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Evaluation of the Glycemic Index of Vitamin- and Mineral-Enriched Cookies in Healthy Indian Participants: A Randomized Crossover Trial

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Abstract

Background: The increasing prevalence of metabolic disorders highlights the need for dietary strategies that regulate postprandial glycemic responses and enhance satiety. Low-glycemic index (GI) foods enriched with whole grains and functional fibers can attenuate glucose spikes and support appetite regulation. This study evaluated the glycemic index and satiety effects of fiber-rich, vitamin- and mineral-enriched cookies, Britannia NutriChoice Advanced[1] Ragi Cookies and Britannia NutriChoice Advanced[1] Oats Cookies, in healthy Indian adults. **Methods:** A randomized, crossover, single-center study was conducted in 20 healthy Indian adults. Each participant consumed five treatments in random order: three administrations of the reference and one administration each of the two test cookies. The dosage was adjusted so that both reference and test products provided 25 g of available carbohydrates. Capillary blood glucose was recorded at baseline (mean of −5 and 0 minutes) and at 15, 30, 45, 60, 90, and 120 minutes post-consumption to calculate the incremental area under the curve (IAUC). The entire study of GI assessment was conducted according to the ISO 26642:2010 protocol. Satiety was assessed using a validated 7-point Visual Analogue Scale (VAS) for up to 240 minutes. **Results:** Both test cookies produced significantly lower IAUC values than the reference glucose ($p < 0.0001$). The GI values were 48.03 ± 4.39 for NutriChoice Advanced Ragi Cookies and 50.23 ± 4.53 for NutriChoice Advanced Oats Cook-

[1]Britannia, NutriChoice (word & device) and NutriChoice Advanced (device) are trademarks of Britannia Industries Ltd.

ies, classifying both as low-GI foods. Both cookies elicited sustained fullness responses, in contrast to the minimal and transient satiety response with glucose. At 15 minutes post-consumption, 94.74% of participants reported fullness after consuming Ragi Cookies and 100% after consuming Oats Cookies; this sensation of fullness remained for up to 60 minutes for both cookies. Satiety persisted up to 90 minutes in 68.42% of participants following Ragi Cookies consumption and 84.21% following Oats Cookies consumption, with residual satiety up to 180 minutes. **Conclusion:** NutriChoice Advanced Ragi and Oats Cookies demonstrated low GI values, attenuated postprandial glycemic responses, and promoted sustained satiety in healthy adults. These findings support these cookies as functional and metabolically supportive snacking options suitable for individuals who practice mindful snacking and those prioritizing their glycemic control.

Keywords

Glycemic Index, Ragi Cookies, Oats Cookies, Low GI, Healthy Snacks, Satiety, Diabetes Management, Cookies

1. Introduction

Diabetes mellitus is a chronic metabolic disorder characterized by an increase in blood glucose levels resulting from defects in insulin secretion, insulin action, or both [1]. The primary classification of diabetes includes Type 1 diabetes (autoimmune β-cell destruction), Type 2 diabetes (progressive β-cell dysfunction with insulin resistance), and other specific types such as monogenic syndromes, drug-induced, and gestational diabetes mellitus [2]. Type 2 diabetes accounts for more than 90% of all diabetes cases and is mostly linked to obesity, sedentary lifestyle, and poor dietary habits [3] [4]. The incidence of diabetes is steadily increasing all over the world, posing significant public health challenges. Globally, the prevalence of diabetes is rising, with 537 million adults affected in 2021 and projections reaching 783 million by 2045 [5]. According to the 2023 ICMR-INDIAB study, in India, 101 million adults have diabetes and 136 million have prediabetes, highlighting a large at-risk population [6] [7]. This growing burden increases the risk of microvascular and macrovascular complications, including retinopathy, nephropathy, neuropathy, cardiovascular disease, and stroke, resulting in higher morbidity and mortality [8] [9].

Dietary management plays a crucial role in managing diabetes, particularly in controlling postprandial hyperglycemia and hunger cravings. The Glycemic Index (GI) is a measure that ranks foods that contain carbohydrates based on how they affect blood glucose levels after being ingested [10]. High GI foods cause rapid glucose spikes, whereas low GI foods are digested more slowly, leading to a gradual glucose release and improved glycemic response [11] [12]. Strategic inclusion of low GI foods that are rich in whole grains, fiber, protein, and con-

tain potential bioactive compounds proven to regulate the glycemic response can stabilize blood sugar levels, prevent peaks and crashes, and manage hunger between meals [13].

Millets are nutrient-dense cereals rich in dietary fiber, polyphenols, and slowly digestible starch, which contribute to lower postprandial glycemic responses [14]. Ragi, also known as finger millet, is a traditional cereal grain whose consumption is widespread in Africa and South Asian regions, mainly in India. Due to its high dietary fiber content, polyphenols, calcium, iron, and resistant starch content, it has a low GI [15] [16]. Studies have revealed that ragi has a low GI; its high content of slowly digested carbohydrates results in a low glycemic response and aids in the control of postprandial hyperglycemia [17]. Oats, like ragi, are also beneficial for blood sugar management. Oats contain soluble fiber, especially β-glucan, which delays digestion, enhances satiety, and regulates postprandial hyperglycemia. In addition to fiber, oats are rich in bioactives such as ferulic acid, avenanthramides, resistant starch, and minerals including calcium, iron, and magnesium [18] [19].

Conventional snacks are mostly low in fiber and high in simple carbohydrates and fats. Consumption of high GI foods can lead to hyperglycemia and associated complications. Therefore, there is a need to develop products incorporated with low GI ingredients that are suitable for diabetic individuals. Biscuits are among the most common snack foods in the world because of their availability, palatability, and affordability [20]. Britannia NutriChoice Advanced Oats and Ragi Cookies, made from whole grains such as atta, oats, ragi, foxtail millet, and little millet, are intended to have a low GI and are designed to provide a mindful snacking option.

The primary objective of the study is to determine the GI of the NutriChoice Advanced Ragi Cookies and the NutriChoice Advanced Oats Cookies as defined in the ISO 26642:2010 method [21]. Furthermore, the secondary objective is to evaluate the satiety effect of the cookies, which supports their potential use in dietary approaches to diabetes care.

2. Materials & Methods

2.1. Product Description

2.1.1. Reference Product

The reference product selected for this study was Glucon-D, manufactured by Zydus Wellness.

2.1.2. Intervention Product

The test products, Britannia NutriChoice Advanced Ragi Cookies and NutriChoice Advanced Oats Cookies, are scientifically formulated using a blend of whole grains, including ragi (finger millet), oats (in the oats variant), wheat (atta), foxtail millet, and little millet, complemented with dietary fiber and plant-based protein sources. Both products are developed with zero added sugar and zero trans fats and are enriched with essential micronutrients, including zinc and chromium, which are known to support glucose metabolism. The Ragi Cookies emphasize

ragi as the primary whole grain, while the Oats Cookies incorporate oats as a major ingredient. On a per 100 g basis, the Ragi Cookies provide 10.4 g of dietary fiber, 7.1 g of protein, 71.7 g of total carbohydrates, and 18.2 g of fat, whereas the Oats Cookies contain 9.2 g of dietary fiber, 9.4 g of protein, 68.6 g of total carbohydrates, and 19.0 g of fat.

2.2. Subject Details

A total of 20 healthy adult participants aged 18 - 45 years were enrolled at the Cliantha Research study site based on specific inclusion and exclusion criteria. Eligible participants were healthy adults with a body mass index (BMI) of 18.5 - 22.9 kg/m^2, fasting blood glucose < 100 mg/dL, HbA1c < 5.7%, and in good general health with no history of cardiovascular disease. Female participants were required to have a negative pregnancy test. All participants provided written informed consent, agreed to refrain from vigorous exercise, and had not donated blood within 30 days. Participants were excluded if they had food allergies or intolerances, had used any medications within the past four weeks, had chronic diseases, a history of recent dehydration, or had participated in another clinical trial within 90 days. Additional exclusion criteria included adherence to special diets, history of alcohol or substance abuse, nicotine use, or smoking within the past three months.

2.3. Study Design

This randomized, crossover, single-center clinical study was designed to determine the glycemic index of two test biscuits in healthy Indian adult participants, following established GI study procedures as per the ISO 26642:2010 method [21]. The overall flow of the study design is illustrated in the Consolidated Standards of Reporting Trials (CONSORT) flow diagram (**Figure 1**). Following written informed consent and screening according to inclusion/exclusion criteria, participants were housed overnight at the clinical site prior to product administration. A standard dinner was provided on the check-in evening, followed by a 10-hour fast (±30 minutes) until product administration the next morning for GI estimation.

The GI of a food was defined as the incremental area under the blood glucose response curve (IAUC) produced by a test food containing 25 g of available carbohydrates, expressed as a percentage of the IAUC produced by an equivalent carbohydrate portion of glucose (27.5 g of glucose monohydrate) consumed by the same participant. Each participant received five treatments in a randomized order: three administrations of the reference product and one administration each of the two test biscuits. The reference product, 27.5 g of glucose dissolved in 250 mL of water, was consumed orally within 12 - 15 minutes at a consistent pace. The test biscuits were portioned to provide 25 g of available carbohydrates, corresponding to five NutriChoice Advanced Ragi Cookies (~42.38 g) and 5.3 NutriChoice Advanced Oats Cookies (~44.75 g), each consumed within 12 - 15 minutes at a consistent pace along with 250 mL of water.

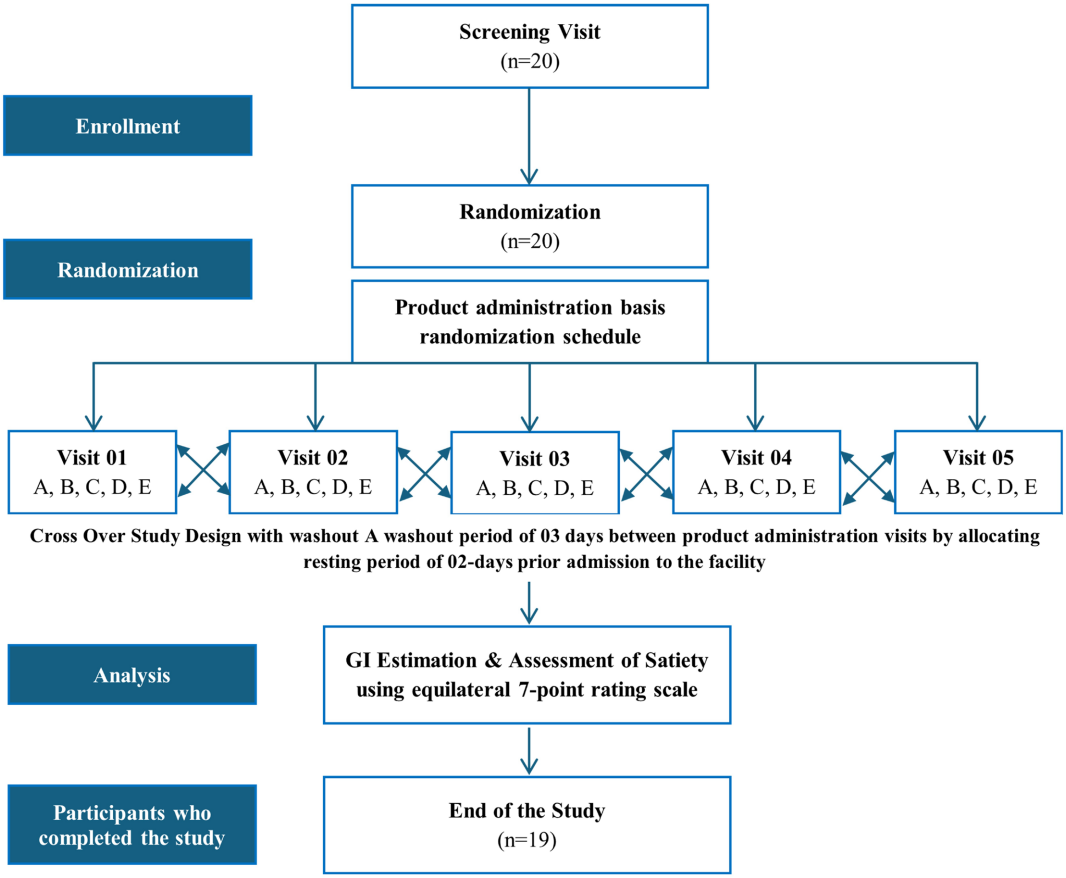


Figure 1. CONSORT flow diagram.

Primary Endpoint

On the day of product administration, blood samples were collected for blood glucose measurement via capillary finger prick using a HemoCue 201+ device at predose (5 ± 1 minutes), 0 minutes (+1 minute, defined as first bite), and post-administration at 15, 30, 45, 60, 90, and 120 minutes (±2 minutes window). The mean glucose values at predose and 0 minutes served as the baseline. To minimize variability, the same operator and glucometer were used for each participant throughout the study when possible.

Secondary Endpoint

Satiety was evaluated using a 7-point equilateral rating scale (1 = extremely hungry to 7 = extremely full) at predose (5 ± 1 minutes), 0 minutes (+1 minute), and at 15, 30, 60, 90, 120, 180, and 240 minutes post-administration (+5 minutes window). The scale followed a Visual Analogue Scale (VAS) format, where participants marked their feeling of fullness or hunger along a continuous 7-point line. Scores of 5 to 7 were considered indicative of satiety. A standard lunch was provided after 240 minutes following completion of all assessments.

A 24-hour dietary recall was collected using standardized questionnaires on each admission day by trained research assistants or nutritionists to assess dietary intake and macro/micronutrients, with special notation of high-calorie food con-

sumption. Physical activity history was obtained using standardized questionnaires on each admission day.

2.4. Safety Evaluation

Throughout the study, continuous monitoring for adverse events (AEs) and serious adverse events (SAEs) was maintained, with participant safety as the primary concern. All adverse events were documented according to standard protocols, with appropriate medical intervention provided as necessary.

2.5. Ethical Approval

The study followed ethical guidelines with human participants. Written approval was obtained from the Institutional Ethics Committee (IEC), and all procedures adhered to the ethical standards outlined by the Indian Council of Medical Research (ICMR), International Council for Harmonization. Additional compliance was ensured with the Declaration of Helsinki and Good Laboratory Practice (GLP). The study received ethical approval under the study code C3B05335 and was registered with the Clinical Trials Registry, India (CTRI/2025/07/090487).

2.6. Statistical Analysis

The statistical analysis was performed using SAS® statistical software (Version: 9.4 or higher; SAS Institute Inc., USA). The IAUC was calculated for each participant using the trapezoid rule. For an individual participant, the GI of each test product, $I_{G,t,}$ will be computed using the formula:

$$I_{G,t} = \frac{A_t}{\overline{A}_{ref}} \times 100$$

where,

A_t is the IAUC of the test product;

$\overline{A}_{ref}$ is the average IAUC of the reference product across the 3 days on which it was administered.

The GI of the test product is expressed as $\overline{I}_G \pm s_{\overline{I}G}$, where $\overline{I}_G$ is the mean GI value of all the participants and $s_{\overline{I}G}$ is the standard error of the mean. The GI will be rounded to the nearest whole number.

Satiety was assessed at predose and at each post-dose time point using frequency and percentages.

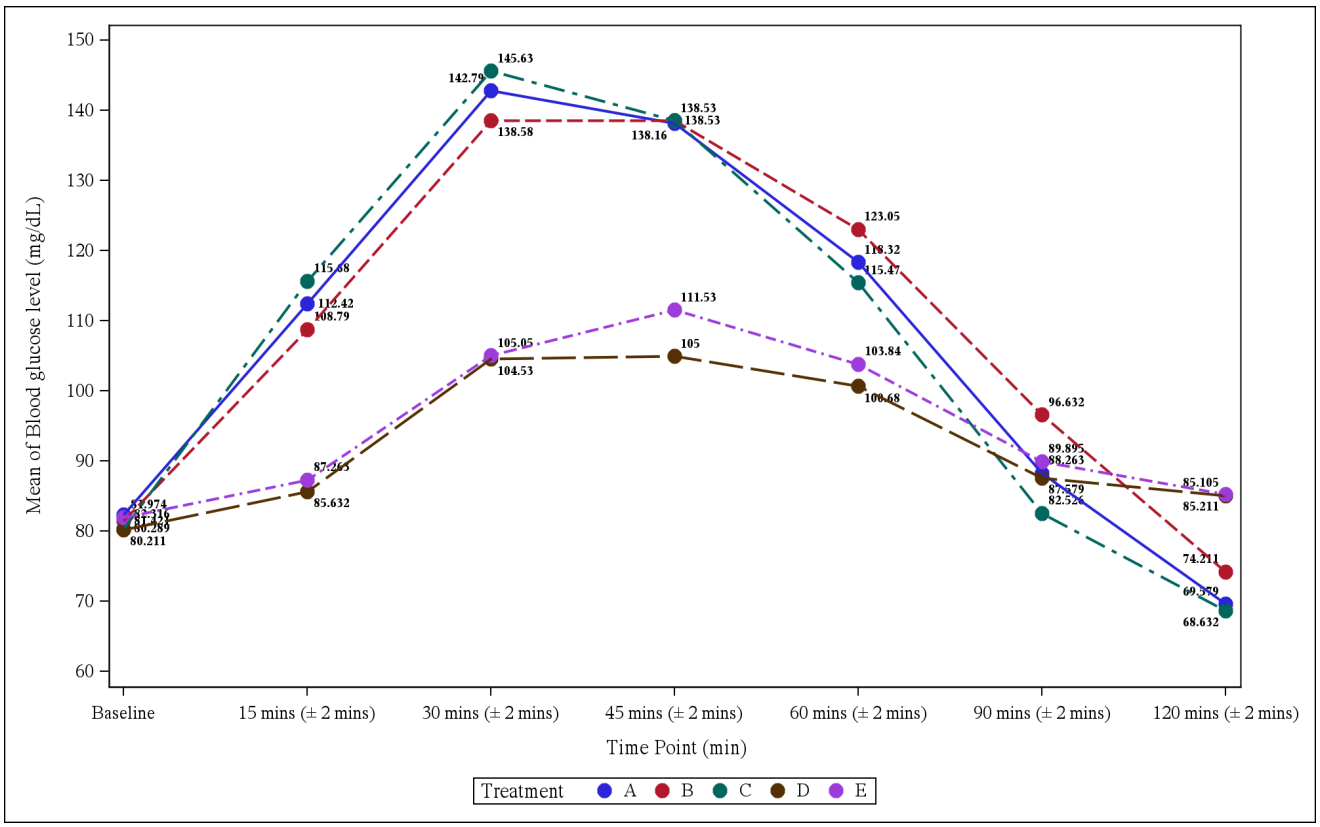
All statistical tests were used at the 5% α level of significance. Two-tailed tests were performed for all analyses that use statistical testing.

3. Result

A total of 62 participants were screened, with 20 healthy Indian adults enrolled in the study (32.26% of those screened) and 19 completing all study procedures (95%). All participants were categorized as Asian (100%), with an equal gender distribution of 10 males (50.00%) and 10 females (50.00%). The participants' ages

ranged from 18 to 44 years, with a mean age of 35.1 years ± 8.42 years. One participant discontinued the study due to a missed follow-up visit. Among the participants who completed the study (n = 19), the mean body mass index (BMI) was 21.337 kg/m^2 ± 1.297 kg/m^2, and the mean glycated hemoglobin (HbA1c) level was 5.436% ± 0.176%, consistent with the predefined inclusion and exclusion criteria.

The primary outcome of the study was the determination of the Glycemic Index (GI) of the two test products, NutriChoice Advanced Ragi Cookies and NutriChoice Advanced Oats Cookies, in comparison with the glucose reference (Glucon-D), according to the ISO 26642:2010 protocol. The mean blood glucose levels of all 19 participants at predetermined time points are illustrated in Figure 2. The IAUC was calculated for each product to estimate the postprandial glycemic response. The mean IAUC for the reference product (Glucon-D) across three separate administrations ranged between 3211.705 and 3546.657 min·mg/dL. Both test cookies produced significantly lower IAUC values ($p < 0.0001$) when compared to the glucose reference. The mean IAUC for the NutriChoice Advanced Ragi Cookies was 1625.096 min·mg/dL, while that for the NutriChoice Advanced Oats Cookies was 1694.455 min·mg/dL.

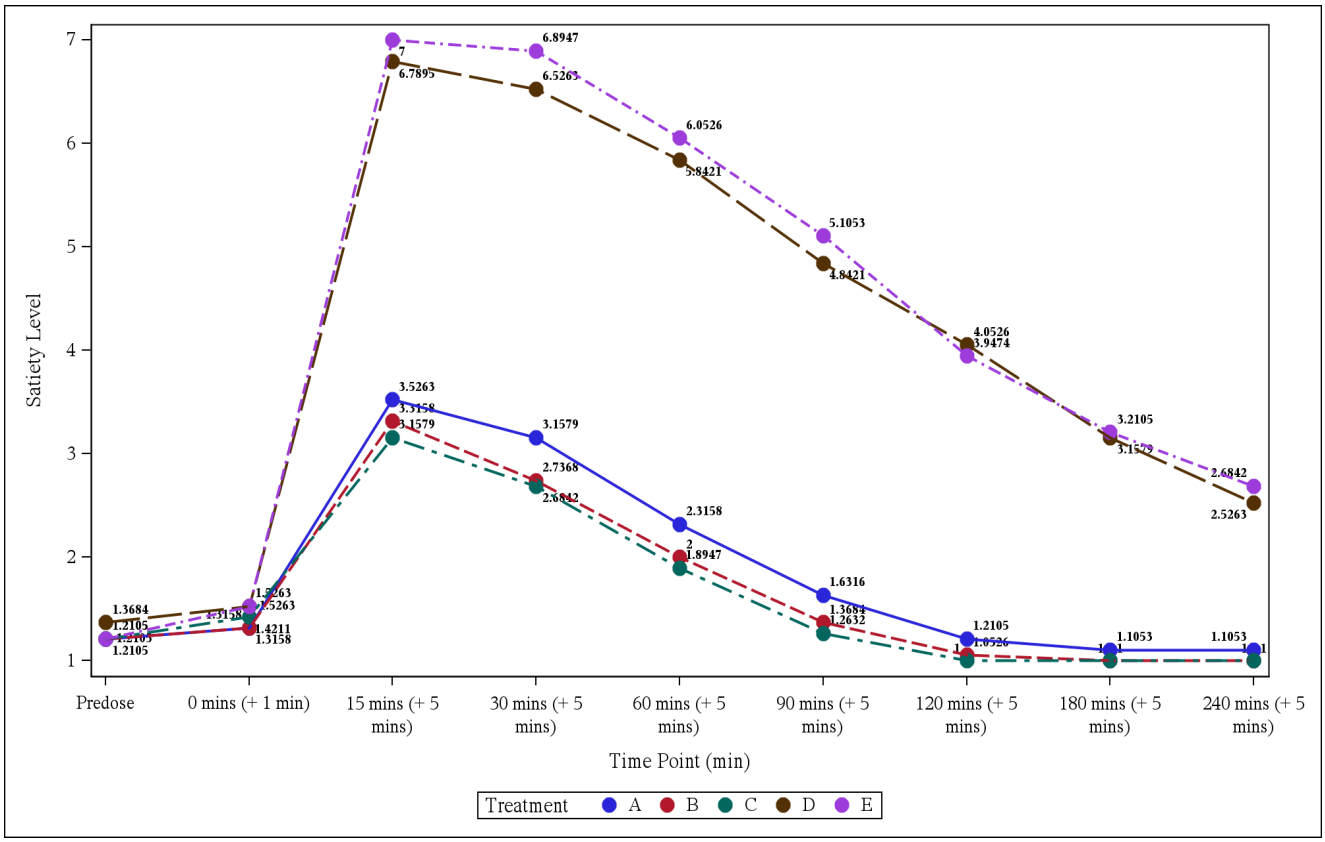


Note: The mean of glucose blood measurements performed at Predose and 0 min is considered the baseline value. A: Glucon D (Glucose Monohydrate); B: Glucon D (Glucose Monohydrate); C: Glucon D (Glucose Monohydrate); D: NutriChoice Advanced Ragi Cookies. E: NutriChoice Advanced Oats Cookies.

Figure 2. Graphical representation of the mean blood glucose level of participants at different timelines.

The mean GI for NutriChoice Advanced Ragi Cookies was 48.03 ± 4.39, while the NutriChoice Advanced Oats Cookies exhibited a mean GI of 50.23 ± 4.53. The GI of both cookies is below 55 and therefore has a low GI as per the ISO 26642:2010 protocol. These findings suggest that consumption of either cookie results in a slower and more gradual rise in postprandial blood glucose compared to a glucose-based reference product, indicating their suitability as low-GI food options for glycemic control.

As a secondary outcome, satiety was evaluated using a 7-point equilateral Visual Analogue Scale (VAS), with mean responses at different time points illustrated in Figure 3. The reference product (Glucon-D) produced only a minimal and transient satiety response, with 7.02% of participants reporting a feeling of satiety at 15 minutes post-consumption, decreasing to 1.75% at 30 to 90 minutes, and none by 120 minutes. In contrast, both test cookies elicited strong and sustained satiety effects throughout the observation period. After post-consumption of NutriChoice Advanced Ragi Cookies, 94.74% of participants reported satiety at 15 minutes, and this effect was maintained up to 60 minutes. 68.42% of participants continued to report satiety at 90 minutes, with residual effects remaining up to 180 minutes (5.26%).



Note: A: Glucon D (Glucose Monohydrate); B: Glucon D (Glucose Monohydrate); C: Glucon D (Glucose Monohydrate); D: NutriChoice Advanced Ragi Cookies; E: NutriChoice Advanced Oats Cookies.

Figure 3. Graphical representation of the VAS score of participants at predetermined time points.

The NutriChoice Advanced Oats Cookies demonstrated an even more pronounced satiety response. All participants (100%) reported satiety within 15 minutes of consumption, and this feeling persisted through 30 and 60 minutes. At 90 minutes, 84.21% of participants continued to report satiety, with minimal residual effects extending to 180 minutes (5.26%). This pattern indicates that both cookie formulations provided sustained postprandial satiety compared to the glucose reference, with the Oats Cookies exhibiting the highest overall effect. The enhanced satiety observed with both test products may be attributed to their high dietary fiber content, protein content, presence of complex carbohydrates, and the inclusion of ingredients such as inulin, which are known to slow gastric emptying and prolong the feeling of fullness.

Collectively, these findings demonstrate that both NutriChoice Advanced Ragi and NutriChoice Advanced Oats Cookies are low glycemic index foods capable of eliciting a controlled postprandial glucose response and are shown to promote sustained satiety in healthy adults.

Throughout the study, continuous safety monitoring confirmed the excellent tolerability of both test products. No adverse events (AEs), serious adverse events (SAEs), or product-related intolerances were reported or observed among participants during the entire study duration.

The results support the potential role of these products as healthier snack options for individuals aiming for mindful snacking, thereby reducing overeating that, in turn, helps in managing their glycemic control, hunger control, and also appetite regulation, serving as a useful dietary component in diabetes management strategies.

4. Discussion

This randomized, crossover clinical study shows that NutriChoice Advanced Ragi Cookies and NutriChoice Advanced Oats Cookies significantly lowered postprandial glycemic responses and exhibited superior satiety effects compared with a glucose reference. Both test products exhibited mean GI values within the low-GI range (GI ≤ 55), with values of 48.03 for the Ragi variant and 50.23 for the Oats variant, in accordance with the ISO 26642:2010 classification. The low GI values observed in this study confirm that both finger millet- and oats-based biscuits provide a slower, sustained blood glucose release, supporting their potential role as a healthy snacking option.

The glycemic index concept, introduced by Jenkins *et al.* (1981), has become a validated tool for evaluating carbohydrate quality and predicting glycemic variability [22]. The increasing burden of metabolic diseases and the growing dependence on processed snack foods in modern dietary patterns are dominated by high-GI, refined, energy-dense foods that provoke rapid glucose spikes, promote insulin surges, and trigger compensatory hunger shortly thereafter. These repeated postprandial excursions are increasingly recognized as independent predictors of endothelial dysfunction, β-cell stress, and cardiometabolic risk. Low-GI diets can

mitigate these risks by reducing postprandial hyperglycemia, oxidative stress, inflammation, and insulin demand [23]-[26]. The integration of low-GI, whole-grain snack options aligns with global dietary recommendations aimed at optimizing carbohydrate quality rather than merely reducing carbohydrate quantity. Such products support metabolic homeostasis by delivering slowly digestible carbohydrates, soluble fibers, and resistant starches [26]. The findings of the current study support this evidence by demonstrating significantly reduced IAUC values for both test biscuits relative to the glucose reference, confirming their ability to maintain a physiologically favorable glycemic profile along with an improved satiety response.

The attenuated glycemic response of the test cookies can be attributed to several compositional factors. Ragi-based products contain slowly digestible starch fractions and higher proportions of insoluble fiber, which reduce enzymatic hydrolysis and promote moderate glucose release [27]. Oat-based foods, in contrast, are enriched with β-glucan, a soluble viscous fiber well known for its ability to increase chyme viscosity, delay gastric emptying, and reduce the rate of glucose uptake in the small intestine, which is also known to improve immune health [28] [29]. Additionally, research shows that Finger millet promotes satiety by influencing appetite-regulating hormones like glucagon-like peptide-1 (GLP-1). It exerts this effect primarily through the actions of its high fiber that supports the growth of probiotics**,** which in turn produces short-chain fatty acids (SCFAs) that help manage GLP-1 levels [30]. The presence of β-glucan in oats has been shown to enhance the secretion of satiety-related gut hormones, including GLP-1 and peptide YY (PYY), which play a critical role in appetite regulation, gastric motility, and energy intake [31] [32]. The presence of comprehensive vitamins like vitamin A, D, B1, B2, B3, B6, E, and B12 in both cookies also imparts nutritional value and helps stabilize metabolic responses. The product also consists of minerals such as zinc and chromium, which are known to have an impact on GI by promoting insulin sensitivity [33]-[36].

Satiety outcomes observed in this study complement the glycemic findings. The glucose reference produced only brief and minimal fullness, with effects diminishing by 90 minutes, consistent with rapidly absorbed simple carbohydrates inducing transient glycemic fluctuations and limited satiation. In contrast, both test products elicited marked and sustained satiety, with 100% of participants reporting fullness after consumption of Oats Cookies up to 60 minutes, and over 94% reporting fullness after Ragi Cookies at the same time point. These prolonged effects persisted up to 90 minutes for both biscuits, with residual satiety evident up to 180 minutes.

The enhanced satiety observed is likely driven by the higher soluble and insoluble fiber content of the cookies. Soluble fibers, particularly β-glucan, are known to stimulate satiety-related gut hormones such as glucagon-like peptide-1 (GLP-1) and peptide YY (PYY), both of which modulate gastric motility, appetite, and energy intake [28]. Complex carbohydrates, rich fibers, and whole-grain matrices

further contribute to delayed gastric emptying, prolonged digestive transit time, and modulation of postprandial hormonal responses, aligning with previously reported effects of finger millet- and oat-based foods on satiety and appetite control [37] [38].

Emphasizing low glycemic index carbohydrates combined with protein and fiber slows gastric emptying and glucose absorption. Along with this, mindful snacking combined with intentional portion control and lifestyle adjustment helps in reducing glycemic variability, insulin demand, and overeating, which supports diabetes management by stabilizing postprandial glycemia through controlled carbohydrate intake and strategic nutrient pairing [39].

In summary, NutriChoice Advanced Ragi and Oats Cookies demonstrated clinically meaningful reductions in glycemic response and prolonged satiety, confirming their classification as low-GI functional snacks and supporting their utility as a healthier, mindful snacking option. These findings contribute to the growing evidence base supporting low-GI, whole-grain, fiber-rich foods as effective dietary strategies for managing glycemic control, appetite regulation, and hunger management. Future long-term and population-specific studies are warranted to further validate their role in metabolic health management.

5. Conclusion

This randomized, crossover clinical study demonstrates that NutriChoice Advanced Ragi and Oats Cookies significantly lowered postprandial glycemic responses compared with a glucose reference. The GI values were 48.03 and 50.23, respectively, confirming their classification as low-GI functional snacks. Currently, snacks are being developed as carriers of functional ingredients that offer nutritional and health benefits, adding a new angle to snacking, enhancing their functional potential, and expanding snack choices for people with diabetes. These outcomes are attributable to their whole-grain, protein, and fiber-rich formulation enriched with β-glucan, inulin, and protein, which contributes to moderate glucose absorption. The study also revealed a positive satiety response, indicating a promising direction for mechanistic exploration. Future research incorporating biochemical markers such as GLP-1, PYY, leptin, and ghrelin could elucidate the physiological pathways underlying the observed satiety effects. Additionally, long-term and population-specific investigations are warranted to validate the sustained metabolic benefits and applicability of these low-GI snack options in diabetic populations. Overall, the present findings support the potential of these cookies as metabolically favorable snacking choices and provide a foundation for more comprehensive studies on glycemic and appetite regulation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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