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Glycemic Index Lowering Effects of Defatted Fenugreek Seed Flakes (Fenuflakes™) on some Indian Food Preparations: A Randomized Controlled Clinical Study

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Abstract

The objective of the study was to investigate the glycemic index (GI) of various Indian breakfast preparations containing defatted fenugreek seed flakes (Fenuflakes™) using validated protocols in compliance with international standards. Fifteen subjects aged 18 to 45 years with a body mass index of 18.5 to 22.5 kg/m^2 were recruited for the study. The study assessed six breakfast preparations based on rice (cooked raw rice and idly), wheat (Semolina upma and Potato paratha), potato (potato sandwich), or oat (oat porridge), each with 10 g Fenuflakes (Test) or without Fenuflakes (Control), standardized to 50 g (25 g for oat porridge) of available carbohydrates. After overnight fasting, blood samples for each participant were collected 5 minutes before, immediately after (0 minutes) consuming the food, and 15, 30, 45, 60, 90, and 120 minutes after the consumption of the assigned food breakfast preparations. Each participant consumed the reference food (55 g of glucose in 250 ml of water) for 3 days and the Test or Control food preparation for 6 days in a random order, with a wash-out period of 2 days. The GI of each food preparation was calculated from the incremental area under the curve (IAUC) of glucose in the food with the IAUC of the reference food. The GI of Fenuflakes-incorporated food preparations (Test)

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shifted from high to low (cooked raw rice) or medium (rice idly, Semolina upma, and potato paratha), or remained unchanged (potato sandwich and oat porridge) as that of compounding controls. In conclusion, Fenuflakes may be a useful addition to Indian breakfast preparations to lower the GI of some rice- or wheat-based Indian breakfast food preparations and lowers postprandial glycemic spikes.

Introduction

Cereal grains, including rice, wheat, and maize, constitute the main source of dietary carbohydrates and substantially contribute to human energy needs and health.[1] Glucose, a breakdown product of carbohydrate metabolism, is central to energy intake. At the same time, the incidence of diabetes mellitus (higher blood glucose levels) has been on the rise in the worldwide[2] with an expected prevalence of 7079 individuals per 100,000 by 2030.[3] In addition, many regions of the world especially Asian and Indian diet is rich in carbohydrate.[4]Therefore, the quantity and quality of carbohydrate intake can be crucial in mitigating public health challenges.

The scientific literature has extensively reviewed four components to assess carbohydrate quality: dietary fibre content/intake, whole grain content/intake, free sugar content/intake, and glycemic index/load.[5] The concept of the glycemic index (GI) has been introduced to rank carbohydrates based on their effect on postprandial glycemia.[6] A recent meta-analysis provided evidence that a higher dietary GI and glycemic load increases the risk of diabetes.[7,8] At the same time, low-GI foods have also been reported to improve glycemic control in diabetes, increase insulin sensitivity,[9] and enhance pancreatic β-cell function,[8] highlighting the importance of considering GI in food choice.

The identification of food ingredients that can mitigate the high glycemic response induced by high-GI foods has garnered significant attention in recent years.[9,10] In addition, convenience foods with low GI are required in the era of increasing prevalence of noncommunicable diseases, such as diabetes.

Several food ingredients[11-13] and strategies[14-16] have been used in recent years to reduce the high glycemic response induced by high-GI foods. Although grain-based foods are consumed for energy requirements, they often lack adequate protein and dietary fibre. In addition, the urgent need for novel and natural functional food ingredients to control postprandial blood glucose surge to manage chronic metabolic diseases has been expressed in the consensus statement of the International Carbohydrate Quality Consortium (ICQC).[17]

One such potential food ingredient is fenugreek (*Trigonella foenum graecum* L., Fabaceae family) seed, a spice commonly used in India, which has robust scientific evidence for its blood glucose-lowering effects in diabetic conditions.[18]

Several studies incorporating fenugreek seed powder into food preparations have demonstrated promising GI-lowering effects. A reduction in glycemic index (GI) values was observed when fenugreek seed powder was added to common Indian dishes, such as dhokla, upma, and laddu.[19] Similarly, replacing 10% refined wheat flour with fenugreek seed powder in buns and flatbreads significantly reduced GI values.[20] Moreover, adding fenugreek seed powder to fried rice and white bread with jam resulted in a substantial decrease in the incremental area under the curve (IAUC) compared with the consumption of these foods alone.[21] The dietary fibres (mucilage and galactomannan) of fenugreek seeds are believed to cause GI lowering effects by reducing the rate of carbohydrate digestion and absorption, and postprandial blood glucose.[22] However, the precise composition of fenugreek seed responsible for GI-lowering effects is unknown. In addition, global regulatory standards require standardized products with consistent quality and quantity of bioactive compounds.

In addition, the incorporation of fenugreek seeds into the daily diet is often hindered by their inherent bitterness. Recently, defatted fenugreek seed flakes (Fenuflakes™) were developed as palatable and standardized forms of fenugreek seeds that are safe for human consumption.[23] Fenuflakes hold promise as a novel ingredient for lowering the GI of high-carbohydrate food reparations because the defatting process enriches seeds with fibres and proteins and removes fats.[24] and further reduces the bitterness of fenugreek.[25] Therefore, the present study evaluated the GI-lowering capacity of Fenuflakes to grain-based Indian food preparations in healthy human subjects using an open-label randomized control study.

Materials and Methods

Trial Design

The present study was conducted following a randomized, controlled, and open-label design to assess the effect of Fenuflakes on the glycemic response in healthy human participants with six food preparations, with and without fenugreek seed flakes. The research protocol adhered to the guidelines of the "Food and Agriculture Organization"(FAO)/ "World Health Organization (WHO)"[26-28] and "ISO:26642:2010" standard[29] for recommendations of GI determination and food classification. The study was conducted following the ethical principles of the Declaration of Helsinki, and the protocol was approved by the Ethics Committee of the "Madras Diabetes Research Foundation (MDRF)" (No: ECR/194/Inst/TN/2013/RR-19). All participants provided written informed consent prior to participation and the study was prospectively registered in the Clinical Trial Registry of India (CTRI) (No: CTRI/2022/02/040940).

Participants

The study recruited 15 healthy participants, (7 females and 8 males) at the Glycemic Index Testing Centre. A sample size of 15 was determined based on the reported guidelines for determining the GI of food where ten individuals can provide a sufficient degree of power and precision.[28]

The inclusion criteria were as follows: healthy males and females, aged 18 to 45 years, body mass index (BMI) between 18.5 and 22.9 kg/m^2, willingness to consume test foods, without known food allergies or intolerances, not on medications known to affect glucose tolerance, on a stable dose of oral contraceptives, acetylsalicylic acid, thyroxin, vitamins, and mineral supplements or drugs to treat hypertension or osteoporosis.

Individuals with diabetes mellitus or the use of anti-hyperglycaemic drugs or insulin to treat diabetes and related conditions, pregnant or lactating women, those who experienced a major medical or surgical event requiring hospitalization within the preceding 3 months, those with any disease or drug use that could impact digestion and absorption of nutrients, or those using steroid, protease inhibitors or antipsychotics, which can significantly impact glucose metabolism and body fat distribution, were excluded from the study. In addition, the participants were allocated to the sequence of food preparation in a randomized manner, with Fenuflakes (test preparation) or without Fenuflakes (control preparation).

The intervention - Fenuflakes

Two batches of samples of Fenuflakes (debittered fenugreek seed flakes) were provided by Indus Biotech, Ltd., Pune, India and used to prepare the food preparations. Both samples have same the specifications and contained more than 25% of each protein, soluble fibres, and insoluble fibres with negligible carbohydrate and fat content by AOAC official methods, as described earlier.[23] Sample 1 (used for oats porridge, cooked raw rice, rice idly, semolina upma) contained 60.0 % total dietary fibres, 34.9 % soluble fibre, 25.1% insoluble fibre, 34.07 % protein content, 0.4 % net carbohydrate, and 1.72 % total fat content. Sample 2 (used for potato sandwich and potato paratha) contained 57.53 % total dietary fibres, 25.28 % soluble fibres, 32.25 % insoluble fibres, 40.07 % protein content, 0.21 net carbohydrate and 0.52 % total fat content.

The intervention, Fenuflakes, was debittered and did not have a bitter taste. However, the open-label design was selected to mask the distinct flavor of fenugreek containing food.

Food Preparations

This study evaluated the glycemic index of six commonly consumed Indian food preparations: oats porridge, pressure-cooked plain raw rice, rice idly, semolina upma, potato sandwich, and potato paratha. Each food preparation was prepared in two versions: without fenugreek seed flakes (Control) and with the incorporation of 10 g of Fenuflakes per serving (Test), each providing 50 g (or 25 g for oat porridge) of available carbohydrate-containing portions.

The details of the food preparations are listed in Table 1.

Table 1: Food preparations with and without Fenuflakes

Preparations	Method
Oats Porridge	1. Rolled oats + salt (± Fenuflakes flakes) + potable water → mix. 2. Cook on medium flame (4 minutes) → stir → soft and glossy oats. 3. Cool (8 minutes) → RT → serve
Cooked Raw Rice	1. Rice + water → rinse x 3 2. Strain rice → pressure cook rice (± Fenuflakes flakes) + water. 3. Cook on medium flame (10 minutes) →10 whistles. 4. Cool (10 minutes) → RT → serve
Rice Idly	1. Idly rice + water, urad dal + water → rinse x 3 times → soak in water separately (5 hours). 2. Rice (± Fenuflakes powder) (grind for 5 mins) + urad dal (grind for 10 mins) → grind → make to batter → add salt and mix. 3. Batter (rest for 5 hours) → refrigerate (10 hours) → rest (1 hours) at RT 4. 35 g batter → idly mold → steam on medium flame (13 minutes) → cool → RT → serve
Semolina Upma →	1. semolina roasted with fenuflakes, water added later. (± Fenuflakes powder) Mix → + Semolina → mix → heat (5 minutes) → cool. 2. Groundnut oil + mustard seeds + whole black gram + split Bengal gram → roast (1 minutes). 3. Onion + ginger + salt + curry leaves → sauté → add water. 4. Add cooled semolina → stir → cover with lid (1 minutes) → cool (10 minutes) → serve
Potato Sandwich	1. Potatoes → pressure cook → cool → mash. 2. Mint + coriander leaves + green chillies + water → blend. 3. Mashed Potatoes (± Fenuflakes flakes) → make paste + chopped onion + salt + spices → mix. 4. Dough into white bread → toast (golden-brown) → cut (4 squares) → serve
Potato Paratha	1. Wheat flour + water (± Fenuflakes flakes) + salt → mix → knead → dough → grease with groundnut oil → rest. 2. Potatoes → pressure cook → cool → peel → mash (± Fenuflakes flakes) + chopped onion + coriander + green chilies + spices. 3. Wheat dough → roll into circle → 30 g potato stuffing → dumpling. 4. Dumpling → flatten → cook both sides on medium flame → cool → RT → serve ± Fenuflakes - (+) Fenuflakes (Test) or (-) without Fenuflakes (Control), RT- Room Temperature

Nutritional analyses were conducted on three batches of each food preparation to determine the content of available carbohydrates, proteins, fats, fibres, moisture, and ash, following validated AAOC methods.[30] The total available carbohydrate content was quantified by an enzymatic method using a Megazyme assay kit (K-ACHDF; Megazyme International, Ireland). The amount of available carbohydrates was standardized across all food preparations, ensuring that participants consumed servings containing either 50 or 25 g of available carbohydrates, depending on the specific preparation.

Study Procedure

The study procedure has been briefly depicted in Figure 1. All participants visited the GI testing centre on each test day in the morning after an overnight fast of 10-12 h. Upon arrival, participants completed a brief questionnaire regarding their diet and physical activity habits over the previous 24 h to ensure a consistent diet and level of physical activity throughout the study period.

Participants' anthropometric characteristics, such as height, weight and body fat (%) (using a digital body composition machine, HBF -224, Omron Health Care Co., Ltd. Kyoto, Japan), waist circumference (using a non-stretchable measuring tape) were recorded. Blood pressure [using digital apparatus, HEM 8712, Omron Healthcare Manufacturing Vietnam Co., Ltd, Vietnam)] and fasting blood glucose (using a glucose analyser, Hemocue 201+, HemoCue AB, Ängelholm, Sweden) were also recorded.

Baseline fasting blood glucose levels were measured on collected blood immediately before and 5 minutes after consumption of food preparations using an automatic lancet device (Hemocue 201+, HemoCue AB, Ängelholm, Sweden). Before the finger prick, the participants were instructed to gently massage and warm their hands to increase blood flow and reduce plasma dilution. The mean of the two readings was used for further analysis.

Food Consumption and Blood Glucose Monitoring

Participants consumed a reference food (55 g of glucose dissolved in 250 ml of water) on three separate occasions. For the preparation of oat porridge, a modified reference food of 27.5 g of glucose in 125 ml of water was used. The participants consumed the reference food, control food preparations, and test food preparations for breakfast at the same time window in a randomized crossover order. A two-day washout period was implemented between each measurement to minimize carry-over effects.

Participants consumed the assigned food preparation within 15 minutes, with the first bite-taking time marked as the baseline time (0). Blood samples were collected 5 minutes before, immediately after, and 15, 30, 45, 60, 90, and 120 minutes after food consumption. Participants were provided with 250 ml of water along with food preparation and an additional 250 ml of water during the subsequent two hours. Throughout the study period, the participants were instructed not to engage in any strenuous physical activity.

To determine the GI value of each food preparation, a plot of blood glucose levels versus time was plotted, and the incremental area under the curve (IAUC) of the food preparations (Reference, Test or Control) was calculated using the trapezoid rule, ignoring the area below the baseline. The IAUC of the reference food was assigned a GI value of 100 and the GI values of the Test or Control food preparations were expressed as a percentage of the reference food as recommended by the FAO/WHO method[26] using the formula: GI value (%) = (IAUC of food preparation/IAUC of reference food) × 100. Each food was assigned to the GI category as low (GI < 55), medium (GI > 55 and ≤ 69), or high (GI ≥ 70), as recommended in the past.[27, 28]

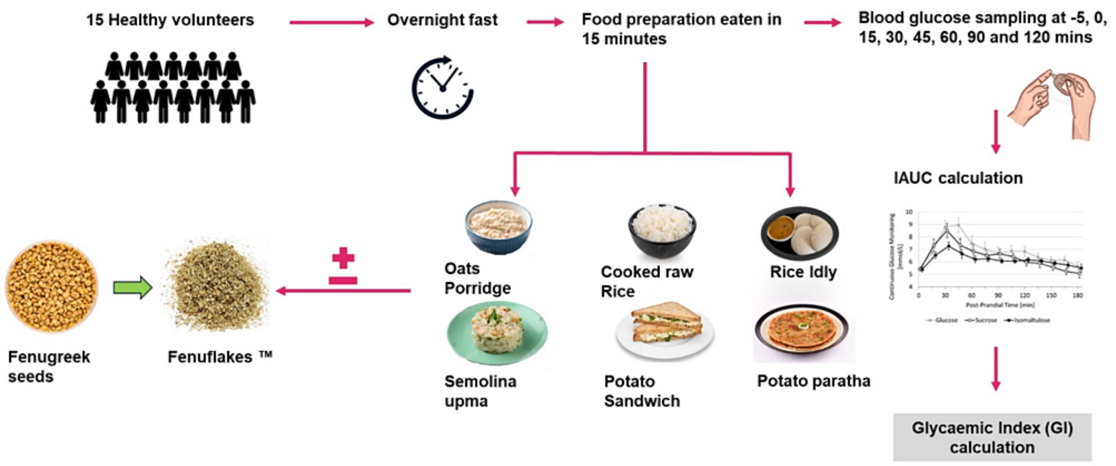

Fig. 1: Study procedure

Statistical Analysis

All 15 participants were included in the statistical analysis (intent-to-treat population). Values with a coefficient of variation > 30 % and > 2 standard deviations (SDs) were considered outliers and excluded from the analysis. The data of nutrient composition, IAUC and GI of the foods are represented as the mean ± standard error of means (SEM) and analysed by independent 't'; test for difference between the groups. All analyses were performed using SAS (version 9.4, SAS Institute, Inc., Cary, NC, USA), with statistical significance set at $P < 0.05$.

Results

Demographic and Clinical Characteristics

Eight male (53%) and seven female (47%) participants were recruited for this study. The values of all demographic and clinical characteristics (Table 2) were within the normal physiological limits.

Table 2: Demographic and clinical characteristics of the study participants

Characteristics	Mean ± SD
Age (years)	25.2 ± 5.1
Weight (kg)	57.7 ± 5.8
Height (m)	165.0 ± 8.8
Body mass index (kg/m2)	21.1 ± 1.3
Waist circumference (cm)	75.3 ± 5.2
Body fat (%)	23.7 ± 7.3
Pulse (beats per minutes)	76.0 ± 10.0
Systolic blood pressure (mmHg)	111.6 ± 11.5
Diastolic blood pressure (mmHg)	75.8 ± 8.0
Fasting blood glucose (mg/dl)	85.2 ± 7.4

Number of participants = 15, SD – standard deviation, mmHg- millimetre of mercury

Nutrient Composition

The nutrient composition of each food preparation is presented in Table 3. The available carbohydrate content in (Test) preparations was not significantly different (vs. Control).

Effects on GI

The glucose levels and corresponding GI details are presented in Table 4. The average blood glucose response for each recipe has been presented in Figure 2.The differences in IAUC were statistically significant for cooked raw rice and potato paratha. Upon addition of Fenuflakes, the IAUC reduced for oats porridge by 8%, cooked raw rice by 35 % ($P < 0.05$), rice idly by 21 %, semolina upma, 5 %, potato sandwich and 8% and that of potato paratha by 27% ($P < 0.05$).

Furthermore, the addition of 10 g Fenuflakes to 25 or 50 g of available carbohydrate-containing portions of food significantly ($P < 0.001$) reduced the GI values of cooked raw rice ($P < 0.001$), idly ($P < 0.001$), and potato paratha ($P < 0.01$). The GI values of the Fenuflakes containing semolina upma, potato sandwich, and oat porridge were less, but the differences were not significant as compared to corresponding control food preparations.

The incorporation of Fenuflakes into various food preparations resulted in a significant modification of their GI values. The GI of Fenuflakes containing cooked raw rice shifted from a high GI category to a Low GI category. The GI of rice idly, semolina upma, and potato paratha showed a transition from the high GI category to the medium GI category with Fenuflakes addition. However, the addition of Fenuflakes to potato sandwiches or oat porridge did not show any change in the GI category.

Table 3: Nutrient composition of the food preparations with (Test) and without (Control) Fenuflakes addition

Food Preparations	Content in g (Mean ± SD)						
	AC#	Protein	Fat	TDF	SDF	IDF	Ash
Cooked raw rice							
Control (Without Fenuflakes)	50.1 ± 0.5	6.5 ± 0.1*	0.5 ± 0.1*	2.4 ± 0.0*	0.8 ± 0.1*	1.6 ± 0.1*	0.2 ± 0.0*
Test (With Fenuflakes)	49.7 ± 0.1	9.7 ± 0.0	2.0 ± 0.1	6.2 ± 0.0	2.0 ± 0.1	4.2 ± 0.1	0.7 ± 0.0
Rice Idly							
Control (Without Fenuflakes)	50.2 ± 1.1	8.3 ± 0.0	0.4 ± 0.1	4.4 ± 0.5	0.6 ± 0.0	3.9 ± 0.2	2.0 ± 0.1
Test (With Fenuflakes)	49.9 ± 0.5	11.3 ± 0.1*	0.5 ± 0.0	12.1 ± 0.0*	3.0 ± 0.3*	9.1 ± 0.5*	3.5 ± 0.0*
Semolina upma							
Control (Without Fenuflakes)	50.1 ± 0.4	8.7 ± 0.1	7.7 ± 0.4	7.9 ± 0.1	0.9 ± 0.1	6.3 ± 0.0	4.1 ± 0.0
Test (With Fenuflakes)	50.0 ± 3.1	13.1 ± 0.3	8.9 ± 0.2*	20.5 ± 0.9*	4.1 ± 0.1*	16.4 ± 0.3*	6.2 ± 0.0*
Potato paratha							
Control (Without Fenuflakes)	50.1 ± 0.1	11.7 ± 0.1	4.2 ± 0.4	15.3 ± 0.1	2.2 ± 0.3	13.1 ± 0.4	2.9 ± 0.2
Test (With Fenuflakes)	50.0 ± 0.1	13.1 ± 0.2*	4.5 ± 0.1	22.4 ± 0.3*	5.0 ± 0.2*	17.6 ± 0.7*	1.9 ± 0.1*
Potato sandwich							
Control (Without Fenuflakes)	50.1 ± 0.4	11.4 ± 0.2	1.7 ± 0.2	8.3 ± 0.2	1.4 ± 0.1	6.8 ± 0.3	4.0 ± 0.3
Test (With Fenuflakes)	50.0 ± 0.8	15.4 ± 0.2*	2.0 ± 0.1	16.1 ± 0.1*	3.9 ± 0.1*	12.3 ± 0.4*	5.4 ± 0.0*
Oats porridge							
Control (Without Fenuflakes)	25.2 ± 0.4	6.5 ± 0.1	5.0 ± 0.6	8.6 ± 0.1	2.2 ± 0.0	6.4 ± 0.0	2.6 ± 0.0
Test (With Fenuflakes)	24.9 ± 0.1	9.0 ± 0.1*	3.6 ± 0.1*	11.1 ± 0.1*	3.6 ± 0.1*	7.5 ± 0.1*	3.3 ± 0.1*

n = 3, # - Portion size of food sample in g, equivalent to 50 g (or 25 g for oat porridge) of AC (available carbohydrates) * $P < 0.05$ (v/s Control)

Discussion

The present study evaluated the impact of adding 10 g of Fenuflakes to Indian food breakfast items on their glycemic index (GI). The findings demonstrated that the incorporation of Fenuflakes led to a consistent decrease in IAUC and GI value across all food preparations when compared to their respective controls. Specifically, the addition of Fenuflakes to rice- and wheat-based dishes such as cooked rice, idly, upma, and paratha resulted in a reduction in postprandial glucose levels and GI, whereas bread- and oat-based preparations did not show similar beneficial effects on glucose levels or GI classification.

The GI values obtained from white rice-based preparations without Fenuflakes (controls), were consistent with reported values of cooked rice[31] and steamed "idly" (a rice cake).[32] The significant decrease in the GI value of Fenuflakes containing cooked rice from high to low in the current study can be attributed to the increased dietary fiber content. Additionally, upon the addition of Fenuflakes, the GI of idly was significantly reduced from high to medium, perhaps due to the combined effect of fibers present in Fenuflakes and urad dal. In addition, pulses and lentils are known as rich sources of protein, dietary fibers,[31] and nonabsorbable carbohydrates,[11] all of which might have contributed to their low GI values.

Upon the addition of water to roasted semolina, the resulting gelatinized product was found to have a high GI value in the present study. Semolina is a rich source of starch, which is responsible for blood glucose levels elevation.[33] However, upon the addition of Fenuflakes, the GI category was lowered to medium, perhaps because of higher amount of dietary fibres, which can reduce starch digestibility and postprandial blood glucose spikes.[34]

Table 4. Glycemic index (GI) of food preparations with (test) and without (control) Fenuflakes addition

Food Preparations	Portion Size (g)$	IAUC (mg/minutes/dL) Mean ± SEM	Glycemic Index	
			Mean ± SEM	Category#
Cooked raw rice				
Control (Without fenuflakes)	188	3928 ± 483	73.4 ± 5.9	High
Test (With Fenuflakes)	231	2573 ± 238*	47.2 ± 2.3***	Low
Rice Idly				
Control (Without Fenuflakes)	192	4183 ± 410	82.0 ± 3.8	High
Test (With Fenuflakes)	252	3295 ± 416	58.1 ± 3.6***	Medium
Semolina upma				
Control (Without Fenuflakes)	273	3856 ± 426	76.3 ± 4.7	High
Test (With Fenuflakes)	284	3673 ± 317	67.4 ± 3.7	Medium
Potato paratha				
Control (Without Fenuflakes)	182	4264 ± 457	78.8 ± 3.6	High
Test (With Fenuflakes)	206	3107 ± 323*	58.9 ± 5.2**	Medium
Potato sandwich				
Control (Without Fenuflakes)	272	4224 ± 427	83.1 ± 6.4	High
Test (With Fenuflakes)	273	3905 ± 357	81.5 ± 8.2	High
Oats porridge				
Control (Without Fenuflakes)	329	2421 ± 286	74.5 ± 4.5	High
Test (With Fenuflakes)	406	2219 ± 336	70.0 ± 7.5	High

Number of participants = 15, SEM - Standard Error of Mean, . *P < 0.05, **P < 0.01, ***P < 0.001 (Test v/s Control) by independent t-test

$ - Portion size of food sample in g, equivalent to 50 g (or 25 g for oats porridge) available carbohydrates

GI category: low (GI < 55), medium (GI > 55 and ≤ 69), or high (GI ≥ 70).

Boiled and mashed potatoes have a higher glycemic index (GI) than fried, microwaved, or baked forms of potatoes, mainly due to the degree of gelatinization and physical changes in the microstructure.[35] In the present study, potato-based food preparations (potato paratha and sandwich) contained boiled and mashed potatoes and showed higher GI values. However, Fenuflakes addition to potato paratha (wheat dough and filling), significantly reduced the GI. GI lowering effects was not observed for potato sandwich, where Fenuflakes are not added to bread dough. Our results are supported by previous studies where the addition of fenugreek seed powder to wheat flour (dough) increases the viscosity of foods[36] and has a positive correlation with a reduction in postprandial glucose response.[11]

Figure 1A Average blood glucose response for Cooked raw rice.

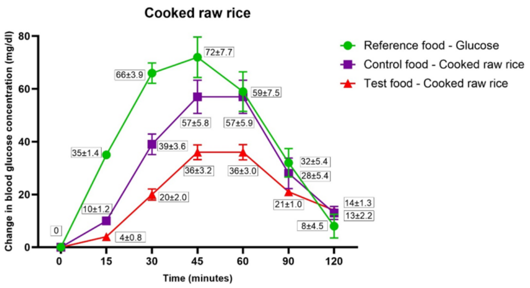

Figure 1B Average blood glucose response for Rice idly.

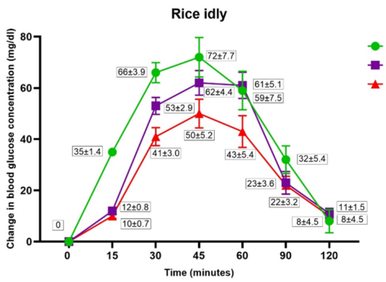

Figure 1C Average blood glucose response for Semolina upma.

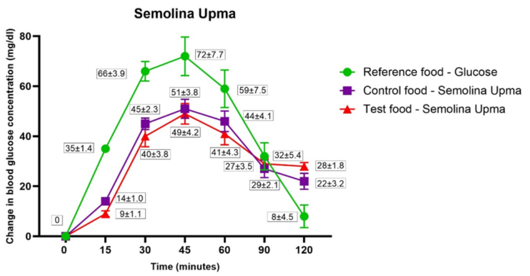

Figure 1D Average blood glucose response for Potato paratha.

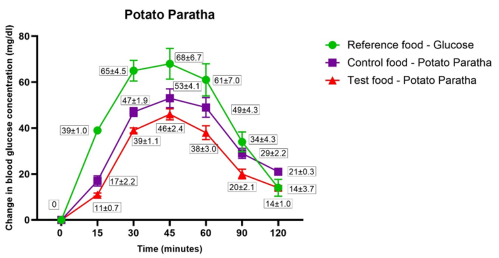

Figure 1E Average blood glucose response for Potato sandwich.

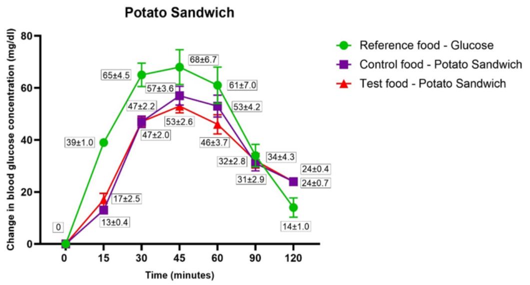

Figure 1F Average blood glucose response for Oats porridge.

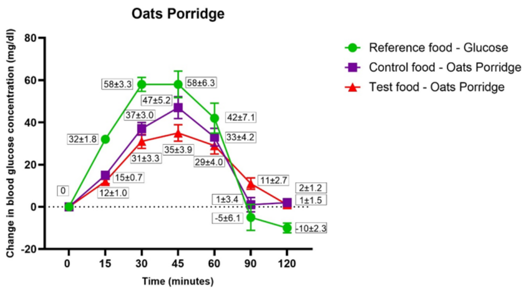

Fig. 2: Average blood glucose response for each recipe

In case of oat porridge, addition of Fenuflakes did not change the IAUC or GI category. These results may be attributed to the similarity in physical properties, especially the particle size of both flakes (Fenuflakes and rolled oats/oat flakes). The smaller particle size and thinner profile of flakes (v/s grains) enables quicker hydration, promotes starch gelatinization led to enormous increase in GI values especially pre-heating conditions during porridge preparation.[37]

Taken together, GI lowering effects of Fenuflakes can be attributed to a higher content of dietary fibers. The dietary fibers are non-digestible carbohydrates that are not digested in the upper GIT. However, adding soluble dietary fibers delays the absorption of dietary carbohydrates[38] and gastric emptying by forming a gel matrix.[34] This gel matrix can reduce the rate of glucose diffusion to the absorptive surfaces of intestinal villi, leading to a reduction in blood glucose levels.[39] Fenuflakes is rich in a water-soluble dietary fibres (such as galactomannans) might have played important role in the observed GI reduction properties and post-prandial glucose reduction observed in the current study, perhaps through delayed gastric emptying[34] and modulation of gastrointestinal transit due to its physicochemical properties of viscosity, fermentability and water solubility.[40] The inter-preparation variations of GI lowering effects of Fenuflakes may be due to procedural factors and differences in the physical characteristics of the tested food preparations. These differences need to be taken into consideration while extrapolating the results.

To the best of our knowledge, our study is first clinical evidence of GI lowering potential of fenugreek seed or constituent addition to commonly used breakfast food preparations using appropriate controls with robust procedures. The study was conducted as per validated protocols and ethical standards, practices and procedures as suggested by international organizations for GI measurements, food categorization and clinical study conduct. Moreover, the lack of bitter taste with improved palatability of fenuflakes makes it more useful ingredient for food preparations. However, double-blind clinical study design could not be adopted due to characteristic smell of Fenuflakes (although significantly less than fenugreek seeds). Nevertheless, the open-label nature of the study does not compromise the validity of results as the outcome (plasma glucose levels) did not involve psychological or behavioral perceptions.

Conclusions

The present study showed the GI lowering potential of Fenuflakes when added to commonly used rice-wheat-based Indian breakfast food preparations. Additional studies with wide range of international food preparations can support Fenuflakes as a broader GI lowering option.

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Conflict of interest

Indus Biotech Limited, Pune, India, funded the study but did not have a role in data collection, acquisition, analysis, or interpretation.

Data Availability Statement

The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics committee statement

The study protocol was approved by the Ethics Committee of the “Madras Diabetes Research Foundation (MDRF)" (No: ECR/194/Inst/TN/2013/RR-19).

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