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Research Article

Evaluation of the Glycemic Index of Protein- and Fiber-Rich Biscuits Designed for Healthy Snacking

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Abstract

The glycemic index (GI) is a measure that classifies carbohydrate-rich foods according to their impact on blood glucose levels. Foods with a low GI are digested and absorbed at a slower rate, leading to a gradual increase in blood sugar, which helps maintain steady energy levels and reduce the risk of chronic conditions like diabetes and cardiovascular disease. This study evaluated the GI of protein- and fiber-rich biscuits to determine their suitability as a low-GI food option. Using a randomized crossover design, participants aged 18–45 years with a body mass index of 18.5–22.9 kg/m ^{2} were instructed to consume both test and reference foods on separate occasions. Blood samples were collected at multiple time points post-consumption, and the GI was determined by calculating the incremental area under the curve (IAUC) for the test food and expressing it as a percentage of the reference food's IAUC. The GI of the nutritionally formulated diabetic biscuits (test food) was estimated to be 54±2, classifying them as low-GI food. These biscuits led to a significant reduction in capillary blood glucose levels at several post-consumption intervals, supporting their potential as a dietary option for prediabetic and diabetic individuals. Our findings indicate that high-protein, high-fiber, low-GI biscuits may offer nutritional benefits for prediabetic and diabetic individuals by supporting blood glucose control. This study highlights the potential role of low-GI foods in diabetes management, emphasizes the importance of GI testing for foods aimed at glycemic control, and reinforces the need for transparent nutritional labeling to impact consumer choices.

Keywords

Glycemic Index, Low-GI Food, Blood Glucose, High-fiber Snacks, Diabetes Management, Protein-rich Snacks, Obesity, IAUC

1. Introduction

The glycemic index (GI) is a widely recognized measure that classifies carbohydrate-containing foods according to their effect on blood glucose levels [1]. It is an essential tool in managing diabetes and promoting overall health, as it

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helps individuals select foods that minimize blood sugar spikes [1, 2]. Low-GI foods are digested and absorbed at a slower pace, resulting in a gradual increase in blood sugar and insulin levels. This slow absorption helps maintain steady energy levels and prevent the onset of chronic diseases, such as diabetes and cardiovascular conditions [2, 3]. The GI classification of foods has been utilized as a tool to evaluate potential prevention and treatment strategies for diseases where glycemic control is crucial, such as diabetes [4]. Diabetes management is a multifaceted approach that typically involves both pharmacological interventions and lifestyle modifications, with diet playing a crucial role [5].

Effective dietary management is essential for controlling postprandial blood glucose spikes, maintaining stable blood glucose levels, and achieving target glycosylated hemoglobin (HbA_{1c}) levels, which are crucial indicators of long-term glucose control. Among various dietary strategies, the adoption of low-GI diets has attracted considerable attention [5, 6]. Low-GI foods break down more gradually, leading to a slower glycemic response (GR) compared to high-GI foods, which are rapidly digested and cause sharp spikes in blood glucose levels. This moderated response is especially beneficial for patients with diabetes, as it helps to prevent the sudden blood sugar increases that can contribute to complications [3, 4]. A systematic review and meta-analysis conducted by Zafar *et al.* demonstrated that low-GI diets can be beneficial for glycemic control and may aid in reducing body weight in patients with prediabetes or diabetes [6]. Several factors influence the GI of foods, including their fat, protein, and dietary fiber content, as well as the method of cooking, the extent of chewing, and the chemical structure of the carbohydrates they contain. For instance, the presence of fat, protein, and dietary fiber typically lowers the GI of a food, resulting in a slower release of glucose into the bloodstream. Additionally, the GI of a food can vary depending on whether it is consumed alone or as part of a meal. These variations highlight the complexity of predicting the GR based solely on the carbohydrate content of a food [3, 7].

The portion size of foods is another critical factor in managing blood glucose levels, as well as in weight loss or maintenance efforts. Recent trends in nutrition emphasize the importance of incorporating high-protein and high-fiber foods into the diet to improve satiety, control weight, and manage blood glucose levels [5]. Protein and fiber are known to moderate the GR, making them ideal components for foods aimed at individuals looking to manage their blood sugar levels [8]. Biscuits, a popular snack food, are typically high in refined carbohydrates and sugars, leading to rapid increases in blood glucose levels. Kim *et al*. demonstrated that consuming fiber-rich snacks, compared to biscuits, resulted in significantly lower blood glucose levels at multiple time points. Specifically, the blood glucose levels showed a substantial decrease at 90 (p=0.024) and 105 minutes (p=0.017) after consuming the fiber-rich snacks [9]. Reformulating biscuits to include protein- and fiber-rich ingredients could potentially transform them into a healthier option, suitable for individuals who need to monitor their GR.

This trial focused on evaluating the GI of protein- and fiber-rich biscuits. The main aim of the study was to determine the influence of biscuits on blood glucose levels and assess their suitability as a low-GI food option. This study is crucial as it addresses the growing demand for healthy snack alternatives that do not compromise taste or convenience while providing metabolic benefits. By testing and validating the GI of these biscuits, the study aimed to offer evidence-based recommendations for their inclusion in the diets of patients with diabetes or those looking to manage their blood sugar levels. The results of this study may have significant consequences for dietary guidelines and the development of functional foods designed to enhance metabolic health.

2. Material and Methods

This study employed globally accepted GI testing techniques, specifically those delineated by the Food and Agriculture Organization of the United Nations (FAO)/World Health Organization (WHO) in 1998 and subsequently enhanced by the International Dietary Carbohydrate Task Force for GI methodology. These protocols are designed to standardize GI testing, making it possible to reliably compare results across different studies and food products.

2.1. Study Participants

Participants were enlisted from the participant roster of the Glycemic Index Testing Centre at the Madras Diabetes Research Foundation (MDRF). In the present study, a total of 15 participants were enrolled, comprising seven males and eight females. Participants were aged between 18 and 45 years, with a body mass index (BMI) ranging from 18.5 to 22.9 kg/m^2. All participants were non-diabetic, meeting the study’s inclusion criteria. Specifically, the inclusion criteria required participants to be between 18 and 45 years of age, include both men and women, have a BMI within the range of 18.5 to 22.9 kg/m^2, and demonstrate a willingness to consume both the test and reference foods. Additionally, participants had to have no known dietary allergies or hypersensitivities, and they could not be on medications known to affect glucose tolerance. Exclusion criteria included individuals with specific diet restrictions, pregnant or lactating women, a known history of diabetes mellitus, any diseases or medications that influence nutrient digestion and absorption, and those who had undergone a major medical or surgical procedure within the past three months.

2.2. Recruitment and Training

To ensure the nutritional criteria for GI testing were met, the study adhered to the International Carbohydrate Quality Consortium (ICQC) guidelines. The ICQC emphasizes the importance of conducting human intervention trials to authenticate health claims related to postprandial blood glucose response reduction.

2.3. Ethical Approval

All the details of the study protocol were provided to the participants, and questions from them were duly addressed. The study methodology adhered to the international standards for conducting ethical research with human subjects and was certified by the Institutional Ethics Review Committee of the MDRF. All volunteers who agreed to participate in this study provided written informed consent. The trial was officially recorded in the Clinical Trial Registry of India with the registration number CTRI/2024/02/063134.

2.4. Study Design and Participants

This study employed a randomized crossover trial design with pre- and post-intervention comparisons over three months. Fifteen participants, with an average age of 24 years, were recruited from the participant roster of a GI testing center. Participants underwent testing over 4 days—3 days for reference food (27.5 g of glucose) and 1 day for the test food (food containing 25 g of carbohydrates) administered in a randomized order. A washout period of 2–3 days was incorporated between measurements to minimize potential carryover effects.

Before each testing session, participants were required to fill out a pre-test survey describing their dietary habits, level of physical activity, smoking habits, alcohol consumption, and caffeine intake.

2.5. Testing Procedure

GI testing is exclusively conducted for foods containing carbohydrates, following stringent protocols to ensure accuracy and reliability [8]. The GI of a food is defined as the incremental area under the curve (IAUC) [10] elicited by a test food containing 25 g of available carbohydrates. This response is expressed as a percentage of the IAUC elicited by an equivalent carbohydrate portion of glucose (27.5 g of glucose monohydrate) consumed by the same participant. This method directly compares how different foods affect blood glucose levels, providing valuable insights into their potential impacts on metabolic health [11].

Participants unfamiliar with blood sampling via finger-pricking performed a practice test to become accustomed to the procedure and mitigate anxiety-related effects on blood glucose response. They arrived at the GI testing center in the morning on each test day, following a 10–12 hour overnight fast. They completed a 24-hour dietary recall questionnaire to ensure consistent dietary and activity patterns before testing and confirm abstinence from smoking and alcohol during the study period. Female participants were rescheduled if their test dates coincided with their menstrual periods. Blood samples were collected before and immediately after fasting (-5 minutes and 0 minutes) using an automated lancet device. The baseline value was determined by calculating the average of these two samples. Participants then consumed 25 g of available carbohydrates from the test food (nutritionally formulated diabetic biscuits) or the reference food (glucose solution). The first bite or sip marked time 0, and subsequent blood samples were collected at 15, 30, 45, 60, 90, and 120 minutes after consumption. Each participant was given a 125 mL portion of water for the duration of the 2-hour testing period.

2.6. Data Analysis

The mean IAUC for both the reference and test food was calculated using the trapezoid rule, excluding the area below the fasting baseline [12, 13]. The mean and standard error of the mean (SEM) for the IAUC of both the reference and test food were then determined to assess variability. The GI value for each participant was determined by expressing the IAUC for the test food as a percentage of the IAUC for the reference food. The average of these values was used to determine the GI of the test food.

$$\text{The GI value of test food (\%)} = \frac{\text{Blood glucose IAUC for the test food} \times 100}{\text{IAUC of the reference food}}$$

3. Results

This study adhered to internationally recognized protocols for GI testing. The study involved healthy human participants who consumed the test food and a reference food (glucose solution) on different occasions. Fifteen participants with a normal BMI were included in the study. However, two participants with GI values greater than [mean + 2 standard deviations (SDs)] and one with a GI value less than [mean − 2 SD] were removed as outliers. Consequently, the GI was calculated using the data from the remaining 12 subjects who consumed the test diet, which consisted of nutritionally prepared protein- and fiber-rich diabetic biscuits.

Table 1 provides the baseline characteristics of the study population, along with the individual GI values and the SEM for both the test and reference food. The participants had an average age of 24±1 years and an average BMI of 21±0.3 kg/m^2.

Table 1. Baseline characteristics and GI metrics of study participants.

	Age (years)	BMI (kg/m^2)	Mean IAUC reference (mg/dL/min)	Mean IAUC test food (mg/dL/min)	GI (%) test food
Mean	24	21	3391	1888	54
SEM	1	0.3	219	147	2

BMI: Body mass index; GI: Glycemic index; IAUC: Incremental area under the curve; SEM: Standard error of the mean.

The primary findings of this intervention study revealed a significant reduction in capillary blood glucose levels during fasting, as well as at 15, 30, 45, 60, 90, and 120 minutes following the consumption of the test biscuits. Figure 1 illustrates the variations in blood glucose levels between the reference food (glucose) and the test food.

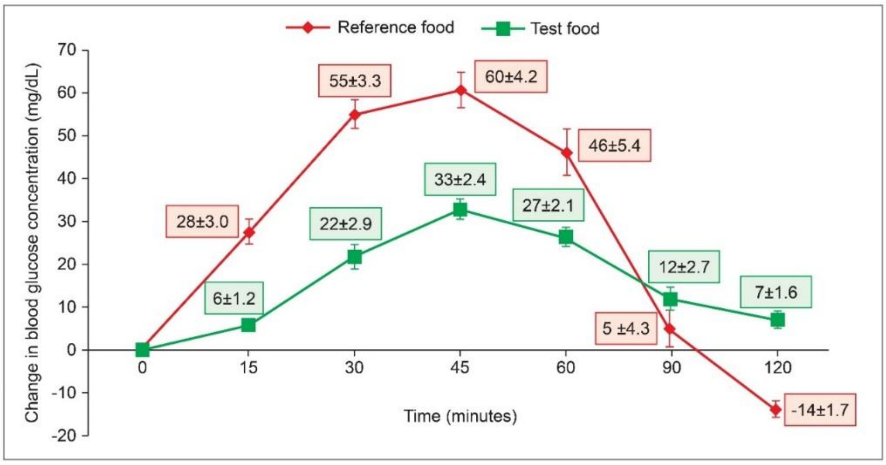

Figure 1. GI of test food (nutritionally formulated diabetic biscuits) and reference food (glucose).

The preliminary results indicated that the nutritionally formulated diabetic biscuits (test food) had a low GI, as shown in Table 2. These biscuits were rich in protein and fiber, designed to provide approximately 11%–12% protein, 14%–16% dietary fiber, 40%–45% carbohydrates, and 16%–18% fat, with no added sugars.

Table 2. GI [mean ±SEM] of test food.

Test Food	GI (%)	GI category
Nutritionally formulated diabetic biscuits	54±2	Low

GI: Glycemic index; SEM: Standard error of the mean.

4. Discussion

The GI of the test food was determined to be 54±2. Based on standard classification criteria, foods with a GI of 55 or below are categorized as low-GI foods [14, 15]. Consequently, the test food was classified as low-GI, indicating that it produced a relatively gradual rise in blood glucose levels post-consumption. This characteristic made it a suitable option for individuals aiming to manage blood glucose levels, particularly those with diabetes or prediabetes. Key findings from this intervention study demonstrated a significant reduction in capillary blood glucose levels, both in the fasting state and up to two hours after consuming the test biscuit. This beneficial glucose response is typically attributed to improved glycemic control, often achieved through the consumption of high-fiber snacks. The observed effect is likely mediated by mechanisms such as delayed nutrient absorption and the replacement of rapidly digestible carbohydrates with slower-releasing alternatives [16]. The GI is a reliable predictor of glycemic variability; foods with a GI of 70 or above are considered high GI, while those with a GI of 55 or below are classified as low GI. It is noteworthy that low-GI foods contribute to smaller fluctuations in blood glucose levels throughout the day, compared to their high-GI counterparts [12, 17]. The findings of this trial are particularly relevant considering the high prevalence of diabetes and the growing demand for convenient, healthy snack options that minimize rapid increases in blood glucose levels [18, 19].

A high-protein diet enhances satiety and fullness, aiding in appetite suppression. High-protein foods do not significantly increase blood glucose levels when consumed, making them safe for patients with diabetes [18, 20]. The test biscuits had a protein content that was significantly higher than what is typically found in standard biscuits. Elevated protein level contributes to increased satiety, facilitates short-term weight loss, and assists in maintaining reduced weight over the long term [21]. This is because more calories are expended during the breakdown of proteins compared to carbohydrates and fats, which increases body heat, promotes satiety, and speeds up metabolism. Additionally, protein helps maintain muscle mass during calorie-restricted diets [18, 22]. Consequently, the high-protein snacks developed in this study could aid in weight management and are expected to help control obesity, a common complication in patients with diabetes [18]. Besides, Yang *et al.* assert that a high-protein snack aligns well with dietary management recommendations for patients with diabetes [18].

Previous research has indicated that the GR of high-GI foods can be reduced when they are consumed with fiber-rich foods, especially those high in soluble fiber [8]. The test biscuits used in this study had a high fiber content with the potential to enhance satiety for extended periods. Optimizing dietary fiber intake is essential for improving metabolic health and reducing the risk of cardiovascular disease and mortality. Therefore, prioritizing fiber intake in dietary practices is a vital public health strategy [23]. In alignment with the primary findings of this study, which demonstrated a significant reduction in capillary blood glucose levels during fasting and at intervals of 15, 30, 45, 60, 90, and 120 minutes following the consumption of the test biscuits, a similar study reported comparable results. Specifically, the consumption of fiber-rich snacks, as opposed to biscuits, was associated with significantly lower blood glucose levels at various time points, including 15 minutes ($p=0.017$), 30 minutes ($p=0.002$), 45 minutes ($p=0.004$), 60 minutes ($p=0.022$), 120 minutes ($p=0.011$), and 135 minutes ($p=0.038$) post-dinner [9]. Multiple other studies have demonstrated the role of low-GI snacks in diabetes prevention. For instance, research by Campbell *et al*. and Rizkalla *et al*. indicated that low-GI meals and snacks mitigate postprandial hyperglycemia and enhance glycemic control. These findings highlight that the slower digestion and absorption of carbohydrates in low-GI foods result in a delayed rise in blood glucose levels, helping to prevent the rapid spikes that pose a challenge for people with diabetes [24, 25].

The benefits of low-GI diets extend beyond immediate glycemic control. Research has shown that adhering to a low-GI diet can lead to a significant reduction in HbA_{1c} levels, which serve as a crucial indicator of the long-term regulation of blood glucose. Lower HbA_{1c} levels are associated with a reduced risk of diabetes-related complications, such as neuropathy, retinopathy, and nephropathy. In addition, low-GI meals have been demonstrated to enhance lipid profiles by decreasing levels of low-density lipoprotein (LDL) cholesterol and triglycerides, both of which are significant risk factors for cardiovascular illnesses [26]. Low-GI foods can assist in achieving improved glycemic control and lowering the likelihood of chronic diseases by supplying a consistent and prolonged energy source without producing significant variations in blood glucose levels. Moreover, the enhanced satiety associated with low-GI foods can support weight management, further adding to the general well-being of individuals with diabetes [27]. The nutritional value and sensory properties of the test biscuits are significantly influenced by their composition, including moisture, ash, protein, fiber, and carbohydrates. Studies emphasize the importance of these components in enhancing sensory attributes such as taste, texture, and overall acceptability [28]. Nevertheless, the precise impact of each ingredient on the composition and nutritional value of the biscuits can vary, necessitating further research to fully elucidate these relationships.

The GI is measured as the area under the two-hour postprandial GR. However, the utility of low-GI foods on the daily 24-hour GR/excursion and further influence on metabolic health need to be evaluated with long-term randomized controlled clinical trials. Long-term studies are also necessary to evaluate the sustained impact of high-protein and high-fiber snacks on glycemic control and weight management. Furthermore, investigating the effects of these biscuits in combination with other dietary components could provide insights into optimizing dietary strategies for people with diabetes or prediabetes.

5. Conclusion

Our research demonstrated that the test food (nutritionally formulated protein- and fiber-rich diabetic biscuits) qualifies as a low-GI food, producing a slow and gradual increase in blood glucose levels after consumption. This characteristic makes these biscuits suitable for individuals managing blood glucose, such as people with diabetes or prediabetes. One factor influencing the GI of the biscuits is the fat content, as fat delays gastric emptying, which contributes to the reduced GI of the product. The findings of this trial highlight the potential benefits of incorporating these nutritionally formulated diabetic biscuits into diets focused on maintaining stable blood glucose levels. Furthermore, this study emphasizes the importance of clear labeling to inform consumers of all relevant nutritional factors. This research also contributes to nutritional science by exploring the effects of combining protein and fiber in snack foods, which may guide future food product development and dietary recommendations. Future research should investigate the long-term effects of regular consumption of low-GI, high-protein, high-fiber snacks on metabolic health, weight management, and diabetes-related complications. Additionally, studies should explore the interaction of low-GI foods with other dietary components to optimize GR across diverse populations, including those with varying BMI and metabolic profiles. Expanding the variety of low-GI snack options could provide broader dietary choices for individuals managing blood glucose, ultimately supporting the development of dietary guidelines and interventions for metabolic health.

Abbreviations

BMI	Body Mass Index
FAO	Food and Agriculture Organization of the United Nations
GI	Glycemic Index
GR	Glycemic Response
HbA_{1c}	Glycosylated Hemoglobin
IAUC	Incremental Area Under the Curve
ICQC	International Carbohydrate Quality Consortium
LDL	Low-density Lipoprotein
MDRF	Madras Diabetes Research Foundation
SD	Standard Deviation
SEM	Standard Error of the Mean
WHO	World Health Organization

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Rachana Bhoite: Conceptualization, Supervision, Writing – review & editing

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Vasudevan Sudha: Conceptualization, Data curation, Formal Analysis, Investigation, Supervision, Validation, Writing – review & editing

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Ethics Approval and Consent to Participate

The study methodology adhered to the international standards for conducting ethical research with human subjects and was certified by the Institutional Ethics Review Committee of the MDRF. All volunteers who agreed to participate in this study provided written informed consent. The research was conducted in accordance with the Declaration of Helsinki (1964). The trial was conducted with the subjects' understanding and consent.

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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