. 2020;10:12929.
31. Kenda CWC, Esfahani A, Sanders LM, Potter SM, Vidgen E. The effect of a PreLoad meal containing resistant starch on spontaneous food intake and glucose and insulin responses. J Food Technol. 2010;8:67-73.
32. Vilsboll T, Krarup T, Sonne J, Madsbad S, Volund A, Juul AG, Holst JJ. Incretin secretion in relation to meal size and body weight in healthy subjects and people with type 1 and type 2 diabetes mellitus. J Clin Endocrinol Metab. 2003; 88:2706-13.
33. Reader D, Johnson ML, Hollander P, Franz M. The glycemic and insulinemic response of resistant starch in a food bar vs. two commercially available food bars in persons with type II diabetes mellitus. Diabetes. 1997; 461:975.
34. Bhupathiraju SN, Tobias DK, Malik VS, Pan A, Hruby A, Manson JE, Willett WC, Hu FB. Glycemic index, glycemic load, and risk of type 2 diabetes: results from 3 large US cohorts and an updated meta-analysis. Am J Clin Nutr. 2014; 100:218-32.