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Original article

Lower nocturnal blood glucose response to a potato-based mixed evening meal compared to rice in individuals with type 2 diabetes

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SUMMARY

Background & aims: Guidelines for reducing postprandial blood glucose concentrations include avoiding high glycemic index (GI) foods, such as white potatoes. However, GI testing is often undertaken in the morning with foods consumed in isolation by non-clinical cohorts. We investigated the impact of potato preparation and consumption as part of a mixed-evening meal on postprandial and nocturnal glycemic responses, and postprandial insulin response, in individuals with Type 2 Diabetes Mellitus (T2DM).

Methods: In a randomized, cross-over design, 24 males and females (age 58.3 ± 9.3 y; BMI: 31.7 ± 6.8 kg/m^2) with T2DM (diet or metformin controlled) completed four experimental trials after consuming a standardized breakfast (25% daily energy intake (EI)) and lunch (35% EI). Dinner (40% EI) was consumed at 1800 h being either: 1) boiled potato (BOIL); 2) roasted potato (ROAST); 3) boiled potato cooled for 24 h (COOLED); or 4) basmati rice (CONTROL). Each meal contained 50% carbohydrate, 30% fat and 20% protein. Blood samples were collected prior to, immediately post meal and at 30-min intervals for a further 120 min. A continuous glucose monitor was worn to assess nocturnal interstitial glucose concentrations.

Results: No differences were detected in postprandial venous glucose area under the curve (iAUC) between CONTROL and all three potato conditions. Postprandial insulin iAUC was greater following COOLED compared to CONTROL ($P = 0.003$; 95% CI: 18.9–111.72 miU/mL). No significant differences between CONTROL and BOIL or ROAST were detected for postprandial insulin concentrations. All potato meals resulted in lower nocturnal glucose AUC than CONTROL ($P < 0.001$; 95% CI 4.15–15.67 mmol/L x h).

Conclusion: Compared to an isoenergetic rice meal, boiled, roasted or boiled then cooled potato-based meals were not associated with unfavourable postprandial glucose responses or nocturnal glycemic control, and can be considered suitable for individuals with T2DM when consumed as part of a mixed-evening meal.

Clinical trial registration: Australian New Zealand Clinical Trials Registry https://www.anzctr.org.au/, ACTRN 12618000480280.

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1. Introduction

Potatoes are the leading vegetable crop in the United States and economically the fourth most important food crop in the world [1], providing several key nutrients including potassium, dietary fibre and vitamin C, and having a low sodium content. However, potato consumption is declining worldwide [2], and has reduced by ~20% in Australia during the past two decades [3]. Furthermore, consumers' level of nutritional knowledge of potato is poor, and people in Europe and Australia perceive potatoes negatively due to their high carbohydrate content [2,4].

Despite a relatively low energy density, potatoes are classified as a high glycemic index (GI) food. While dietary management of Type 2 Diabetes Mellitus (T2DM) is complex, the use of GI of carbohydrate foods is of interest to individuals with T2DM [5]. Evidence based guidelines recommend consuming low GI foods (i.e., wholegrain bread, legumes and basmati rice) in place of high GI foods (such as potatoes) to manage glycemic control [5–8]. While the GI of potatoes has been well documented, there is wide variability depending on potato variety and cooking method [9,10]. The protocol for GI testing requires foods to be consumed in isolation,

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Abbreviations

GI	glycemic index
T2DM	Type 2 Diabetes Mellitus
BMI	body mass index
EI	energy intake
BOIL	boiled potato
ROAST	roasted potato
COOLED	boiled potato cooled for 24 h
CONTROL	basmati rice
AUC	area under the curve
HbA1c	hemoglobin A1c
BM	body mass
DXA	Dual X-ray absorptiometry
CV	coefficient variation
RMR	resting metabolic rate
CGM	continuous glucose monitor
VAS	visual analogue scale
REE	resting energy expenditure
TEI	total energy intake
ELISA	Enzyme-linked immunosorbent assay
CHO	carbohydrate
GL	glycemic load

typically following an overnight fast in 'healthy' individuals with normal glycemic control [11]. There are major limitations using the GI of single foods and their acute effect on blood glucose when trying to determine their influence on long-term health indices, particularly in individuals with T2DM [1]. Indeed, individual foods are rarely consumed in isolation but are more likely to be eaten with other foods as part of mixed meals. In this regard, the GI and glycemic response to potatoes is influenced by not only the co-ingestion of other foods and their physical properties (i.e. macronutrient composition), but also by the method of preparation and cooking, which can substantially alter the content of resistant starch [1,9,10]. With repeated cooling and reheating, the resistant starch content of potatoes is known to increase, slowing digestion and absorption, and consequently reducing glycemic response [9]. Finally, there is large individual variability in the glycemic response to the same foods, regardless of the GI [12].

The current study determined the impact of different methods of potato preparation when consumed as part of a mixed-evening meal on postprandial glycemic response. Additionally, the study determined the nocturnal glycemic responses and postprandial insulin response in individuals with T2DM. We compared several potato-based meals to a low GI (basmati rice) isoenergetic, macronutrient-matched control meal, and hypothesized that co-ingestion of potato as part of a mixed meal would not result in worsened postprandial or nocturnal glycemic response, or postprandial insulin responses. A secondary hypothesis was that pre-cooking then cooling potato before consumption would lower the postprandial glycemic response of potato as part of a mixed-evening meal due to changes in resistant starch.

2. Materials and methods

2.1. Study design

Participants completed four experimental conditions in a randomized, cross-over design, separated by a 9-day washout period (Fig. 1). The study was conducted at the St Patrick's (Fitzroy, Victoria) campus of Australian Catholic University (ACU; July 2018–April 2019). The study was approved by the ACU Human Research Ethics Committee (2017-263H), prospectively registered with the Australian New Zealand Clinical Trials Registry (ANZCTR12618000480280) and was carried out in accordance with the Declaration of Helsinki. Eligible participants provided written informed consent.

2.2. Participants

Adults with overweight/obesity (body mass index (BMI) 25–45 kg/m^2), aged 35–75 years old and diagnosed with T2DM (diet or metformin controlled, ≥3 months' duration, based on American Diabetes Association diagnostic criteria) and a sedentary lifestyle (in terms of both activity and job; <150 min/week of moderate-intensity exercise for >3 months and >3 h/d sitting) were recruited via social media advertisements. Potential participants were excluded if they met the following exclusion criteria: HbA1c <6.5% or ≥9%, taking insulin or any other hypoglycemic agents except metformin, pregnancy, pre-peri menopausal, current smoker, major systemic illness, previous bariatric surgery, gastrointestinal disorders and intolerance to principal study foods. Telephone pre-screening included medical history, age, self-reported height and body mass (BM; to calculate BMI) and detailed explanation of the study.

2.3. Baseline testing

After initial telephone pre-screening, eligible participants attended the lab for a morning, fasted, baseline testing visit a minimum of one week prior to the first experimental condition where height and body mass were measured using a wall-mounted stadiometer and digital scales (SECA 703 scales, Hamburg, Germany). Resting blood pressure was measured in duplicate using an automated oscillometric blood pressure monitor (Welch Allyn, NY, USA). Waist and hip circumference were measured using a metal tape measure (Lufkin W606 2M, Texas, USA) in duplicate to the nearest 0.1 cm, or triplicate if the difference between the first two measures was >0.5 cm. Following this, participants underwent a dual-energy x-ray absorptiometry (DXA) scan (GE Lunar iDXA Pro, enCORE software 2009, version 16, General Electric, Boston, USA) to obtain total mass (kg), fat mass (FM; kg) and fat-free mass (FFM; kg) with a coefficient of variation (CV) of <1.5% for all measures in our laboratory. Finally, participants underwent a test to determine resting metabolic rate (RMR) (TrueOneRMR, Parvo Medic, Sandy, UT, USA) to determine resting energy expenditure (REE) as previously described [23].

2.4. Study protocol

Block randomization by cohort was determined using computer generated random numbers and sealed opaque envelopes. Participants were assigned to cohorts of n = 2–5 for experimental trials. Three days of habitual monitoring of each participant took place prior to each experimental condition (Day −3, Day −2 and Day −1; Fig. 1). During this time, dietary intake was recorded via a three-day food record, which participants were asked to replicate and record prior to each subsequent trial. On Day −3, activity monitors were fitted (details outlined below). Additionally, a continuous glucose monitor system (CGMS; iPro2 CGM with Enlite Sensor, Medtronic, Northridge, CA, USA) was inserted into the subcutaneous fat tissue of the lower back and secured with waterproof dressings. Following

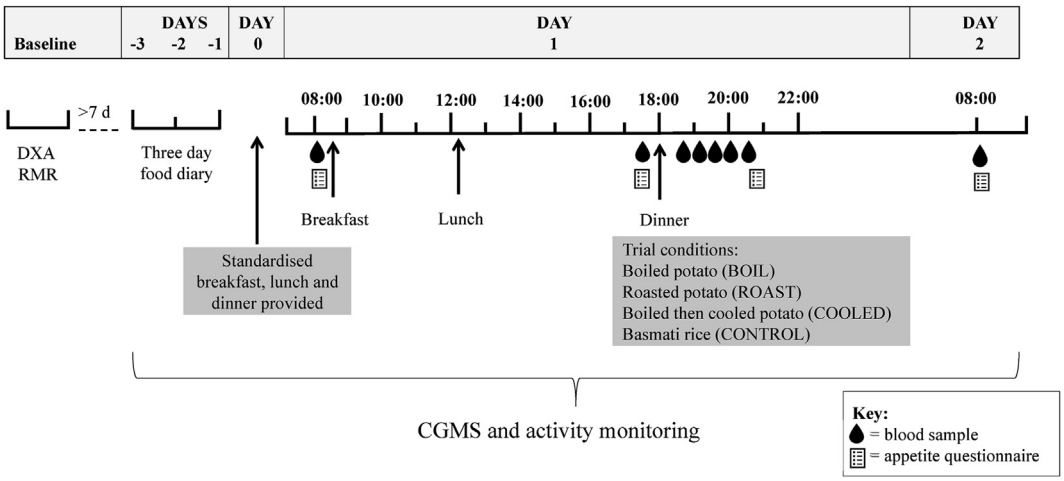

Fig. 1. Schematic of study protocol. Four trial conditions (evening meals consisting of boiled potato, roasted potato, boiled then cooled potato and basmati rice) were completed in a randomized order separated by a 9-day washout. Interstitial glucose was measured continuously throughout each trial condition (from Day −3 through to Day 2) via a continuous glucose monitoring system (CGMS).

insertion, a one-hour period was used to allow the CGM sensor to adjust to the interstitial fluid before the initial calibration. A hand-held, commercial, time-stamped glucometer (Accu-Chek Performa II, Roche Diagnostics Ltd., Basel, Switzerland) was used for CGMS calibration from finger stick samples four times per day of wear (before each meal and sleep).

On Day 0 (Fig. 1), all participants were provided with standardized meals including breakfast, lunch and dinner to be consumed at 0830, 1300, and 1800 h respectively. On Day 1 (trial day), participants arrived at the laboratory at 0745 h for a fasted blood sample (6 mL; EDTA) via forearm venipuncture. Participants were then provided with a standardized breakfast to be consumed in the laboratory (at ~0830 h). Before leaving the laboratory participants were provided the same lunch as Day 0 to be consumed in 'free-living' environment at ~1300 h. Participants then returned to the laboratory at 1730 h and a cannula (22G; Terumo, Tokyo, Japan) was inserted into the antecubital vein, before consuming an evening meal, which varied depending on the condition being tested. The four conditions tested were: boiled potato (BOIL), roasted potato (ROAST), boiled potato and then cooled for 24 h and reheated prior to consumption (COOLED) and control condition of basmati rice (CONTROL) (Fig. 1). The basmati rice control meal was identical to the dinner meal provided on Day 0. Blood samples (6 mL; EDTA) were collected prior to evening meal consumption, immediately post meal and at 30-min intervals following the post-meal blood sample up to 120 min post meal completion (30, 60, 90, 120 min post). Visual analogue scales (VAS; where 0 = low (i.e. not full) and 100 = high (i.e. very full)) for hunger, satiety, fullness and appetite [24] were completed using a computer based program on four occasions per experimental condition: Day 1 before breakfast (Day 1 fasted; D1F), before evening meal on Day 1 (T0), 120 min following evening meal after dinner (T120) and Day 2 fasted (D2F) before all monitors removed (Fig. 1). At ~2100 h the cannula was removed, and participants vacated the laboratory. Participants returned to the laboratory at ~0800 h on Day 2 for a final fasted blood sample (6 mL; EDTA) and removal of all monitoring devices.

The nutrient composition of all foods in each experimental condition was obtained using FoodWorks© (Version 9, Xyris Software, Brisbane, Australia). Total daily estimated energy intake (kJ/d) was calculated using REE measured at the first baseline visit multiplied by a 1.3 activity factor to determine the total energy to be provided on Day 0 and Day 1. Energy distribution of standardized meals was spread as 25% of total energy intake (TEI) at breakfast, 35% of TEI at lunch and 40% of TEI at dinner meal. No snacks were provided or consumed on Day 0 or Day 1. Diet composition for the total day for Day 0 and Day 1 was 50%TEI from carbohydrate, 30%TEI from fat and 20%TEI from protein with each meal also consisting of this same macronutrient composition. Participants were instructed to consume the meals at standardized times throughout both experimental conditions (within 30 min of 0830, 1300 and 1800 h) and the evening meal on Day 1 was provided in the laboratory at ~1800 h. Time of meal consumption was recorded by participants in the study handbook and cross-checked by researchers during the laboratory visits.

During each experimental period (Day −3 through to Day 2), participants abstained from alcohol consumption, but habitual caffeine consumers were instructed to consume and record caffeine intake (no added milk or sugar/sweetener) as usual on Day 0, with no caffeine consumed on Day 1 for all conditions. Participants were able to consume water *ad libitum* and were instructed to record daily water intake volume. All potatoes provided within the study were Russet Burbank variety (Mount Prospect Produce, Daylesford, Victoria, Australia). Potato preparation was consistent prior to all trials and conditions. Potatoes were peeled, washed and cut into 30 g cubes for all cooking methods. Boiled potatoes and roasted potatoes were cooked immediately prior to consumption. The roasted potatoes were prepared in a convection oven with no fat or oil added in cooking process. Cooled potato condition involved boiling potatoes 28 h prior to consumption, allowing potatoes to cool for 24 h and reheating immediately prior to consumption. Basmati rice was purchased in microwave packs and prepared in the microwave according to packet instructions. The remainder of the mixed evening meal consisted of crumbed chicken breast, prepared in the convection oven and frozen mixed vegetables (carrot, cauliflower and broccoli) prepared in the microwave.

2.5. Activity monitoring

Participants were asked to continue their regular daily activities (i.e. work and home life) throughout the study period. Throughout each trial period, participants wore an activPAL inclinometer (activPAL3™ tri-axial physical activity monitor, PAL-technologies Ltd., Glasgow, Scotland) on the thigh, and an ActiGraph accelerometer (ActiGraph GTX3+, Pensacola, FL, USA; during waking hours only) around the waist over the right hip, to assess and monitor physical activity and movement patterns. Participants

were asked to maintain their habitual sleep routine and sleeping patterns throughout the study periods.

2.6. Biochemical analysis

Upon collection, blood samples (EDTA) were inverted and triglycerides were measured from whole blood using a Cobas b 101 instrument (Roche Diagnostics Ltd, Basel, Switzerland). The remaining blood was centrifuged at 1800 g, for 10 min at 4 °C and plasma was aliquoted and stored at −80 °C for subsequent analysis. From thawed samples, plasma glucose was measured in duplicate using the hexokinase method on a YSI 2900D (Yellow Springs, OH, USA) with a CV of <1.0%. Plasma insulin was measured using enzyme-linked immunosorbent assay, (ELISA; Alpco Ltd, Windham, New Hampshire, USA) with intra-assay CV of 4.6%.

2.7. Data analysis

Habitual dietary intake of all foods and beverages reported throughout the baseline recording periods was analysed using FoodWorks© (Version 9, Xyris Software, Brisbane, Australia). Vitamin and mineral supplements were excluded. Average energy, macronutrients (carbohydrate, protein, fat including unsaturated and saturated fats), sugar, alcohol, and fibre were obtained and reported.

The glycaemic index and subsequent glycaemic load (GL) of each meal provided in the experimental period was estimated using data from the International GI database [20]. As most of the foods had multiple GI values, the selection of the GI was made hierarchically in order of preference from: 1) the same brand/variety and method of preparation; 2) an Australian tested food; 3) an average value; or 4) the closest match (e.g., matched to food item with similar amount of CHO) [21]. The percentage of available CHO (excluding fibre) that each food item contributed to the total meal was multiplied by the GI value. Values were summed to estimate the GI of the total meal. The formula used for calculating the GI of a meal using the GI values of the individual food items was:

$$\text{Meal GI} = \{(\text{GI food A} \times (\text{CHO avail. food A g/CHO meal avail. g}) + (\text{GI food B} \times (\text{CHO avail. food B g/CHO meal avail. g}) + \ldots)\}$$

The GL was calculated for each meal for each participant by multiplying the GI of the meal by the amount of CHO available, which was specific to the allocated calorie band based on baseline tests, and dividing by 100. The formula for calculating GL of a meal was:

$$\text{Meal GL} = (\text{GI meal} \times \text{CHO available g meal})/100$$

Incremental area under the curve (iAUC) was calculated for venous glucose and insulin concentrations using the trapezoid method with pre-meal concentration as baseline using GraphPad Prism (Version 7.01, GraphPad Software Inc., CA, USA). Total AUC was calculated for venous triglyceride concentrations (trapezoid method with baseline of 0). Twenty-four h CGMS data (from 0700 h on Day 1 until 0700 h on Day 2) was used to calculate mean, peak, and AUC_{total} for each trial day. The CGMS 3-h postprandial periods were analysed from the reported time of finished meal consumption for the evening meal consumed on Day 1 (i.e. potato-based evening meal). Postprandial CGMS measures of mean, peak glucose, incremental AUC_{meal} (iAUC; trapezoid method with pre-meal glucose as baseline) were calculated. Nocturnal AUC (AUC_{total}; baseline of 0) was calculated from midnight to 0600 h following the evening meal. Nocturnal CGMS measures of peak glucose and mean glucose were determined from midnight to 0600 h following the evening meal.

Activity monitoring (ActiGraph and ActivPal) analysis was performed using each monitors proprietary software, as previously described [22,23].

2.8. Resistant starch

Resistant starch content of the potatoes and rice was determined following the commercially available Megazyme Resistant Starch Assay (K-RSTAR, Megazyme International Ireland Ltd, Co. Wicklow, Ireland) kit. Potatoes and rice samples were prepared at the Australian Export Grain Innovation Centre laboratory with the cooking methods replicated and a homogenous, ground 100 g sample obtained and measured in duplicate.

2.9. Statistical analysis

SPSS (version 25, SPSS Inc., Chicago, IL, USA) was used for all statistical analyses. Linear mixed models were used to assess changes between conditions, between trial order and across time. Models were adjusted for covariates (BMI and age) and residuals were plotted to assess normality of data. Where significant, post-hoc tests were performed using Bonferroni corrections. Significance for main effects was set at $P < 0.05$ and all data are presented as mean ± SD, with 95% confidence intervals (CI) presented when significant. Power calculation was completed using G*Power 3.1.2 software with postrandial glycemic response (iAUC for venous glucose following the evening meal) as primary outcome. Based on previous nutrition interventions [25,26], with an effect size of 0.60, minimum power of 80% and $\alpha = 0.05$, it was estimated that a sample size of 24 would be needed (two-tailed test).

3. Results

3.1. Participant characteristics

Of the 92 participants phone-screened, 27 eligible participants consented and 24 participants (18 male, 6 female) were randomized (Fig. 2). Baseline characteristics of participants who completed the study are shown in Table 1.

3.2. Diet analysis and compliance

Participants complied with recording three-day dietary intake prior to each experimental condition (Table 2) with no difference between conditions for pre-trial dietary intake nutrition composition. All participants reported consuming the standardized meals that were provided to them to be consumed outside the laboratory (Day 0 and Day 1 lunch), along with adhering to the time guides and caffeine/alcohol restrictions. Complete analysis of the diet provided on Day 1 (trial day) is outlined in Table 3. Of note, the majority (86%) of carbohydrate for the evening meal was provided by the rice or potato component with only 10% of carbohydrate provided by the crumbed chicken breast and 4% of carbohydrate from the vegetables.

3.3. Venous glucose, insulin and triglyceride concentrations

A main effect of time was detected for venous glucose concentrations ($P = 0.026$; Fig. 3A), with no differences observed between meal conditions. No differences in postprandial peak glucose concentrations (Fig. 3B) were detected. No differences in postrapandial venous glucose iAUC were detected between any of the potato meal conditions and CONTROL (Fig. 3C). A main effect of condition

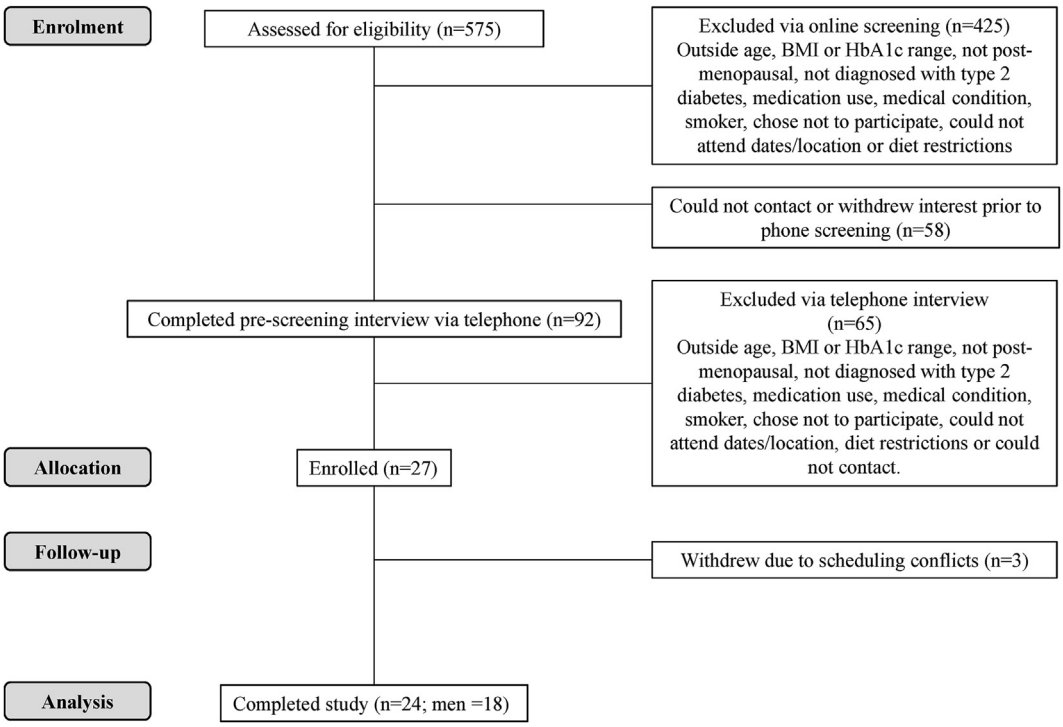

Fig. 2. Consolidated Standards of Reporting Trials (CONSORT) flow diagram of participant recruitment.

Table 1
Anthropometric, exercise and biochemical characteristics from participants.

	All (n = 24)	Females (n = 6)	Males (n = 18)
Age (y)	58.3 ± 9.3	60.5 ± 5.7	57.6 ± 10.3
Body mass (kg)	93.5 ± 23.1	84.2 ± 17.4	96.7 ± 24.4
Lean mass (kg)	55.9 ± 12.8	41.8 ± 4.7	60.7 ± 10.9
Fat mass (kg)	34.7 ± 14.0	40.4 ± 13.9	32.8 ± 13.9
BMI (kg/m^2)	31.7 ± 6.8	33.8 ± 7.7	31.0 ± 6.6
Resting energy expenditure (kJ/d)	7193 ± 2285	6033 ± 528	7580 ± 2520
Systolic blood pressure (mmHg)	140 ± 19	129 ± 14	141 ± 20
Diastolic blood pressure (mmHg)	83 ± 12	82 ± 4	83 ± 14
HbA1c at enrolment to study (%)	7.3 ± 0.9	7.2 ± 0.6	7.4 ± 0.9
Years since diabetes diagnosis (Years)	9 ± 8	10 ± 9	6 ± 4
Fasting glucose (mmol/L)	8.5 ± 1.9	8.2 ± 1.1	8.7 ± 2.1
Fasting insulin (uIU/mL)	9.5 ± 6.2	14.2 ± 8.3	7.9 ± 4.6
HOMA-IR	1.4 ± 0.9	2.0 ± 1.1	1.2 ± 0.7
Fasting triglycerides (mmol/L)	1.89 ± 0.66	1.75 ± 0.49	1.94 ± 0.70
Fasting total cholesterol (mmol/L)	4.53 ± 1.10	4.87 ± 0.98	4.41 ± 1.12
HDL cholesterol (mmol/L)	1.13 ± 0.27	1.25 ± 0.14	1.08 ± 0.29
LDL cholesterol (mmol/L)	2.54 ± 0.98	2.82 ± 0.89	2.45 ± 1.00

kJ, kilojoules; BMI, body mass index. Data are mean ± SD.

(P < 0.001) as well as a time and interaction effects (P = 0.026) were observed (Fig. 3D). Insulin concentrations following the CONTROL evening meal were lower at 30- and 60-min post-meal consumption compared to the COOLED potato condition (P = 0.036; 95% CI: 0.61–30.22 uIU/mL, P = 0 < 0.001; 95% CI: 10.31–39.92 uIU/mL, respectively). Insulin concentrations following the CONTROL evening meal were lower at 90 min following consumption compared to the BOILED potato condition (P = 0.046; 95% CI: 0.15–30.84 uIU/mL). A main effect of condition for peak postprandial insulin concentrations was observed (P = 0.035; Fig. 3E), where peak venous insulin concentration was higher in COOLED potato condition (83.3 ± 54.92 uIU/mL) compared to CONTROL (63.2 ± 31.95 uIU/mL, P = 0.016; 95% CI: 2.71–39.72 uIU/mL). A main effect of condition was observed for venous insulin iAUC (P = 0.003; Fig. 3F), where iAUC was greater in the COOLED potato condition (154.3 ± 90.7 uIU/mL/h) compared to CONTROL (103.8 ± 52.1 uIU/mL/h, P = 0.002; 95% CI 18.9–111.7). A main effect of time was detected for triglyceride concentrations (P < 0.001; Fig. 3G), with no differences observed between conditions. No differences in peak venous triglyceride concentrations or in triglyceride AUC_{total} between conditions were observed (Fig. 3H and I).

3.4. Interstitial glucose

Due to the multiple measurement points (n = 288), the interstitial glucose by time (24 h) was not subjected to statistical analyses but is presented in Fig. 4A. A main effect of condition (P = 0.014) was found for interstitial glucose 24 h AUC_{total} (Fig. 4B) where AUC_{total} was higher in CONTROL (222.9 ± 49.5 mmol/L x h) compared to ROAST condition (208.9 ± 48.6 mmol/L x h, P = 0.037,

Table 2
Habitual dietary intake of participants prior to each experimental trial (Day −3, Day −2, Day −1).

	ROAST	BOIL	COOLED	CONTROL
Energy intake (kJ/d)	9105 ± 561	8901 ± 553	9244 ± 376	9014 ± 365
CHO (g/d)	219 ± 22	220 ± 16	219 ± 16	216 ± 18
CHO (% TEI)	40.8 ± 0.5	41.4 ± 2.2	40.1 ± 0.7	42.7 ± 5.1
Sugars (g)	76.4 ± 5.4	72.5 ± 8.4	78.8 ± 12.0	88.0 ± 10.1
Protein (g/d)	95.3 ± 6.7	91.0 ± 4.4	96.8 ± 4.1	97.7 ± 5.7
Protein (% TEI)	18.5 ± 0.2	18.0 ± 1.0	18.4 ± 1.2	19.4 ± 1.5
Fat (g/d)	91.9 ± 3.0	86.6 ± 10.9	91.4 ± 6.0	95.9 ± 11.0
Fat (% TEI)	36.9 ± 1.0	35.8 ± 2.6	36.3 ± 0.7	42.2 ± 6.7
Saturated fat (g)	33.2 ± 2.1	31.8 ± 3.4	34.5 ± 4.5	37.9 ± 2.9
Monounsaturated fat (g)	35.3 ± 0.9	34.5 ± 5.6	35.0 ± 2.0	37.5 ± 5.0
Polyunsaturated fat (g)	17.2 ± 1.2	13.6 ± 2.0	14.8 ± 2.1	16.0 ± 2.3
Fibre (g)	21.5 ± 3.2	23.9 ± 1.4	21.5 ± 2.0	22.5 ± 4.1
Alcohol (g)	7.3 ± 3.3	6.9 ± 3.2	11.1 ± 2.9	10.9 ± 4.3

CHO, carbohydrate; TEI, total energy intake; Data are mean ± SD.

Table 3
Dietary analysis of meals consumed over Day 0 (24 h prior to each trial) and Day 1 (trial day).

	Day 0 and Day 1				Day 1		
	Total	Breakfast	Lunch	Dinner (CONTROL)	Dinner (ROAST)	Dinner (BOIL)	Dinner (COOLED)
Energy (kJ)	9494 ± 270	2290 ± 391	3388 ± 578	3816 ± 651	4086 ± 697	3867 ± 660	3867 ± 660
CHO (g)	270 ± 46	67 ± 11	96 ± 16	108 ± 18	107 ± 18	107 ± 18	107 ± 18
CHO (%TEI)	49	50	48	48	47	48	48
Protein (g)	102 ± 17	24 ± 4	36 ± 6	41 ± 7	42 ± 7	43 ± 7	43 ± 7
Protein (%TEI)	19	18	19	19	18	19	19
Total fat (g)	78 ± 13	19 ± 3	28 ± 5	32 ± 5	32 ± 6	32 ± 6	32 ± 6
Total fat (%TEI)	30	31	31	31	30	30	30
Sat fat (g)	39 ± 7	11 ± 2	16 ± 3	12 ± 2	16 ± 3	16 ± 3	16 ± 3
Polyunsaturated fat (g)	11 ± 2	1 ± 1	2 ± 1	9 ± 1	7 ± 1	7 ± 1	7 ± 1
Monounsaturated fat (g)	20 ± 3	4 ± 1	7 ± 1	10 ± 2	10 ± 2	10 ± 2	10 ± 2
Fibre (g)	33 ± 6	6 ± 1	16 ± 3	10 ± 2	21 ± 4	21 ± 4	21 ± 4
GI		44	40	54	78	71	71
GL		29	38	58	83	76	76
Resistant Starch, RS3 (%)				1.4	1.3	0.7	1.1

95% CI 0.8–40.2 mmol/L x h). No significant difference in evening meal postprandial iAUC was detected between conditions (Fig. 4C). For nocturnal interstitial glucose AUC_{total} a main effect of condition was observed ($P < 0.001$), where the CONTROL condition (52.64 ± 12.18 mmol/L x h) was significantly higher than all three potato conditions (44.45 ± 9.26 mmol/L x h, 46.10 ± 10.62 mmol/L x h and 45.96 ± 10.10 mmol/L x h for BOIL, COOLED and ROAST potato conditions, respectively; $P < 0.001$; 95% CI 4.15–15.67 mmol/L x h; Fig. 4D). There were no differences in interstitial glucose concentrations between conditions for 24-h mean, 24-h peak, 3-h postprandial mean or 3-h postprandial peak (Fig. 4E and F). A main effect of condition for the mean nocturnal interstitial glucose concentration was detected ($P = 0.001$, Fig. 4G) where the mean nocturnal glucose concentration following the CONTROL was significantly higher compared to BOIL, COOLED and ROAST potato conditions ($P = 0.021$, 95% CI 0.13–2.45 mmol/L; $P < 0.001$, 95% CI 0.53–2.40 mmol/L; and $P = 0.002$, 95% CI 0.38–2.31 mmol/L, respectively). A main effect of condition for nocturnal peak interstitial glucose was detected ($P = 0.003$, Fig. 4G) where the nocturnal peak interstitial glucose concentration was significantly higher in the CONTROL condition compared to COOLED and ROAST potato ($P = 0.005$, 95% CI 0.39–3.00 mmol/L; and $P = 0.007$, 95% CI 0.33–3.00 mmol/L, respectively).

3.5. Subjective measures of appetite

A main effect of time was detected for ratings of hunger ($P < 0.001$; Fig. S1A), satiety (satisfaction; $P = 0.031$, Fig. S1B), fullness ($P < 0.001$; Fig. S1C), and prospective food consumption ($P < 0.001$; (Fig. S1D). No difference between conditions for all subjective measures of appetite was detected. No differences were detected in ratings of hunger, satisfaction, fullness or appetite at the fasted time points of either Day 1 and Day 2.

3.6. Physical activity monitors

There were no differences between conditions for time spent in light or moderate-vigorous physical activity, or for the proportion of waking time spent lying, sitting, standing and stepping (Table S1).

4. Discussion

We investigated the impact of the method of potato preparation on postprandial glucose and insulin response, and nocturnal glycemic response in individuals with T2DM when potato was consumed as part of a mixed-evening meal. Ingestion of a potato-based evening meal did not result in a greater postprandial glucose concentrations compared to an isoenergentic 'control' test meal containing basmati rice. Additionally, the cooking method of potato (boiled, roasted or boiled then cooled for 24 h) did not influence postprandial glucose responses. However, when potato was pre-cooked then cooled before consumption, there was a higher postprandial insulin area under the curve (iAUC) compared to rice. As hypothesized, co-ingestion of potato as part of a mixed-evening meal did not worsen the postprandial glucose response. Yet, pre-cooking and cooling did not lower the postprandial glycemic response as per our secondary hypothesis.

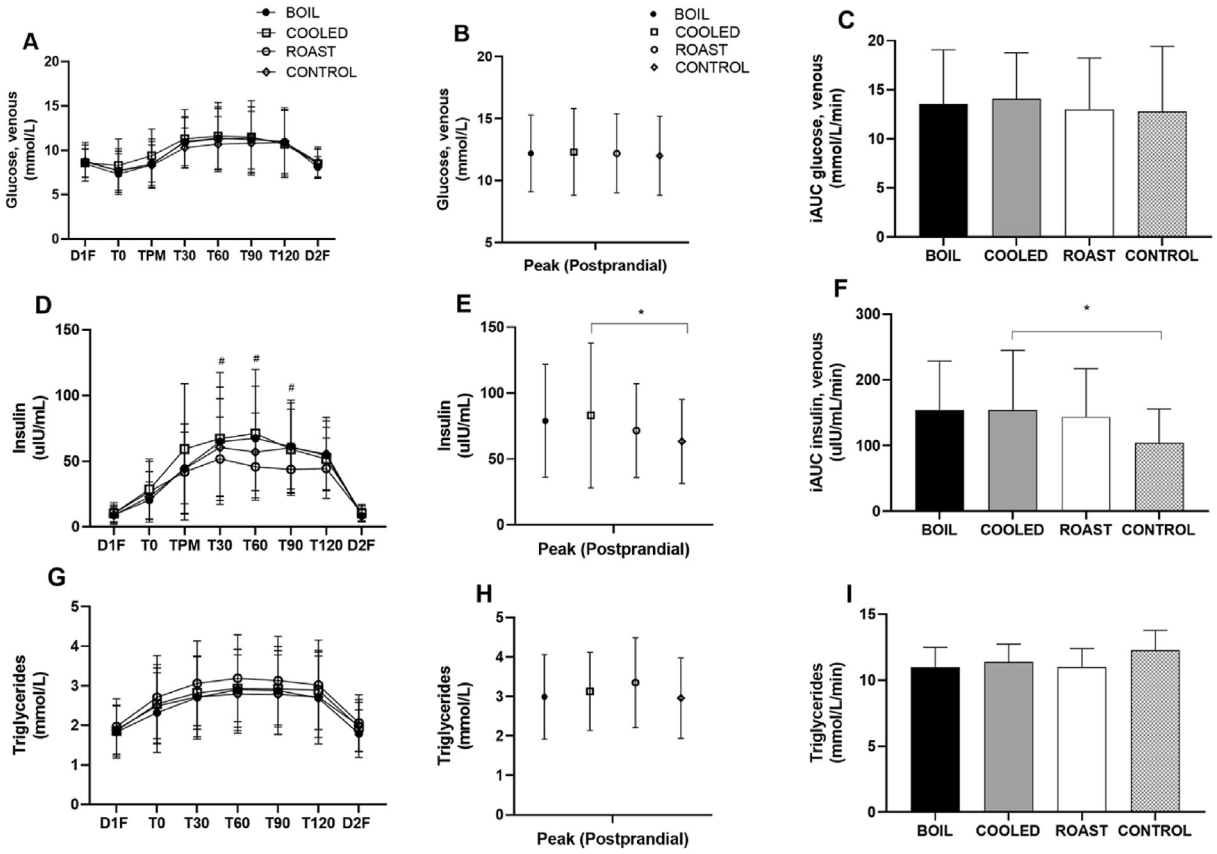

Fig. 3. Venous glucose (**A-C**), venous insulin (**D-F**) and triglycerides (**G-I**) concentrations, peak postprandial concentrations and area under the curve (AUC) values, respectively, from participants with Type 2 Diabetes (n = 24) throughout trial conditions of an evening meal containing boiled potatoes, boiled then cooled for 24 h potato, roasted potato and control of basmati rice. Data are mean ± SD. $P < 0.05$ for *main effect of condition; # significantly different between conditions within timepoint. D1F = Day 1 fasted measure, T0 = prior to evening meal, TPM = immediately after evening meal consumed, T30, T60, T90, T120 = 30, 60, 90, 120 min post evening meal, respectively, D2F = Day 2 fasted measure.

The majority of work that has determined the GI and glycemic response to meals and foods has been undertaken in the morning, following an overnight fast in healthy individuals [27]. A previous investigation of the glycaemic response to mixed-meals (incorporating 50 g carbohydrate portion of pasta, bread and potatoes) reported the blood glucose response to the potato meal in individuals with T2DM was similar to bread [28]. However, that study included only seven participants, test meals were not adjusted for energy requirements, and all test meals were consumed at 1130 h. In the current study, the 'test' meals were consumed as part of a balanced evening meal, increasing the ecological validity of the outcomes. One previous study compared the diurnal postprandial response to a low and high GI mixed meal, matched for energy, and macronutrients [25]. Ten healthy participants consumed a low (37) and high (73) GI meal at 0800 h and 2000 h following a standardized pre-meal and an eight hour fast. Despite differences in the GI of meals (i.e. 37 vs 73), there was no difference in glycemic response following the meal consumed at 0800 h yet following consumption at 2000 h the glycemic response was greater following the low GI meal. The timing of meal consumption may have greater impact than small dietary substitutions on overall glycemic control in both healthy and individuals with T2DM [18,19,29]. It is known that the responsiveness of metabolic tissues to insulin exhibits circadian variation, with decreased glucose tolerance and reduced insulin sensitivity in the evening in individuals with normal glucose control [14–17]. The opposite has been reported in individuals with T2DM, whereby increased glucose tolerance from morning to evening is exhibited due to increased insulin sensitivity in the evening [18,19]. Adjusting the time of evening meal may impact overall glycemic control more substantially than focusing solely on food types. However, the current study did not assess glycaemic responses to the same meals in the morning, and further investigation would be needed to confirm this notion.

This is the first study to investigate glycemic response beyond the 'early' postprandial period by measuring the nocturnal glucose response to evening meals. Compared to all three potato cooking methods under investigation, mean blood glucose concentration was higher in the night (midnight to 0600 h) following the consumption of a low GI control meal (rice). This is an important finding as nocturnal hyperglycemic "excursions" are associated with early endothelial dysfunction and cardiovascular disease [30,31]. Additionally, we observed the total 24 h glucose AUC from CGMs was higher in rice compared to roasted potato, with this difference mostly attributable to the nocturnal period. Basmati rice is classified as a low GI food, resulting in sustained nocturnal blood glucose levels. It has been previously reported that low GI foods do not produce a sustained glucose response compared to high GI foods, however, this was in individuals with normal glucose tolerance and following an overnight fast [11]. When providing clinical recommendations regarding foods for individuals with T2DM, the influence of nocturnal glucose concentrations on overall 24 h mean glucose concentrations needs to be considered and not merely their effect in the postprandial period. This is especially relevant for individuals with persistent hyperglycaemia. However, the nocturnal glucose response to a large, carbohydrate based mixed-evening meal may vary in

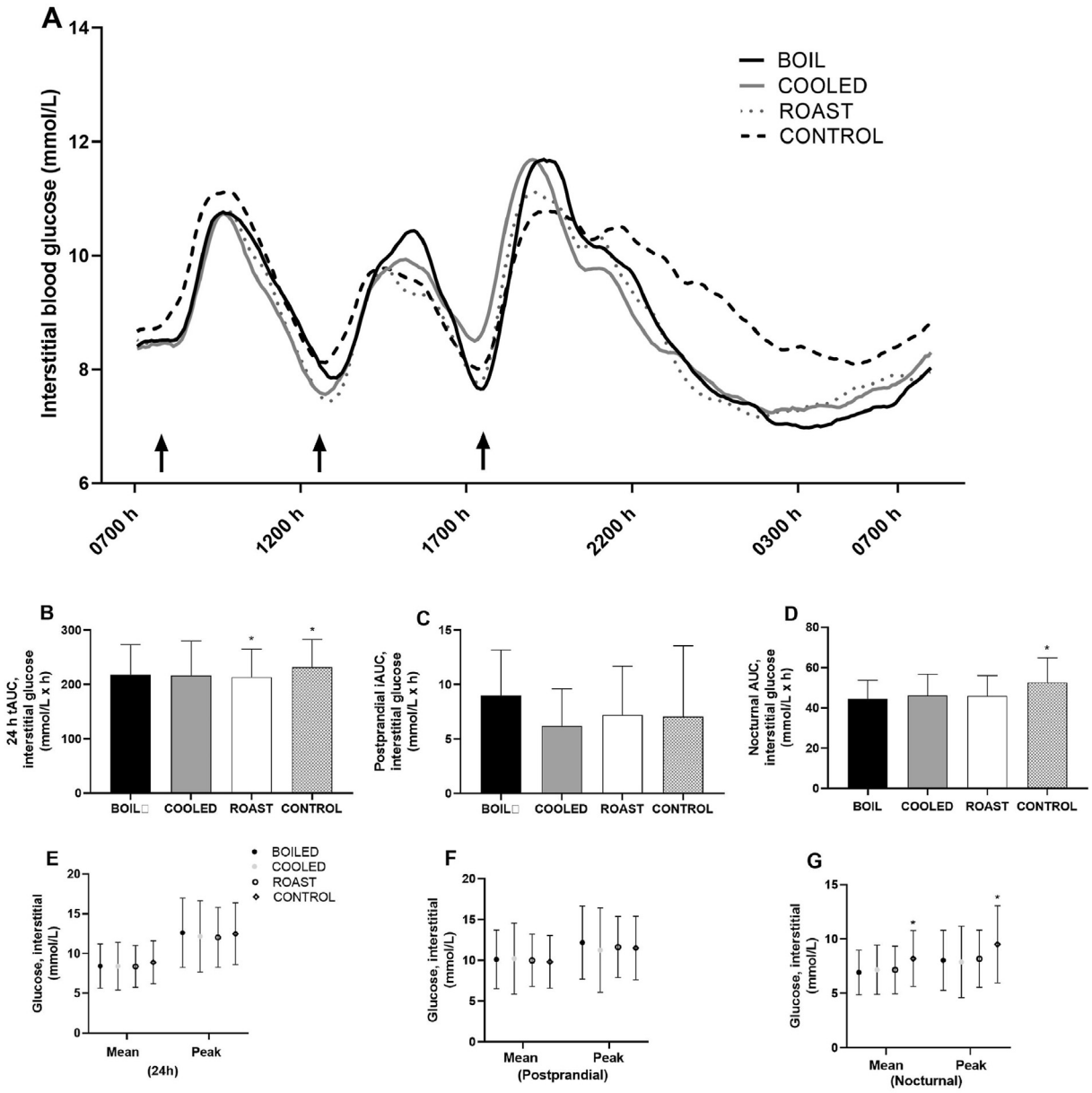

Fig. 4. Interstitial glucose trace (**A**), interstitial glucose 24 h (**B**), postprandial (**C**) and nocturnal (**D**) area under the curve (AUC) values and mean and peak interstitial glucose (**E-G**) for total 24 h, postprandial period and nocturnal period, respectively from participants with T2DM (n = 24) throughout trial conditions of boiled potato (black bars), boiled then cooled potato (grey bars), roasted potato (white bars), and control of basmati rice (pattern bars). Data are mean ± SD.

individuals with T2DM that is managed more aggressively (i.e. medication other than metformin) or with lower glucose concentrations. Regardless, individual monitoring of nocturnal glucose concentrations can help to improve the overall blood glucose control of individuals with T2DM.

Previous studies have determined cooking methods along with consumption of other foods with potatoes and the associated postprandial blood glucose response [13,32]. One study demonstrated the addition of protein, fat and salad to lower the overall GI of a mashed potato meal, decreased the postprandial glycemic response [13]. An earlier investigation assessed the glycemic and insulin response of hot compared to cooled potato meals and reported a lower glucose peak and AUC following cooled potato [32]. However, in both these studies, meals were consumed in the morning after an overnight fast. Additionally, a standard portion (50 g) of carbohydrate was provided, regardless of individual daily energy requirements or differences in body mass. In our study, evening meals were provided based on energy requirements and of individualised portion sizes, with the observation that the cooled potato condition induced the highest insulin response. Cooled potato has previously been reported to alter the resistant starch of the potato meal and therefore lower the glycemic response [32]. However, the resistant starch content was highest in the basmati rice and lowest in the boiled and cooled potato conditions. In this study, when the carbohydrate (potato or rice) was consumed as part of a mixed evening meal and in individuals with T2DM, the amount of resistant starch did not impact the glycemic response of the potato or rice-based evening meals, contrasting what has been previously reported [32].

To explain differences in glycemic response, the GI and glycemic load (GL; product of GI and total available carbohydrate content) was calculated [33]. Both GI and GL were lowest in basmati rice

meal and highest in roasted potato meal. Yet glucose and insulin responses following roasted potato were not higher than basmati rice meal, as might be expected. Indeed, the 24 h AUC from CGMs was lowest in roast potato condition. One reason for lower than expected glucose response following roasted potato could be the greater fibre content of potato based meals compared to the rice condition. Additionally, wide variation of GI values of foods and individual responses under varying circumstances makes extrapolation of GL limited. Consequently, GI and GL should not be used in isolation when suggesting appropriate carbohydrate food choices for individuals with T2DM [29].

Potato cooking method did not influence the subjective ratings of satiety, appetite or hunger when consumed as part of a mixed evening meal. Ratings of these measures did not differ between foods classified as high (potatoes) and low (basmati rice) GI. A recent study investigating the impact of potato varieties classified as low GI (Carisma) and high GI (Arizona) also revealed no difference in ratings of satiety [34]. This suggests that the GI values of foods are not a valid predictor for appetite suppression and subjective satiety. However, another study reported participants felt fuller and more satisfied following a potato-based meal compared with rice and pasta meals, where all meals provided 45 g of carbohydrate [35]. The superior satiating effects of the potato were attributed to their lower energy density as a large volume of potatoes was required to obtain 45 g of carbohydrate. The size of the evening meal provided in the current study was similar for all conditions (45% of daily TEI) and likely to have overridden any differences in satiety between the conditions.

We acknowledge that despite a standardized lead in period prior to each trial day, only one evening meal of each condition was assessed and there is known individual and day to day variability in glycemic response to the same meals and foods [12]. As such, future advances in glycemic management are likely to be based around personalized nutrition where predictors of blood glucose response will include individual dietary and physical activity patterns to assist in managing blood glucose responses and metabolic health [12]. Studies investigating glycemic control over longer periods of time in response to different meals and foods will accelerate the field of personalized nutrition [12]. In conclusion, we provide evidence that compared to an isoenergetic mixed meal of low GI basmati rice, boiled or roasted potatoes, classified as high GI, consumed as part of a mixed-evening meal are not associated with unfavourable postprandial glucose and insulin responses or nocturnal glycemic control. High GI foods such as potatoes do not need to be avoided based on GI rankings alone when consumed as part of a mixed-evening meal in individuals with T2DM. The GI of foods continues to be of relevance to individuals with T2DM in their blood glucose control and diabetes management, but excluding foods solely based on GI recommendations may lead to unnecessary avoidance of nutrient rich foods.

Data sharing

Data described in the manuscript will be made available after application and approval.

Statement of authorship

BLD and JAH designed the research; BLD, EBP and BER conducted the research; BLD and BER analysed the data; EBP assisted with data interpretation; BLD and JAH wrote the paper; BER and EBP participated in revision of the manuscript. BLD had primary responsibility for final content. All authors read and approved the final manuscript.

Conflict of interest and funding sources

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clnu.2020.09.049.

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