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Carbohydrate Replacement of Rice or Potato with Lentils Reduces the Postprandial Glycemic Response in Healthy Adults in an Acute, Randomized, Crossover Trial FREE

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Abstract

Background

The postprandial blood glucose response (PBGR) following carbohydrate replacement of high–glycemic index (GI) foods with pulses, in a mixed meal, has not been accurately defined.

Objective

We aimed to determine the extent to which PBGR and relative glycemic response (RGR) are lowered when half of the available carbohydrate (AC) from rice or potato is replaced with cooked lentils.

Methods

Using a crossover design, 2 groups of 24 healthy adults randomly consumed 50 g AC from control white rice alone [mean ± SD body mass index (BMI, in kg/m^2): 24.3 ± 0.5; mean ± SD age: 27.7 ± 1.2 y], instant potato alone (BMI: 24.0 ± 0.5; age: 27.4 ± 1.2 y), or the same starch source in a 50:50 AC combination with each of 3 types of commercially available lentils (large green, small green, split red). Fasting and postprandial blood samples were analyzed for glucose and insulin, and used to derive incremental area under the curve (iAUC), RGR, and maximum concentration (Cmax). Treatment effects were assessed with the use of repeated-measures ANOVA within the rice and potato treatments.

Results

In comparison to rice alone, blood glucose iAUC and Cmax ($P < 0.001$) were lowered after consumption of rice with large green ($P = 0.057$), small green ($P = 0.002$), and split red ($P = 0.006$) lentils. Blood glucose iAUC and Cmax were also significantly lowered ($P < 0.0001$) after consumption of potato combined with each lentil, compared to potato alone. Plasma insulin iAUC and Cmax were significantly ($P < 0.001$) decreased when lentils were combined with potato, but not with rice. The RGRs of rice and potato were lowered by ~20% and 35%, respectively, when half of their AC was replaced with lentils.

Conclusions

Replacing half of the AC from high-GI foods with lentils significantly attenuates PBGR in healthy adults; this can contribute to defining a health claim for pulses and blood glucose lowering.
This trial was registered at clinicaltrials.gov as NCT02426606.

Keywords: lentil, human trial, insulin, post prandial glycemic response, health claim

Topic: body mass index procedure, carbohydrates, glucose, adult, food, lentils - dietary, plasma, postprandial period, potato, rice, starch, blood glucose, insulin, pulse, white rice, cmax

Issue Section: Nutrient Physiology, Metabolism, and Nutrient-Nutrient Interactions

Introduction

The incidence of type 2 diabetes (T2D) continues to increase in North America and worldwide (1, 2); as such, research on its prevention and management is increasingly important. Current research is heavily focused on interventions involving dietary modifications given that diet is a preferred first-line approach in diabetes management (3). Reductions in postprandial blood glucose response (PBGR) are important for achieving improvements in glycemic control (4, 5), which is the aim of any dietary intervention (4), in order to avoid the complications associated with hyperglycemia.

Dietary interventions for diabetes prevention have frequently focused on foods with a low glycemic index (GI) (6), among which pulses stand out not only for having low GIs (7) but also for other positive nutritional attributes including high amounts of dietary fiber, micronutrients, and phytochemicals, low amounts of fat, and rapidly digestible carbohydrates (8, 9). Pulses, defined as the dried seeds of legumes including lentils, chickpeas, dried peas, and beans (10), have long been recommended as part of a healthy diet (11–15). Pulses have also been widely studied for their role in human health, including reduction of T2D risk (9, 15). In a systematic review of 41 randomized controlled clinical trials, pulse consumption was shown to be associated with improvements in markers of long-term glycemic control, regardless of whether pulse consumption was increased in combination with a low-GI, high-fiber diet or regular diet (16). Other studies have focused on acute consumption of various pulse types, with some finding reductions (17–19) and others finding no significant differences (20) in PBGR compared to control foods. These studies have mainly focused on comparing PBGR of pulses with that of a high-GI, starchy control food. However, in the context of meal planning and common dietary practices, pulses are usually consumed in combination with other starchy foods as part of a larger meal.

Intuitively, the combination of a high-GI food with pulses will likely result in a lowering of PBGR; however, the magnitude and consistency of this effect, as well as the minimum effective dose of pulses required to significantly lower PBGR, are unknown (15). The latter represent critical evidence gaps in the advancement of an approved health claim for pulses and blood glucose lowering. Importantly, regulatory approval of a pulse health claim for blood glucose lowering would provide a sound rationale for promoting increased consumption of pulses, which is currently between 8% and 13% amongst persons living in North America (9, 21). An approved health claim would also reinforce current population-based dietary recommendations as well as clinical practice guidelines for the management of persons with diabetes and cardiovascular disease (CVD).

Although all pulses have PBGR-lowering properties, it is not known whether this effect is consistent amongst pulses. For example, in vitro studies have shown that lentil starch has higher slowly digested starch and lower rapidly digested starch, hydrolysis rate, and predicted GI compared to other pulses (22). Similarly, lentil flour displays slower hydrolysis and a lower predicted GI compared to pea and chickpea flours (23). Consequently, we reasoned that these results provide a strong rationale for the use of lentils in an acute human trial in order to accurately determine the extent to which PBGR is lowered when a portion of a high-GI food is replaced with lentils. As the applicability of the outcome of such studies will depend on the relevance of the study design, it is important that lentils are assessed as they would be realistically consumed—cooked and in combination with other foods—and compared to foods that serve a similar dietary role. The latter has been highlighted in available regulatory guidance on food health claims related to the reduction in PBGR (24) and is consistent with promoting dietary recommendations that focus on improving carbohydrate quality in mixed meals.

This study assessed the PBGR-lowering effects of cooked lentils in a mixed meal that included a high-GI food. We employed a novel design in which half of the available carbohydrate (AC) from high-GI, starch-rich foods was replaced by that of cooked lentils in a mixed meal. The aim of this study was to compare PBGR and relative glycemic response (RGR) following meals of starch-rich foods alone and in combination with commercially available lentil varieties.

Methods

Study design and approvals

A randomized crossover design was used in this study; 2 separate groups of participants attended a total of five 3-h morning study visits, separated by a 3- to 7-d washout period, at the Human Nutraceutical Research Unit at the University of Guelph. The study was approved by the University of Guelph Research Ethics Board (REB#14SE012) and registered on clinicaltrials.gov (NCT02426606).

Participant recruitment, screening, and randomization

Healthy adults 18–40 y of age with a BMI (in kg/m^2) of 20–30 were recruited from Guelph, Ontario, Canada. Exclusion criteria included diabetes (fasting blood glucose ≥7.0 mmol/L), impaired fasting glucose (fasting blood glucose 6.1–6.9 mmol/L), major medical conditions, medical or surgical events requiring hospitalization within 3 mo, medication use except stable (3 mo) doses of oral contraceptive, blood pressure >140/90 mm Hg, use of probiotics, dietary fiber, or any other natural health products for glycemic control, consumption of >4 servings of pulses/wk, food allergies or nonfood life-threatening allergies, pregnancy or breastfeeding, shift work, recent significant weight loss or gain (>4 kg within 3 mo), tobacco use, alcohol consumption of >14 drinks (196 g ethanol)/wk or >4 drinks (56 g ethanol)/sitting, and being an elite athlete.

Participants were screened with the use of a phone questionnaire and those eligible were invited to an onsite screening visit. They arrived after a 10–12-h overnight fast and having been asked to avoid alcohol, unusual physical activity, over-the-counter medication, and consumption of pulses for 24 h prior. Participants completed an extended eligibility questionnaire and had height and body weight measurements taken. A fasted blood sample was collected by finger prick and immediately analyzed in duplicate for glucose with the use of the StatStrip Glucose Hospital Meter (#53634, Nova Biomedical Canada Ltd, Mississauga, Ontario, Canada). Eligible participants were assigned to a group (rice or potato) and the order in which they would consume treatments was determined with the use of an online random number generator (https://www.randomizer.org/). The study consent form was signed during a study orientation session.

Study treatments

Study treatments were standardized to provide 50 g AC, based on glycemic carbohydrates (total starch and free sugars) and proximate analysis (Table 1). The latter was performed on raw foods in order to prevent errors associated with moisture loss after cooking. Analyses performed before and after cooking showed no difference in total starch, free sugar, and resistant starch.

TABLE 1

Nutritional composition of study treatments[1]

	Rice group treatments				Potato group treatments	
	Long-grain white rice	Large green lentil + rice	Small green lentil + rice	Split red lentil + rice	Instant white potato	Large green lentil + potato
Energy, kcal	237	339	330	309	265	353
Protein, g	4.4	18.2	18.0	14.9	7.0	19.5
Fat, g	0.5	1.4	1.3	1.1	0.3	1.2
Carbohydrate, g	54.2	67.6	65.4	61.5	61.3	71.1
Dietary fiber, g	0.9	8.2	7.5	3.2	5.4	10.5
Available carbohydrate,	50	50	50	50	50	50

[2] g

[1]Proximates were obtained for individual foods (lentil, rice, and potato) and used to calculate the nutritional composition of the mixed meals. Composition of the study treatments was determined commercially (Maxxam Analytics International Corporation, Mississauga, Ontario, Canada) (n = 1) using the following methods: energy, by calculation; ash, AOAC 923.03; fat, AOAC 922.06 and 933.05; protein, AOAC 992.15; carbohydrate by difference. Moisture (Mettler Toledo Classic Plus HB43-S, Metler Toledo Inc., Mississauga, Ontario, Canada), dietary fiber (AOAC 991.43), free sugars (25), total starch (AACC Method 76-13.01 with DMSO pre-treatment as outlined by the kit manufacturer; Megazyme International Ireland Ltd., Bray, Ireland), and resistant starch (AOAC 2002.02 as outlined by the kit manufacturer; Megazyme International Ireland Ltd., Bray, Ireland) were measured in-house using established methods.

[2]Available carbohydrate = [total starch – resistant starch] + free sugars.

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Treatments included white rice (Selections Long Grain White Rice; Metro Inc., Montreal, Quebec, Canada) or white potato (Idahoan Original Mashed Potatoes; Idaho Fresh-Pak, Inc., Idaho Falls, ID) alone or in combination with 3 different varieties of lentils (large green, small green, and split red lentils; Alliance Grain Traders Inc., Regina, Saskatchewan, Canada) and white bread (Wonder White Bread, Weston Bakeries Ltd., Toronto, Ontario, Canada) which served as a standard test.

On the morning of each study visit, treatments were prepared in the metabolic kitchen of the Human Nutraceutical Research Unit. All cooking protocols were standardized and serving sizes were predetermined based on AC. Rice and lentils were prepared in separate rice cookers (Black & Decker Inc., model # RC3406C Type 1, New Britain, CT) after being rinsed separately with cold tap water, drained, and placed into their respective rice cooker with a fixed amount of water to facilitate optimal cooking and no residual liquid. Lentils were considered cooked when 8 out of 10 seeds had little to no resistance to squeezing between thumb and forefinger. Potato flakes were mixed with hot water. White bread was de-crusted and cut into small squares. All treatments were consumed within 10 min with 250 mL of bottled water, except for potato treatments when participants were allowed to drink water ad libitum, since the meal contained about twice as much water as the other treatments. Participants were also provided with salt and pepper to add as desired to all study treatments.

Study procedures and blood analysis

At each study visit, participants arrived after a 10–12-h overnight fast having been instructed to avoid alcohol, unusual physical activity, over-the-counter medication, and consumption of pulses for 24 h prior and to consume the same dinner (of their choice) the evening prior.

Anthropometric measurements

Body weight was measured in duplicate at each study visit (Acculab Sartorius Group SVI-200F, Sartorius Stedim Biotech, Aubagne, France) without shoes and without heavy objects in participants' pockets. Height was measured without shoes with the use of a SECA Portable Stadiometer 214 (Hanover, MD). Blood pressure was measured in duplicate after participants had been seated for 5–10 min (Omron Digital Blood Pressure Monitor, HEM-907 XL, Omron Healthcare Inc., Burlington, Ontario, Canada). Waist circumference was measured in duplicate at the first study visit.

Blood collection and analysis

Blood samples were collected via finger prick into a Microtainer microtube (1.0mg K_2EDTA) with the use of a Microtainer contact-activated lancet (1.5mm X 2.0, Becton Dickinson, Mississauga, Ontario, Canada) at fasting and 15, 30, 45, 60, 90, and 120 min after the first bite of the study treatment. Blood samples were immediately analyzed in duplicate for glucose, as before, with the use of a StatStrip Glucose Hospital Meter, which had an inter- and intra-assay variation of 7.47% and 1.80%, respectively. Remaining blood was centrifuged (Beckman Coulter Allegra X-22R, Beckman Coulter, Mississauga, Ontario, Canada; or Thermo Scientific Sorvall ST8R centrifuge, Thermo Fisher Scientific, Cambridge, MA) within 15 min at 1200 × *g* for 10 min at 4°C. Plasma was aliquoted into 1.2-mL cryovials (Corning 1.2 mL Internal Threaded Polypropylene Cryogenic Vial, Corning Inc., Corning, NY) and stored at −80°C until analysis. All plasma samples were analyzed in duplicate for insulin with the use of a commercial kit (Insulin ELISA, ALPCO, Salem, NH). Inter- and intra-assay variation for plasma insulin was 9.49% and 2.71%, respectively.

Data and statistical analysis

A total of 24 participants were included in each study group to account for possible attrition while enabling detection of a minimum 20% reduction in blood glucose incremental AUC (iAUC) at a 5% significance with 80% power. Postprandial blood glucose and plasma insulin response curves for each treatment were summarized by analysis of 2-h iAUC using the trapezoid rule (26). RGR was calculated by dividing the iAUC of lentils treatments by the iAUC of the controls (rice or potato) and multiplying the ratio by 100 (26). Maximum blood glucose concentration (Cmax) and time at Cmax for each time point curve were determined by inspection in Microsoft (Redmond, WA) Excel spreadsheets.

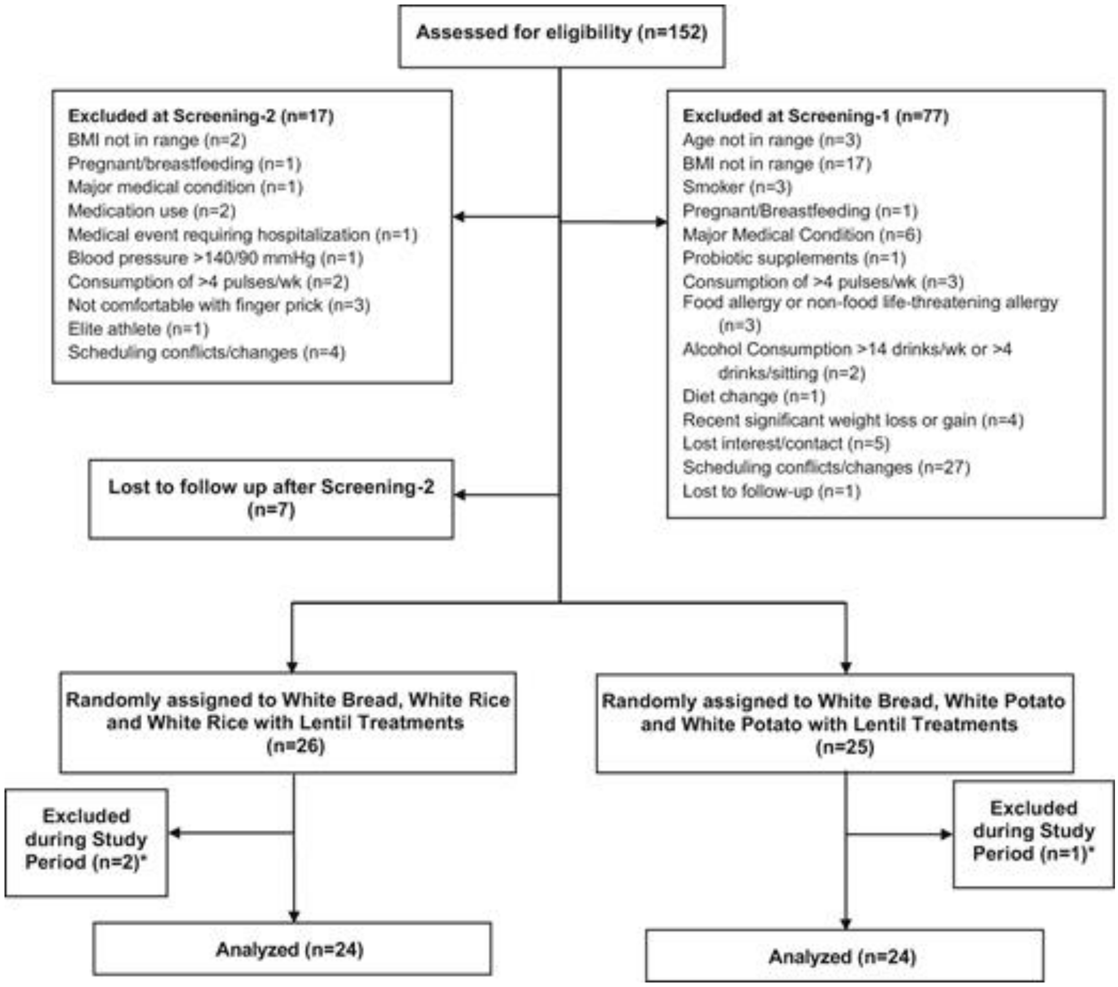
All statistical analyses were performed with the use of the Statistical Analysis System (version 9.4, Cary, NC) with $P < 0.05$ considered statistically significant. Data were examined for normality and it was determined that insulin data required log transformation. Insulin data are therefore presented as geometric means and 95% CIs. All variables were compared among treatments within groups with the use of 1-factor repeated-measures ANOVA and Tukey's post hoc tests for multiple comparisons.

Results

Participant flow and characteristics

A total of 26 and 25 participants were randomly assigned to the rice and potato treatment groups, respectively. Two participants were excluded from the rice treatment group and 1 from the potato treatment group due to impaired glucose tolerance, leaving a total of 24 participants who completed each of the rice and potato treatments (Figure 1). On average (mean ± SE), participants in the rice and potato treatment groups were, respectively, 27.7 ± 1.2 and 27.4 ± 1.2 y old and had BMIs of 24.3 ± 0.5 and 24.0 ± 0.5 (Table 2). Eleven participants completed both the rice and the potato treatments.

FIGURE 1



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Participant flow diagram. *2-h white bread challenge indicated prediabetes.

TABLE 2

Participant baseline characteristics for rice and potato treatment groups[1]

	Rice (*n* = 24)	Potato (*n* = 24)
Age, y	27.7 ± 1.2	27.4 ± 1.2
Sex, *n*	9 male/15 female	10 male/14 female
Body weight, kg	73.4 ± 2.6	71.4 ± 2.3
BMI, kg/m^2	24.3 ± 0.5	24.0 ± 0.5
Waist circumference, cm	83.1 ± 1.7	83.2 ± 1.7

Systolic blood pressure, mm Hg	116 ± 2	115 ± 2
Diastolic blood pressure, mm Hg	68 ± 2	67 ± 2

[1]Values are means ± SEs unless otherwise indicated.

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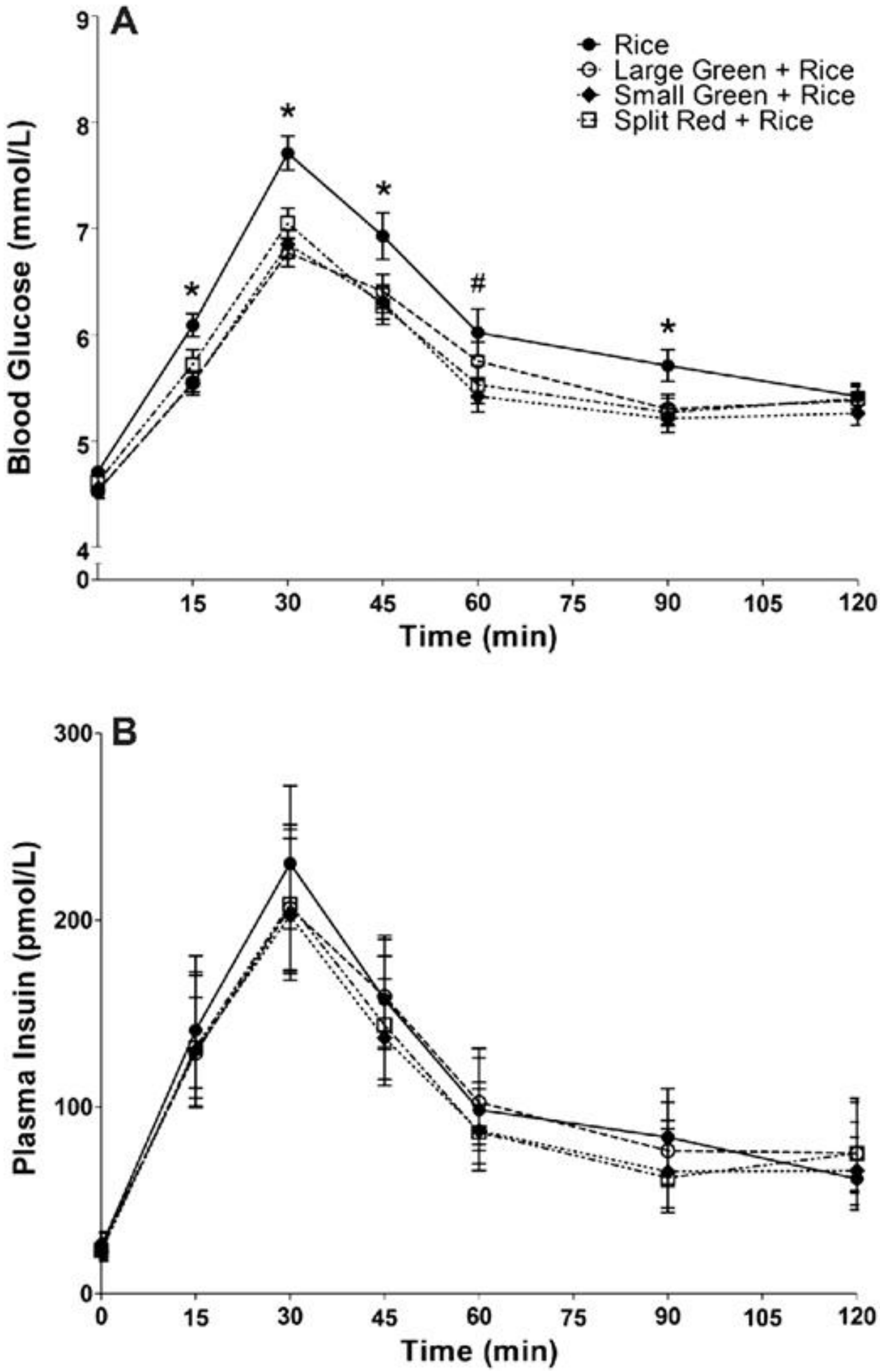
Blood glucose and insulin response

Blood glucose and plasma insulin after rice- (Figure 2) and potato-containing (Figure 3) treatments showed similar patterns over time with an increase from baseline following consumption, peaking most frequently at 30 min, and returning towards baseline by 120 min. Compared to rice alone, lentil and rice mixed meals resulted in significantly lower ($P < 0.05$) blood glucose at 15, 30, 45, and 90 min following consumption (Figure 2A). At 60 min, blood glucose for rice alone was significantly higher ($P < 0.05$) than small green and split red lentil, but not large green lentil mixed meals. Plasma insulin was not different at any time point (Figure 2B). Table 3 shows that compared to rice alone, blood glucose iAUC and Cmax were lowered with consumption of rice combined with large green ($P = 0.057$ and $P < 0.0001$, respectively), small green ($P = 0.002$ and $P < 0.0001$, respectively), and split red ($P = 0.006$ and $P = 0.0004$, respectively) lentils, and were not significantly different among the lentil varieties. Replacement of half of the AC of rice with large green, small green, and split red lentils resulted in mean ± SE RGR of 86.5% ± 6.5%, 78.5% ± 5.0%, and 79.5% ± 6.3%, respectively, compared to rice (Table 3), translating to a 13.5%, 21.5%, and 20.5% reduction in glycemic response.

FIGURE 2



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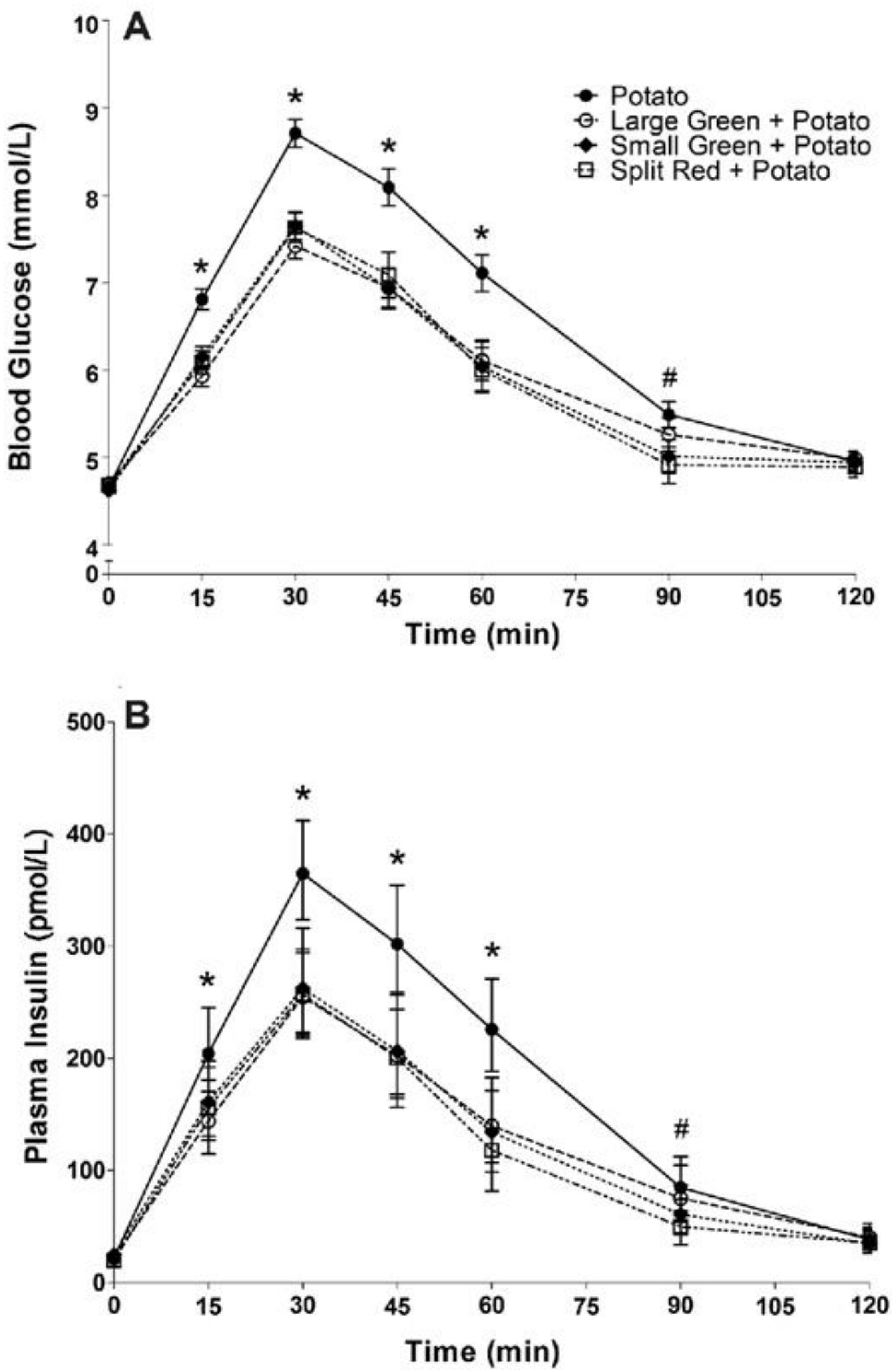
Postprandial blood glucose (A) and plasma insulin (B) response curves of healthy adults after rice or lentil + rice treatments. Glucose values are means ± SEs, $n = 24$. Insulin values are geometric means and 95% CIs, $n = 24$. *Different from all lentil + rice treatments at that time, $P < 0.05$. #Different from small green lentil + rice, and split red lentil + rice at that time, $P < 0.05$.

FIGURE 3



Postprandial blood glucose (A) and plasma insulin (B) response curves of healthy adults after potato or lentil + potato treatments. Glucose values are means ± SEs, $n = 24$. Insulin values are geometric means and 95% CIs, $n = 24$. *Different from all lentil + potato treatments at that time, $P < 0.05$. [#]Different from small green lentil + potato and split red lentil + potato at that time, $P < 0.05$.

TABLE 3

Postprandial blood glucose and plasma insulin response in healthy adults following consumption of long-grain white rice with and without different lentil varieties[1]

	Rice	Large green lentils + rice	Small green lentils + rice	Split red lentils + rice
Postprandial blood glucose				
Glucose iAUC, mmol/L·min	170 ± 12[a]	142 ± 13[a,b]	130 ± 11[b]	133 ± 14[b]
Glucose Cmax, mmol/L	7.8 ± 0.2[a]	6.9 ± 0.1[b]	6.9 ± 0.1[b]	7.1 ± 0.1[b]
Relative glycemic response, %	100	86.5 ± 6.5	78.5 ± 5.0	79.5 ± 6.3
Postprandial plasma insulin				
Insulin iAUC, nmol/L·min	10.9 (8.9, 13.5)	10.4 (8.5, 12.8)	9.7 (7.7, 12.2)	10.0 (7.8, 12.8)
Insulin Cmax, nmol/L	0.24 (0.20, 0.28)	0.22 (0.18, 0.25)	0.21 (0.17, 0.25)	0.22 (0.18, 0.26)

[1]Values are arithmetic means ± SEs or geometric means (95% CIs), $n = 24$. Labeled means in a row without a common superscript letter differ, $P < 0.05$. Cmax, maximum concentration; iAUC, incremental AUC.

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Compared to potato alone, lentil and potato mixed meals resulted in significantly lower ($P < 0.05$) blood glucose (Figure 3A) and insulin (Figure 3B) at all time points between 15 and 60 min following consumption. At 90 min, mean blood glucose and insulin for potato alone were significantly higher ($P < 0.05$) than were small green and split red lentil, but not large green lentil mixed meals. Blood glucose and insulin iAUC and Cmax (Table 4) were significantly lowered ($P < 0.05$) with consumption of potato combined with large green, small green, and split red lentils compared to potato alone ($P < 0.0001$ for all comparisons) but did not differ significantly among the lentil varieties. The RGR (mean ± SE) resulting from replacement of half of the AC of potato with large green, small green, and split red lentils was 66.2% ± 3.7%, 66.1% ± 3.8%, and 64.4% ± 3.6%, respectively, compared to potato (Table 4), translating to a 33.8%, 33.9%, and 35.6% reduction in glycemic response.

TABLE 4

Postprandial blood glucose and plasma insulin response in healthy adults following consumption of instant white potato with and without different lentil varieties[1]

	Potato	Large green lentils + potato	Small green lentils + potato	Split red lentils + potato
Postprandial blood glucose				
Glucose iAUC, mmol/L·min	234 ± 12[a]	153 ± 12[b]	158 ± 16[b]	152 ± 15[b]
Glucose Cmax, mmol/L	8.8 ± 0.2[a]	7.6 ± 0.2[b]	7.7 ± 0.2[b]	7.8 ± 0.2[b]
Relative glycemic response, %	100	66.2 ± 3.7	66.1 ± 3.8	64.4 ± 3.6
Postprandial plasma insulin				
Insulin iAUC, nmol/L·min	19.9 (17.3, 23.0)[a]	13.1 (10.7, 16.1)[b]	12.8 (10.2, 16.1)[b]	12.3 (9.8, 15.5)[b]
Insulin Cmax, nmol/L	0.38 (0.34, 0.43)[a]	0.27 (0.23, 0.31)[b]	0.28 (0.23, 0.34)[b]	0.27 (0.23, 0.32)[b]

[1]Values are arithmetic means ± SEs or geometric means (95% CIs), $n = 24$. Labeled means in a row without a common superscript letter differ, $P < 0.05$. Cmax, maximum concentration; iAUC, incremental AUC.

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Discussion

This study demonstrated that replacing half of the AC from a starch-rich food, such as rice or potato, with lentils in a mixed meal significantly reduced PBGR and glucose Cmax. Large green, small green, and split red lentils all lowered blood glucose iAUC and RGR compared to both the rice and potato controls. The decreases in PBGR were not due to hyperinsulinemia, as evidenced by the fact that insulin iAUC for the lentil treatments was either not significantly different (compared to rice) or significantly lower (compared to potato). These results suggest that AC replacement is an effective approach for attenuating PBGR, which in the long term could reduce risk for both T2D and CVD (4, 15, 27) as well as complications associated with T2D (28, 29).

To our knowledge, this is the first study to report the effects on PBGR when lentils replace a fixed amount of AC (in this case 50%) from starch-rich, high-GI foods. In this study, all meals were standardized to contain 50 g AC with lentils providing 25 g AC, which provides a realistic meal scenario given that lentils are frequently consumed as side dishes alongside or in combination with high-GI, starch-rich foods.

Results of the current study are consistent with that of Mollard et al. (30) who found a significant reduction in blood glucose AUC when healthy adults consumed lentils with tomato sauce compared to a white bread control. However, interpretation of that study was confounded by the fact that the white bread control contained almost 12 g more AC than the lentil treatment, which highlights a key challenge in PBGR studies regarding whether treatments should be standardized according to volume, energy content, AC, or other characteristics. Since PBGR is largely dependent on the amount of AC, treatments in the current study were standardized according to AC, although other factors (e.g., volume) may have influenced results. Standardizing treatments according to AC was used by Anderson et al. (19) to compare differently processed (whole, pureed, powdered) lentils mixed with sauce, with a whole wheat flour control. They found that whole and powdered lentils significantly reduced blood glucose AUC compared to whole wheat flour, while pureed lentils led to an intermediate response (19). This study showed that processing lentils may affect their biological efficacy; however, it did not address the issue of replacement of AC from a high-GI food with that of a pulse.

Pulses are rarely consumed in isolation so it is best to evaluate their PBGR-lowering effect in the context of mixed meals. Anguah et al. (18) used mixed-meal treatments to evaluate PBGR after whole or blended lentils were consumed, and although the difference in AC between the treatment and control was large (20 g), a burrito containing blended lentils was found to significantly decrease blood glucose AUC compared to a lentil-free burrito. In another mixed-meal study, Jenkins et al. (31) found that lentils served with butter and tomatoes resulted in a PBGR that was similar to wholemeal bread with cottage cheese and tomatoes consumed in small portions over 4 h. Unfortunately, the result of this study was likely confounded by the protracted eating time and a slightly lower AC content of the lentil treatment.

The combination of lentils with starch-rich foods was utilized in 2 separate studies by Mollard et al. (17, 20) that examined the PBGR of lentils combined with pasta. In the 2011 study, the lentil treatment and control were almost equal in AC and energy content, but no significant effect on PBGR was seen. Treatments in the current study were prepared on the morning of each visit, as opposed to the day before in the Mollard study (20); whether this had an effect on resistant starch content through heating and cooling cycles is unclear, but highly likely. In the 2012 study by Mollard et al. (17), treatments were also prepared the day before each study visit and the authors found that lentils with pasta and sauce significantly reduced postprandial blood glucose AUC compared to pasta and sauce. However, in that study, ad libitum feeding resulted in participants consuming approximately 20 g more AC from the control (17). In some of the previously mentioned studies, treatments often had energy contents of 600–800 kcal, which seems excessive for a single meal. Treatments in the current study contained 230–350 kcal, were matched for AC, contained common starchy foods for which mixed-meal PBGR data are lacking, and used a novel replacement approach, thereby addressing many inconsistencies in the literature.

Although the components in lentils responsible for blunting PBGR are yet to be elucidated, several suggestions have been advanced. Any lentil component that affects starch digestion, and thus glucose entry into the blood, may contribute to reduced PBGR. Lentils have a high slowly digestible starch and resistant starch content, and a low rapidly digested starch content (22); the PBGR-lowering effect found in our study could be partially attributed to this combination. Lentils also contain high amounts of protein, which can interact with starch to slow or prevent starch digestion in the upper gastrointestinal tract (23). Additionally, total dietary fiber has long been suggested to attenuate postprandial blood glucose by increasing the viscosity of intestinal contents (32). However, the split red lentils in this study contained less than half of the amount of dietary fiber of the large and small green lentils, yet all lentil varieties were effective and did not differ significantly in their ability to decrease PBGR. Phenolic compounds have also been found to have an effect on starch digestion—some by inhibiting starch-digesting enzymes, and others by interacting with the starch (33). A study by Zhang et al. (34) found a significant correlation between amounts of phenolic compounds (especially flavonols) in different lentil varieties and reduction in α-glucosidase activity in vitro. In addition, Amoako and Awika (33) showed that tannins had a large effect on starch digestion when various starches were incubated with a high-tannin sorghum extract.

The current study was limited in its inability to elucidate the mechanism of action in PBGR reduction. This study was also unblinded since participants were aware of which treatment they were consuming. There may be concern that proximate analyses were performed on raw, not cooked, samples, which leaves the possibility that some nutrient levels changed following cooking. However, the use of published food composition tables to derive nutrient content and serving sizes is common in glycemic response studies. Our study was superior in that serving sizes for the test foods were based on AC, calculated from our measurements of total starch and free sugars; we also determined that these values were not changed with cooking. We acknowledge that the instrument used to measure blood glucose was not the gold standard, although it is widely applied in clinical settings. Lastly, the study was conducted in healthy adult participants, leaving information unknown regarding other populations such as the overweight or obese, postmenopausal women, elderly, and individuals at risk for T2D.

The study also has several strengths, including the use of a randomized crossover design, which reduced confounding factors, and a realistic and novel treatment design wherein lentils replaced half the AC from starch-rich foods. In addition, all the treatments contained the same amount of AC, which allowed for simple comparison of PBGR. The lentils used in this study were common Canadian market-class varieties and therefore widely available to the public. Studying lentils both with and without the hull allowed for detection of differences in PBGR based on this difference, and none were found, which is useful information pertaining to dietary recommendations.

In conclusion, replacing half of the AC from a starch-rich food with lentils significantly reduced postprandial blood glucose iAUC, Cmax, and RGR; this approach could be helpful in lowering postprandial glycemic response. As efforts to increase pulse consumption continue, scientific substantiation of the health benefits is warranted; this study adds to such evidence. However, similar studies need to be conducted on other populations and with other pulses in order to determine whether they are equally effective in lowering PBGR.

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Notes

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Abbreviations used: AC, available carbohydrate; Cmax, maximum concentration; GI, glycemic index; iAUC, incremental area under the curve; PBGR, postprandial blood glucose response; RGR, relative glycemic response; T2D, type 2 diabetes.

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