

Influence of rice, pea and oat proteins in attenuating glycemic response of sugar-sweetened beverages

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Abstract

Purpose Liquids have higher ingestion and gastric-emptying rates, resulting in rapid glycemic response. They are also less satiating than solid foods. This study examined if the addition of plant proteins alter postprandial glucose, insulin, triglycerides, glucose-dependent insulinotropic peptide (GIP), glycogen-like peptide-1 (GLP-1) and appetitive responses to a sugar-sweetened beverage.

Methods This was a randomized, crossover acute feeding study consisting of four treatments: chocolate beverage alone (50 g carbohydrate), or added with 24 g oat, pea or rice proteins. Twenty Chinese males (mean \pm SD age 26 ± 5 years; body mass index 21.5 ± 1.7 kg/m²) ingested the test drink after an overnight fast. Venous blood samples and subjective appetite ratings were collected before test beverage and at fixed intervals for 180 min. Blood biochemical data and appetite ratings were compared using repeated-measures ANOVA.

Results Significant interaction effects were found in postprandial glucose excursions (time \times protein effects, $p = 0.003$). Glucose iAUC was lower in pea and rice proteins, although not significantly ($p > 0.385$). Insulin iAUC

was significantly higher in the oat ($p = 0.035$) and pea ($p = 0.036$) protein beverages. GIP and GLP-1 release in a sub-sample ($n = 10$) followed a comparable order as insulin release ($p = 0.397$ and 0.454 , respectively). Significant interaction effects were found in fullness ratings ($p = 0.024$), and a trend of greater suppression of hunger and desire-to-eat was also documented ($p = 0.088$ and 0.080 , respectively).

Conclusions Plant proteins altered the glycemic and appetitive responses of Asian males to a sugar-sweetened beverage. Food-based interventions are useful in promoting glycemic control. This trial was registered with ClinicalTrials.gov as NCT02933424.

Keywords Dietary proteins · Blood glucose · Insulin · Incretin · Appetite

Introduction

The global prevalence of type 2 diabetes is rising and maintaining blood glucose within recommended ranges is crucial. Although fasting blood glucose is often used as an indicator of optimal glycemic control [1], postprandial blood glucose levels have been shown to be better predictors of long-term health consequences [2, 3]. Therefore, emphasis should also be placed on lowering the peaks and fluctuations of blood glucose following carbohydrate meals. Compared to Caucasians, Asians have higher postprandial glycemic response to the same carbohydrate load [4]. Asians are also more susceptible to rapid transition from pre-diabetes to diabetes status with greater metabolic consequences [5]. This warrants the need to find simple food-based interventions to modulate postprandial glycemia in Asia.

Since blood glucose is affected by the type and amount of dietary carbohydrate, strategies that modify starch structure

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[6] and increase the dietary fiber content [7] were found to be effective in regulating postprandial glycemic response. Besides carbohydrate, our previous experiments demonstrated that the co-ingestion of dietary fat also lowers human glycemic response to carbohydrate-rich foods or meals [8]. The modification of dietary carbohydrate and fat content modulates postprandial glycemic responses by reducing the rates of glucose digestion and absorption. Another pathway to lower postprandial glycemia is to increase glucose uptake by tissues via incretin hormones such as glucose-dependent insulinotropic peptide (GIP) and glucagon-like peptide-1 (GLP-1) and insulin release. The most recent Standards of Care released by the American Diabetes Association states that “ingested protein appears to increase insulin response without increasing plasma glucose concentrations” [9]. This implies that increasing the protein content of a food may be an effective glycemic-lowering strategy. Indeed, dietary protein has been reported to show insulinotropic effects [10]. Similarly, amino acids and peptides have also shown insulinotropic effects [11, 12].

Besides macronutrients, the rheology of foods has important health implications too. In recent years, the consumption of sugar-sweetened beverages has been associated with increased risk for obesity and type 2 diabetes [13]. From an ingestive behavior perspective, liquids are consumed and emptied from the stomach faster than solid foods [14]. This is especially relevant in sugar-sweetened beverages, where faster ingestion and gastric-emptying rates induce rapid rise in postprandial glucose and lower insulin release [15]. Furthermore, faster ingestion rate of beverage implies shorter oral residence time for sensory stimulation, and rapid gastric emptying reduces gastric distention, all of these lead to weaker appetitive effects [16]. The total elimination of liquids from our daily diets is impossible as beverages contribute to approximately 20–37% of total daily energy intake in adults and children [17–19]. Instead, increasing the protein content of foods may counter the adverse effects of carbohydrate-containing liquid beverages. Because dietary protein stimulates insulin and GLP-1 release [10, 20], this effect may dampen the rapid rise in glucose concentrations following a big carbohydrate load from a sugar-sweetened beverage [21]. Dietary protein has also been shown to reduce gastric emptying rates [20, 22] and increases fullness sensations [23].

Not only is the total amount of dietary protein important, the sources where they come from may also determine their effectiveness in the regulation of postprandial glycemia [24, 25] and appetite [26]. In addition, studies have also demonstrated that various amino acids show different levels of insulin- and incretin-stimulating capacity [12, 27–29], which further supports the need to investigate how protein sources influence postprandial glycemic responses. Since Asians consume a largely plant-based diet [30], intakes of meat and

milk remains low compared to industrialized countries [31], and that plant protein had superior glycemic-reducing effects than animal protein [32], the emphasis should be placed on comparing dietary protein from various plant sources. Of all the plant-based proteins, soy remains a major source of protein in Asia. Given the increasing consumer concerns related to the consumption of sugar-sweetened sodas, there is a recent resurgence of interest in sugar-based beverages containing plant-based proteins. Historically, rice and oats have been noted as a source of carbohydrate. Recent advances in extraction and application has enabled the production of rice and oat protein with unique rheological properties [33]. Since peas are a rich source of protein and comparable to soy in protein quality, much interest in its use and application has emerged recently.

In this study, we aimed to examine the effects of protein supplementation from three plant sources to a sugar-sweetened beverage on postprandial glycemic responses in healthy adults. Based on the literature, we hypothesized that a beverage enriched with dietary protein would stimulate insulin and incretin e.g., GLP-1 and GIP release and subsequently reduce postprandial glycemic responses when compared to a carbohydrate-matched control beverage with negligible amount of protein. Our secondary aim was to examine the effects of protein supplementation on appetitive responses to a beverage, and it was hypothesized that higher protein content would suppress appetite more than a control beverage.

Methods

Participants

Participants aged 21–45 years, males, with a BMI of 18.5–24.9 kg/m², overall healthy, of Chinese ethnic background, and who ate regular meals were recruited through study flyers placed at local community. Individuals with food allergies, gout, smoking, on prescription medication, on a weight loss regime and partaking in endurance exercise were excluded. The study was conducted at the Clinical Nutrition Research Centre from October 2016 to February 2017. The study protocol was explained to the participants and written informed consent was obtained prior to study commencement. Twenty subjects completed the study. Since postprandial glycemia was our primary outcome, this study was powered to detect the difference between the glucose area under the curve after consuming carbohydrate-alone or carbohydrate with added cod protein meals (effect size = 0.79) [25]. Based on our calculation, at least 15 participants were needed to detect this effect size at 80% statistical power using a crossover study design. Assuming an attrition rate of 30%, 22 participants were recruited in this study.

Study design

This was a randomized, controlled, crossover study. At baseline visit, informed consent was obtained and baseline measurements such as height, weight, body fat percentage, waist and hip circumferences, and blood pressure were taken. Subsequently, participants attended four test visits where they consumed four test beverages, with a washout period of at least 7 days between study sessions. The order of treatments was randomized using a computer-generated randomizer software (Randomize.org). Twenty-four hour prior to each test day, the participants were asked to avoid alcohol, caffeine, and intense physical activity, and they were instructed to consume their habitual diets before and after the test sessions. After a 10-h overnight fast, participants reported to the research facility and were instructed to void their bladder before weight and body fat were measured. The fasting state of the subject was confirmed verbally. The antecubital vein of the subject's forearm was cannulated and baseline blood samples were collected. Test drink was served and the subjects were required to consume the entire beverage within 15 min. Subsequently, blood samples were taken at 15, 30, 45, 60, 90, 120, 150 and 180 min after the consumption of the test drink. Appetite sensations (hunger, desire to eat, amount, fullness and preoccupation with foods) were also assessed at similar time points when blood samples were taken. After 3 h, the blood catheter was removed and ad libitum lunch consisting of fried rice and 250 ml of plain water (water was consumed entirely) was served in a dining room where the participants ate alone for 30 min until comfortably full. The subjects had to fully consume the water. The meal challenge was calculated by the difference between the amount served and the amount left on the plate. The liking for the test beverages and ad libitum lunch was also assessed using a visual analog scale (VAS). This study was approved by the local Domain Specific Review Board (approval no. DSRB 2016/00796) and in accordance with the Helsinki Declaration of 1975 as revised in 1983. The experimental protocol was also registered at clinicaltrials.gov (identifier number NCT02933424).

Test beverages

Participants consumed four test beverages in a random order. All beverages were chocolate-based drinks that were matched in available carbohydrate, total fat, fibre, and total weight (Table 1). The control beverage contained 3 g protein, while the oat, pea and rice protein-enriched beverages contained 27 g of protein from these sources. For this reason, the protein-enriched beverages were approximately 400 kJ higher in energy content. The amount of protein added to the test beverages was determined based on previous studies where the addition of 25–30 g of protein to a

Table 1 Nutritional composition of test beverages consisting of no additional (control) or 24 g of protein from oat, pea and rice. The amino acid profiles of the proteins are also reported

	Control	Oat	Pea	Rice
Energy (kJ)	1252	1672	1680	1672
Available carbohydrate (g)	50	50	50	50
Protein (g)	3	27	27	27
Total fat (g)	10	10	10	10
Fibre (g)	4	4	4	4
Weight ^a (g)	400	400	400	400
Amino acid composition (g/24 g protein)				
Aspartic acid		1.76	2.78	2.24
Threonine		0.73	0.85	0.94
Serine		0.98	1.19	1.27
Glutamic acid		5.10	4.06	4.47
Proline		1.26	1.00	1.13
Glycine		0.82	0.86	1.10
Alanine		0.96	0.95	1.40
Cysteine		0.58	0.25	0.67
Valine		1.29	1.23	1.43
Methionine		0.43	0.29	0.75
Leucine		1.85	1.94	2.08
Isoleucine		1.00	1.15	0.97
Tyrosine		0.93	0.91	1.27
Phenylalanine		1.35	1.28	1.45
Lysine		0.66	1.54	0.80
Histidine		0.50	0.57	0.65
Arginine		1.67	2.10	1.90
Tryptophan		0.35	0.23	0.22

^aPlain water was added to match the total weight of all test beverages

meal increased insulin release [21] and reduced glycemic response [34] significantly. The amino acid profiles from the additional protein powder are also presented in Table 1. The test drinks were prepared by dissolving cocoa powder, sugar, protein powder and whipped cream in hot water. They were then cooled in 4 °C fridge overnight and served chilled. The treatments included oat protein (Tate & Lyle PLC, London, UK), pea protein (Roquette Frères, Lestrem, France) or rice protein concentrates (Wilmar International Limited, Singapore). Water was added to account for the difference in volume among the drinks.

Measures

At baseline, height was measured with a stadiometer (Seca Limited, Birmingham, West Midlands, Middlesex, UK), body weight with a weighing scale (Tanita BC-418, Tokyo, Japan), body fat percentage with an air displacement plethysmography method (Bod Pod software version 5.2.0, COSMED, Rome, Italy), and blood pressure with an Omron

blood pressure monitor (Model HEM-907, Omron Healthcare Singapore, Singapore). On test days, body weight and fat percentage were measured with a bioelectrical impedance (BIA) scale (Tanita BC-418, Tokyo, Japan). Venous blood samples were collected for serum glucose, insulin, and triglycerides analyses, and for plasma active glucagon-like peptide 1 (GLP-1), glucose-dependent insulinotropic polypeptide (GIP), and amino acid analyses. Blood samples for GLP-1 and GIP were collected in the K₂EDTA tubes with added protease inhibitor cocktail (cOmplete™ EDTA-free, Roche, USA) and DPP-IV inhibitor (Merck, USA). The tubes were centrifuged at 1500×g for 10 min at 4 °C (Sorvall™ ST 16 Centrifuge, Thermo Fisher Scientific, Waltham, MA, USA). Plasma was aliquoted into Eppendorf tubes and stored at –80 °C until analysis. Serum insulin was determined on the immunoassay chemistry analyzer Cobas e411 (Roche, Hitachi, USA), which has an intra-assay CV < 5% and inter-assay CV < 6%. Serum glucose (intra-assay CV < 0.7% and inter-assay CV < 1.2%) was determined using Cobas c311 (Roche, Hitachi, USA). Due to budget constraints, plasma GIP and GLP-1 were analyzed in a sub-sample of 10 participants, at 0, 30, 60, and 180 min of plasma samples. Plasma total GIP and active GLP-1 concentrations were determined by Luminex xMAP (Luminex Corp., USA) using the human metabolic hormone MILLIPLEX MAP kit (Millipore HMHEMAG-34K, Billerica, MA, USA), which has an intra-assay CV < 10% and inter-assay CV < 15%. Appetite ratings (hunger, fullness, prospective eating, desire-to-eat, and preoccupation with foods) of participants were assessed using validated 100 mm visual analogue scales (VAS) [35]. Participants' likings to test beverages and ad libitum lunch were also assessed using VAS anchored at 'dislike extremely' (– 100 mm), 'Either like or dislike' (0 mm), and 'like extremely' (+ 100 mm).

Statistical analysis

Descriptive statistics are reported in mean ± standard deviation. Data distribution was checked using Shapiro–Wilk test. Temporal changes in postprandial glucose, insulin, triglycerides, GLP-1, GIP, and appetite sensations were tabulated as changes from baseline fasting values and they were compared using general lineal model for repeated measures ANOVA (GLM RMANOVA) with Bonferroni correction, and the type of protein being the between-subject variable. Where time-by-protein effects were significant or near significant ($p < 0.10$), post hoc analyses comparing the effects of protein enrichment against the Control treatment at each time point were performed using the Dunnett tests. Temporal changes in these variables over 180 min were also transformed into incremental area under the curve (iAUC) for glucose, insulin, incretin hormones, and fullness ratings ignoring area below baseline using the trapezoidal rules

[36]. Since appetite ratings such as hunger, desire-to-eat, food preoccupation and amount of foods were expected to decrease from baseline following test beverage ingestion, incremental area above the curves (iAAC) were calculated. Body weight, body fat percentage, AUC of blood biochemistry and appetite ratings, likings of test meals, and food intake at ad libitum meal challenge between treatments were also compared using GLM RMANOVA. Statistical analyses were performed using the Statistical Package for Social Sciences (IBM SPSS version 23.0, IBM Corp, Armonk, NY, USA), and two-tail statistical significance was set at $\alpha = 0.05$.

Results

Twenty-two volunteers who met study criteria were recruited and 20 completed all study visits. One participant withdrew his consent due to issues related to time commitment and another due to difficulty in obtaining blood samples from the upper-arm blood catheter. The baseline characteristics of study participants are summarized in Table 2. Participants' body weight and body fat percentage remained unchanged throughout all study visits (Table 3).

After the ingestion of test beverages, significant time ($p < 0.001$) and interaction (time × protein, $p = 0.003$) effects were found in 180-min glucose excursions, while protein effect approached statistical significance ($p = 0.086$, Fig. 1a). When presented as iAUC, pea and rice proteins appeared to reduce glycemic response, but overall no significant difference was found between all treatments ($p = 0.199$). On the other hand, temporal insulin changes showed significant time ($p < 0.001$) and protein effects ($p = 0.018$) (Fig. 1b), which translated into significantly higher iAUC for insulin after oat ($p = 0.036$) and pea ($p = 0.035$), but not rice proteins than the control beverage (Fig. 1b, right panel). Serum triglyceride excursions (time × treatment effects, $p = 0.185$) and iAUC ($p = 0.490$) did not differ between all test beverages (Fig. 1c). Although

Table 2 Participants' baseline characteristics

Variable	Mean ± SD	Range
Age	26 ± 5	21–41
Weight (kg)	64.4 ± 6.4	49.5–77.6
Height (cm)	172.8 ± 5.6	162.2–181.7
BMI (kg/m ²)	21.5 ± 1.7	18.8–24.3
Waist circumference (cm)	75.3 ± 4.4	65.5–84.5
Hip circumference (cm)	94.1 ± 4.1	85.0–101.5
% Body fat (Bod Pod)	15.7 ± 3.4	8.2–29.7
Systolic blood pressure (mmHg)	116 ± 10	98–133
Diastolic blood pressure (mmHg)	71 ± 9	52–87

Values are mean ± SD ($n = 20$)

Table 3 Anthropometry, –appetite sensations and meal challenge intake of Chinese male participants on test days

	Control	Oat	Pea	Rice	<i>P</i>
Anthropometric measurements					
Body weight (kg)	64.0 ± 6.7	64.2 ± 6.7	64.0 ± 6.8	64.1 ± 6.7	0.999
Body fat (%)	15.3 ± 3.1	15.3 ± 3.2	15.9 ± 3.2	15.1 ± 3.0	0.868
Appetite sensations					
iAAC hunger (mm min)	3281 ± 3007	4456 ± 2795	4706 ± 3554	4749 ± 3208	0.417
iAUC fullness (mm min)	3783 ± 2674	4941 ± 2534	4623 ± 2526	4005 ± 3137	0.578
iAAC desire to eat (mm min)	3143 ± 2820	4693 ± 2616	4489 ± 3346	4574 ± 3207	0.330
iAAC food pre-occupation (mm min)	2357 ± 2852	3902 ± 2565	3452 ± 3249	3239 ± 3084	0.455
iAAC amount of foods (mm min)	2291 ± 2842	4162 ± 2494	3666 ± 3291	3433 ± 3130	0.239
Test meal and lunch					
Liking of test beverages (mm)	69 ± 16	60 ± 18	67 ± 21	47 ± 19 ^a	0.002*
Liking of ad libitum lunch (mm)	47 ± 24	52 ± 21	55 ± 23	52 ± 18	0.680
Intake of ad libitum lunch (g)	511 ± 196	531 ± 187	517 ± 215	505 ± 176	0.977

Values are mean ± SD, *n* = 20, except for GIP and GLP-1 where *n* = 10

*Significant differences between all test beverages, GLM RMANOVA, *p* < 0.05

^aSignificantly different from Control, Dunnett post hoc tests, *p* < 0.05

the sub-sample (*n* = 10) postprandial excursions and iAUC of GIP and GLP-1 followed the trend of insulin response, these parameters were not statistically significant (Fig. 1d, e).

The addition of rice protein significantly reduced participants' liking to the test beverage. However, oat and pea proteins did not reduce the palatability of test beverages (Table 3). Changes in appetite ratings after the ingestion of test beverages are summarised in Fig. 2. There was a trend of greater reduction in hunger and desire-to-eat excursions (time × protein effects, *p* = 0.088 and *p* = 0.080, respectively). Although there was a significant time-by-protein effect for fullness ratings (*p* = 0.024), the fullness-promoting effects of protein-enriched beverages were not apparent until later part (after 90 min) of the test sessions. Three hours after the ingestion of test beverages, participants' intake of ad libitum lunch did not differ significantly (*p* = 0.977, Table 3).

Discussion

The primary aim of our study was to examine whether the addition of dietary protein from three different plant sources would reduce the glycemic response to a sugar-sweetened beverage in humans. Significant time × treatment effects were observed in postprandial glucose excursions (*p* = 0.003) and glucose levels were significantly lower in rice and pea protein treatments than Control at 45 min after test beverage ingestion. Although not statistically significant, the lower glucose peaks (at 30 min) of approximately 1 mmol/L in pea and rice protein treatments compared to

control (Fig. 1a) may have clinical importance. Similarly, the addition of 24 g dietary protein to a sugar-sweetened beverage also altered serum insulin excursions, especially at 120 and 150 min after meal ingestion (Fig. 1b). The delayed effect of protein on insulin release was not a novel observation as it has also reported in a previous study [37]. Oat and pea proteins produced significantly higher insulin iAUC but not rice protein. Of these two proteins, higher insulin iAUC induced by pea protein appear to explain its lower glucose iAUC (albeit not statistically significant). Our observation that pea protein significantly stimulated insulin release was consistent with the finding from previous studies [38, 39]. Although the insulin stimulating effects of rice protein has previously been observed in rats, these effects were not seen in our study, potentially due to inherent differences between animal and humans in their responses to rice protein, or the relatively high dose (2 g/kg) used in the animal study [40]. Nonetheless, the lower iAUC of glucose despite lower iAUC insulin appear to suggest that insulin sensitivity was higher after the rice protein treatment when compared to other proteins. A subsample analysis of incretin hormones appear to confirm the observed insulin excursions. For example, the higher insulin release induced by test beverages with oat and pea protein was consistent with the same pattern of GIP release. GLP-1 release also followed the same hierarchy, although the variations were bigger than GIP.

Several studies have reported positive correlations between plasma insulin and several amino acids such as branched-chain amino acid BCAA [25, 38], lysine [25], tyrosine [12], phenylalanine and arginine [38, 41]. If these observations hold veracity, it is reasonable to expect that oat and pea proteins, which resulted in significantly higher

Fig. 1 Postprandial excursions and incremental area under the curves (iAUC) of serum glucose (a), insulin (b), triglycerides (c), plasma active GIP (d), and GLP-1 (e) among Asian males following the control, oat, pea, and rice protein test beverages. Values are mean \pm SEM. Serum glucose and insulin, $n = 20$; plasma GIP and GLP-1, $n = 10$

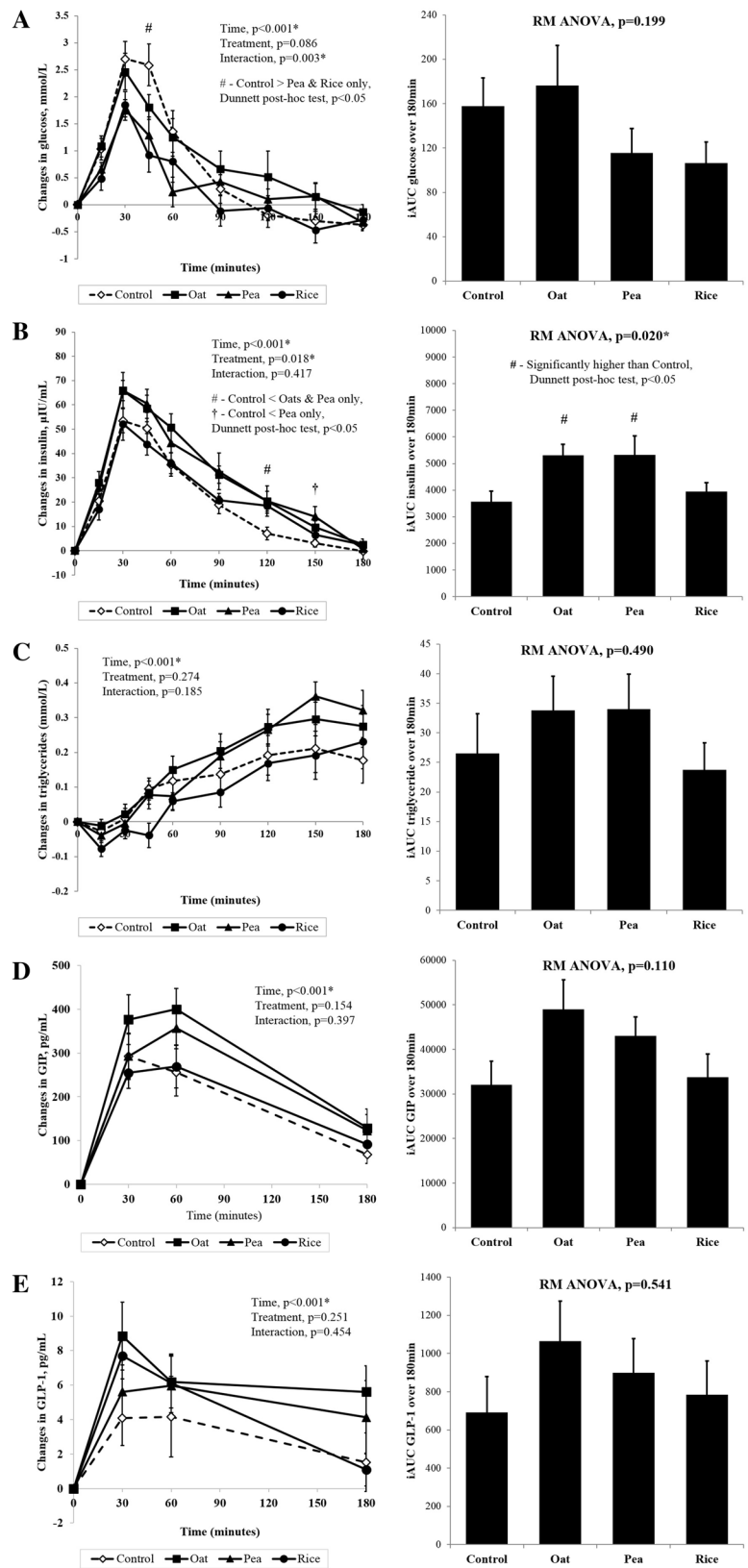
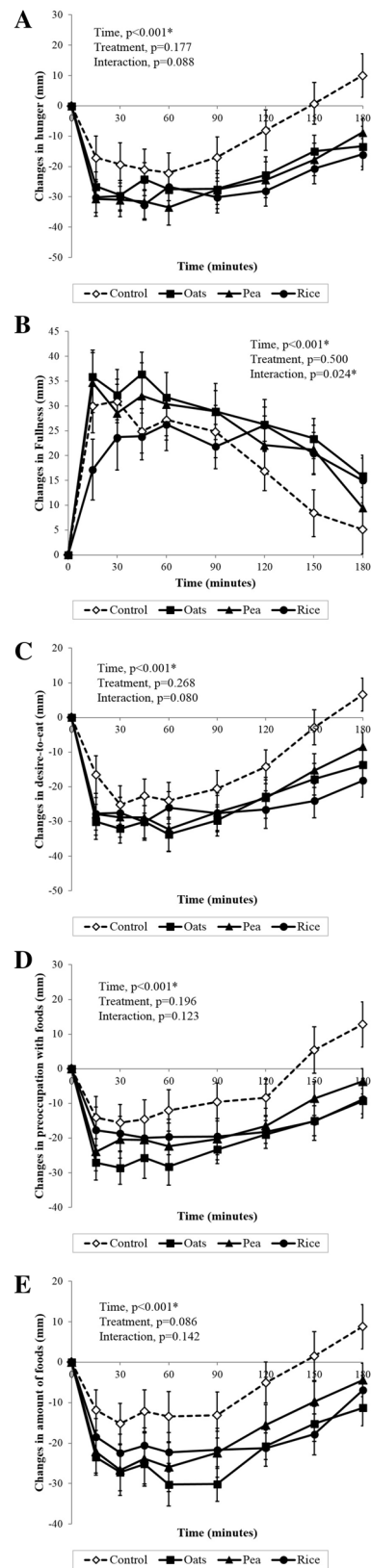


Fig. 2 Changes in participants' perception on hunger (a), fullness (b), desire-to-eat (c), preoccupation with foods (d), and amount of foods could be eaten (e) following the control, oat, pea, and rice protein test beverages in 20 Asian males. Values are mean \pm SEM, $n = 20$

iAUC for insulin, were higher in these insulinotropic amino acids than rice protein. However, this was not the case because: first, the amino acid profile of oat, pea and rice proteins were comparable as shown in Table 1; second, the content of insulinotropic amino acids were lower in both oat and pea than the rice protein; third, the insulinotropic amino acids content in oat and pea protein were inconsistent e.g., they were high in one protein concentrate but low in another although both proteins stimulated higher insulin equally. Furthermore, there are several other factors that could influence the relationship between amino acid content of test foods and insulinemic response such as differences in protein digestibility, which may determine the availability of these amino acids after food ingestion [42]. Therefore, the prediction of insulinotropic capability of various proteins based on selected amino acid profiles alone may be oversimplistic and should be done with care.

Our secondary aim was to examine if 24 g of protein from three plant sources were able to promote satiation and satiety when they were added to a sugar-sweetened beverage. As suggested by the VAS excursions and iAUC over 180 min, they appear to follow the expected directions, where the addition of proteins led to bigger increase in fullness and decreases in participants' perception on hunger, desire-to-eat, preoccupation with foods, and the amount of foods could be consumed than the control beverage (Fig. 2, Table 3). Of these appetite ratings, temporal fullness excursion achieved statistical significance, while hunger and desire-to-eat excursions approached statistical significance. The iAUC and iAAC of all appetite ratings did not achieve statistical significance, which was likely to be due to the large between-subject variations. Our findings were consistent with a recent meta-analysis, where satiety may be promoted by the increased protein content in a meal [23]. It should also be pointed out that the suppression of appetite by the protein treatments was also likely to be explained by the slightly higher energy content due to the additional protein in the test beverages (1252 vs. 1672 kJ). Regardless of protein or energy effects, the appetitive effects of test beverages with plant proteins failed to translate into lower food intake during the meal challenge. This was perhaps not too surprising as a systematic review has recently concluded that appetite rating was not predictive of energy intake [43]. Post-hoc comparisons also showed no differences between three sources of plant proteins on appetite ratings. Although protein sources have been suggested to play an important role in



regulating human appetite and subsequent food intake [28, 44–47], our findings were opposite and consistent with a number of other studies that did not observe the effects of protein sources on subsequent energy intake [48–51]. It should be pointed out that inconsistent findings may stem from differences in the forms of proteins (whole food vs. concentrate) and experimental design (time lapse between preload and meal challenge).

One limitation of our study was that the effect of protein on postprandial glycemia was smaller than what would be anticipated in this group of participants with normal fasting blood glucose. For this reason, we failed to detect a statistically significant difference in the iAUC of postprandial glucose after pea and rice protein treatments even though they appeared to be lower than the control beverage. It is speculated that the ingestion of plant proteins in individuals with pre-diabetes may elicit a greater reduction in glycemia. However, the clinical significance of the findings even in healthy individuals should not be discounted as a reduction in glycemia has been shown to significantly influence HbA1c [52], a biomarkers of long-term glucose control. Future studies should, therefore, investigate whether the insulin-stimulating effects of oat and pea proteins and the glycemic-lowering property of rice and pea proteins could be used to benefit people with pre-diabetes. This study further highlights the importance of food-based interventions in the management and prevention of type 2 diabetes. Such studies are likely to play a pivotal role in Asia where the escalating prevalence of type 2 diabetes and the combined consumption of high glycemic index rice, may be delayed by the use of protein-based dietary strategies.

In conclusion, our study demonstrated that the enrichment of a sugar-sweetened beverage with pea and rice proteins reduced glucose excursions, and oat and pea proteins stimulated insulin release. Increasing the protein content of a sugar-sweetened beverage modestly promoted fullness and tended to suppress hunger and desire-to-eat sensations. Plant-based proteins may be used to counter the potential adverse glycemic excursions observed with the ingestion of sugar-sweetened beverages.

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Compliance with ethical standards

Conflict of interest All authors declare no conflict of interest.

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