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Comparison of the Glycemic Impact of Popular Snack Bars in the Chilean Market

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ABSTRACT

The increased consumption of snacks has raised concerns regarding metabolic health, particularly due to their content of rapidly absorbed carbohydrates. This study assessed the glycemic impact of three representative snack bars from the Chilean market: a plant-based protein bar formulated with isomaltulose (NotProtein® Snack Bar, NPSB), a cereal-based bar (CBS), and an animal-based protein bar (ABPS). The glycemic response was analyzed in ten healthy adults, following the consumption of standardized portions containing 25 g of available carbohydrates in a crossover trial. The results indicated that NPSB exhibited the lowest glycemic load (GL = 2.2) and the slowest glucose absorption, with a more sustained metabolic response compared to the other bars. These effects are attributed to its formulation with isomaltulose, as well as its higher protein and fiber content, particularly low-molecular-weight soluble fiber (LMW-SF). CBS, in contrast, had the highest glycemic impact (GL = 10.1), reflecting its high content of rapidly digestible carbohydrates. Reformulating snacks with lower glycemic load profiles and increased functional ingredients, such as soluble fibers and slow-digesting carbohydrates, could contribute to improving metabolic health in consumers seeking healthier options.

1. Introduction

The global snack market has experienced sustained growth in recent decades, driven by changes in consumer habits, urbanization, and the demand for ready-to-eat products [1]. According to recent market reports, the global snack industry was valued at $533 billion in 2023, with projections reaching $800 billion by 2030, growing at a compound annual growth rate (CAGR) of 5.1% [2]. In Latin America, snack consumption has increased significantly, with a growing preference for products perceived as healthier, driving the development of clean-label products, sugar reduction, and reformulation with functional ingredients [3].

Despite these trends, many commercially available snacks still contain high amounts of rapidly absorbed carbohydrates and refined sugars, raising concerns about their metabolic health impact [4]. Epidemiological evidence shows that frequent consumption of foods with a high glycemic index (GI) and glycemic load (GL) is associated with an increased risk of insulin resistance, obesity, and chronic metabolic diseases [5]. According to the International Diabetes Federation, approximately 537 million adults worldwide suffer from type 2 diabetes, a figure projected to rise to 783 million by 2045 if effective preventive measures are not implemented [6]. In Chile, this issue is particularly alarming, as 12.3% of the adult population has diabetes, and more than 74% are overweight or obese [7,8].

Given this scenario, the food industry has prioritized the reformulation of snack products to achieve more balanced nutritional profiles [9]. The incorporation of functional ingredients, such as soluble fibers and slow-digesting carbohydrates, has been shown to effectively reduce postprandial glycemic spikes, improve metabolic response, and increase satiety [10]. Studies have demonstrated that the modulation of GI and GL through food matrix composition, fiber content, and carbohydrate type can help reduce the risk of metabolic disorders [11-13].

Considering the growing snack market and the urgent demand for healthier options, this study aimed to evaluate the glycemic impact of three representative snack bars available in Chile. These bars were selected through a market exploration considering products with contrasting compositions, focusing on differences in carbohydrate sources, fiber content, and protein levels. By comparing their nutritional profiles and postprandial glycemic responses, this study provides key insights for the formulation of snack products with lower metabolic impact, aligning with global trends in health-conscious consumption.

2. Experimental Methods

2.1 Product Selection

A market analysis was conducted in which 41 snack bars available in the Chilean market were identified and evaluated based on their nutritional labels. These bars were classified into cereal-based bars (CBS), animal-based protein bars (ABPB), and plant-based protein bars. From this evaluation, three representative bars with contrasting nutritional profiles were selected for experimental analysis: a CBS, an ABPS, and a plant-based protein bar formulated with isomaltulose (NotProtein® Snack Bar, NPSB). These bars were chosen based on their macronutrient, fiber, and sugar content, aiming to assess their glycemic impact.

2.2 Proximate Analysis

Proximate analysis was performed for the three selected snack bars from the market research at the Food Center Laboratory of the Institute of Nutrition and Food Technology (INTA) at the University of Chile. Moisture determination was conducted using the gravimetric method according to NCh 841:2018 and protocol LCA-PRE-011. Total ash content was also determined using a gravimetric method following NCh 842:2018 and protocol LCA-PRE-002. Protein content was quantified using the Kjeldahl method, based on ISP.PART-711.02-173 (2014), protocol LCA-PRE-006. The acid hydrolysis Mojonnier method was employed to determine total fat, following AOAC Official Methods 935.38, 925.32, and 922.06, according to protocol LCA-PRE-035. Total integrated dietary fiber was analyzed using an enzymatic-gravimetric-HPLC method, following AOAC Official Method 2011.25 and protocol LCA-PRE-003. Available carbohydrates were obtained by difference, subtracting the contributions of moisture, ash, protein, total fat, and total dietary fiber from 100%. Finally, energy content was calculated using Atwater factors of 4, 9, and 2 for proteins, total fats, carbohydrates, and total soluble dietary fiber, respectively [14].

2.3 Study Design

Glycemic response was evaluated in ten healthy adults (six women and four men) aged between 20 and 54 years, with a body mass index (BMI) between 20 and 24.3 kg/m^2. Participants met inclusion criteria requiring stable weight over the past six months and the absence of metabolic

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disorders. Individuals with food allergies, chronic diseases, or supplement consumption that could alter glycemic response were excluded.

2.4 Experimental Procedure

The study was approved by the Human Research Ethics Committee of the Faculty of Medicine at the University of Chile and was conducted following ISO 26642:2010 for glycemic index determination [15]. Each participant consumed a standardized portion of the selected bars equivalent to 25 g of available carbohydrates. A glucose solution (GS, 25 g in 250 mL of water) was used as a control. Capillary blood samples were collected via fingertip puncture at the following time points: 0 min (fasting), 15-, 30-, 45-, 60-, 90- and 120-min post-ingestion. Blood glucose was measured using an Accu-Chek Instant glucometer (Roche Diabetes Care Inc., Indiana, USA). Participants fasted for 12 hours before each test and were instructed to avoid alcohol consumption and intense exercise in the hours leading up to the evaluation.

2.5 Glycemic Index and Load Calculation

The glycemic index (GI, Eq.(1)) was determined as the incremental area under the curve (iAUC) of the glycemic response for each snack, calculated using the trapezoidal rule and normalized against the iAUC of the glucose control [16].

$$GI_{Test\ food} = \frac{iAUC_{Test\ food}}{iAUC_{Control\ food}} \times 100 \qquad (1)$$

Glycemic load (GL) was calculated using the following Eq.(2):

$$GL = \left(\frac{GI \times available\ carbohydrates\ (\frac{g}{portion})}{100}\right) \qquad (2)$$

2.6 Statistical Analysis

To classify the nutritional profiles of the snack bars, a principal component analysis (PCA) was conducted. The analysis included nutritional attributes per 100 g, such as protein, carbohydrate, sugar, calorie, total fat, saturated fat, fiber, and sodium content. Data were standardized using z-score transformation to eliminate scale differences among variables. The scikit-learn library in Python was used for statistical computations. Additionally, a hierarchical heatmap was generated using standardized nutritional values from the PCA. Ward's clustering method with Euclidean distance metric was applied to identify similarity patterns among the analyzed bars. The Seaborn library in Python was used for visualization. Differences between iAUC, GI, and GL values among the bars were evaluated using the Friedman test, followed by Tukey's post-hoc test for pairwise comparisons. A p-value < 0.05 was considered significant.

3. Results and Discussion

3.1 Exploratory Analysis of Snack Bars

A market survey was conducted across popular retail locations in Chile, identifying 41 snack bar samples that were consistently available across all visited points of sale. These snacks were classified using their nutritional information, applying PCA and hierarchical heatmap clustering (Fig. 1). This data-driven approach allowed for an unbiased selection of representative snack bars for the crossover trial conducted in human subjects.

In the PCA plot (Fig. 1a), distinct clustering patterns emerged based on carbohydrate, protein, and fiber content. Specifically, CBS (red marker) was positioned in the lower right quadrant, reflecting its high carbohydrate and sugar content (40.1 g). In contrast, ABPS (blue marker) was located in a more central region, indicating a balanced macronutrient profile between proteins and carbohydrates. Meanwhile, NPSB (green marker) was distinguished by its higher fiber content (17.0 g) and lower available carbohydrate content (5.4 g), aligning with formulations designed for reduced glycemic impact. The hierarchical heatmap (Fig. 1b) complemented this analysis, visually highlighting the relationships among the evaluated bars. CBS clustered alongside high-caloric-density products with elevated sugar content, whereas NPSB was characterized by its high fiber content and lower available carbohydrate levels. These findings informed the final selection of the three products—CBS, ABPS, and NPSB—for glycemic index and glycemic load evaluation.

3.2 Nutritional Composition of Selected Snack Bars

To verify and standardize the nutritional content of the selected snack bars prior to clinical study, proximate analysis was conducted (Table 1). Significant differences in macronutrient composition were observed, with CBS exhibiting the highest carbohydrate content (66.8 g/100 g) and the lowest protein content (5.9 g/100 g). In contrast, NPSB had the highest total fiber content (23.1 g/100 g), with a substantial proportion of low-molecular-weight soluble fiber (18.6 g/100 g), which is associated with a potential reduction in glucose absorption. Regarding moisture content and water activity, NPSB (0.610) and ABPS (0.606) exhibited higher values, which may influence both stability and sensory perception. These findings indicate that the composition of each bar could impact not only glycemic response but also texture and consumer acceptance.

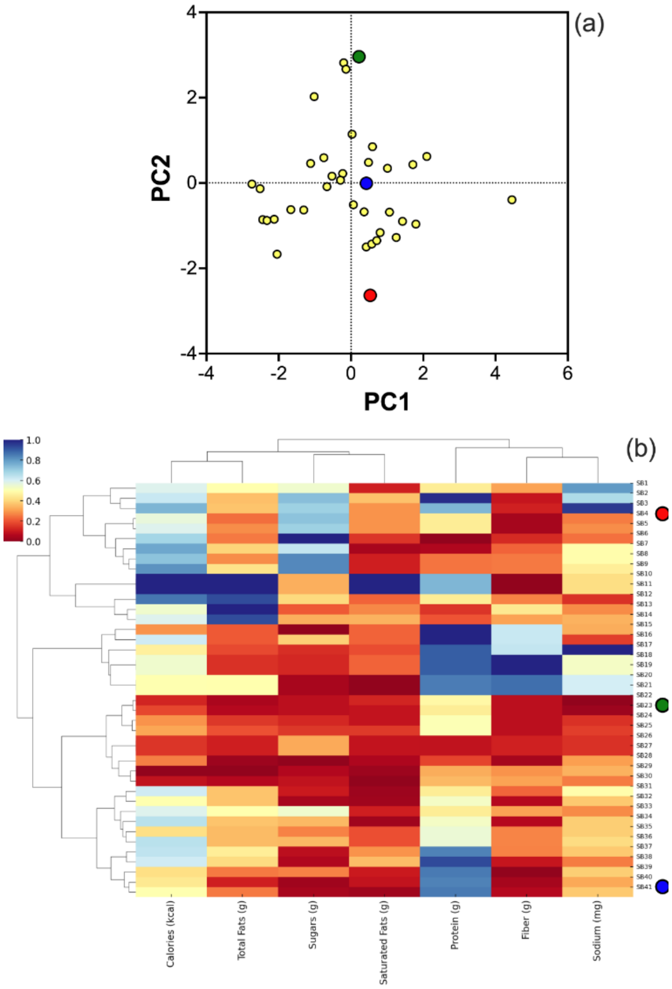

Fig. 1 Nutritional profiling and clustering of snack bars based on market research. (a) Principal Component Analysis (PCA) plot displaying the distribution of snack bars based on their nutritional profiles. Each point represents a unique snack bar, with PC1 and PC2 capturing the majority of the variance in the data. Key bars are highlighted: CBS (brown), ABPS (red), and NPSB (green), representing distinct nutritional profiles identified through market research. (b) Hierarchical clustering heatmap showing standardized values for nutritional attributes (calories, total fats, sugars, saturated fats, protein, fiber, and sodium) across all snack bars. Rows represent individual bars (labeled by their codes), while columns represent nutritional attributes. Clustering highlights patterns and groupings based on nutritional similarity, with warm colors (red) indicating higher standardized values and cool colors (blue) representing lower standardized values.

Table. 1 Comparison of nutritional and functional properties of three snacks. Cereal-Based Snack (CBS), Animal-Based Protein Snack (ABPS), and NotProtein® Snack Bar (NPSB). Parameters include macronutrients, dietary fiber fractions, energy, and water activity

Parameter	CBS	ABPS	NPSB
Moisture (g/100g)	9.3	11.4	19.7
Ash (g/100g)	1.7	2.5	2.2
Proteins (g/100g)	5.9	34.5	34.5
Total Fat (g/100g)	11.4	11.1	9.1
Total Dietary Fiber (g/100g)	4.9	7.7	23.1
Insoluble Dietary Fiber (g/100g)	2.4	4.0	2.0
Total Soluble Dietary Fiber (g/100g)	2.5	3.7	21.1
Soluble Dietary Fiber (HMW) (g/100g)	0.7	1.6	2.5
Soluble Dietary Fiber (LMW) (g/100g)	1.8	2.1	18.6
Available Carbohydrates (g/100g)	66.8	32.8	11.4
Energy (kcal/100g)	398	377	308
Water activity	0.497	0.606	0.610

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3.3 GI and GL of Selected Snack Bars

The GI values varied significantly among the snack bars (Table 2). CBS exhibited the highest GI (83.7 ± 27.1), indicating rapid glucose absorption and metabolism. In contrast, NPSB and ABPS showed significantly lower values, 42.9 ± 13.6 and 39.9 ± 12.6, respectively. Regarding GL, CBS had the highest value (10.1 ± 3.3), followed by ABPS (5.9 ± 2.6) and NPSB (2.2 ± 0.7). These findings suggest that NPSB, with its lower available carbohydrate content and higher soluble fiber proportion, may exert a reduced impact on postprandial glycemic regulation.

Table 2 Glycemic index, glycemic load and servings of the snack bars evaluated

Parameter	CBS	ABPS	NPSB
Glycemic index	83.7 ± 27.1[a]	39.9 ±12.6[b]	42.9 ± 13.6[b]
Available carbohydrates, serving (g)	12.87 (18 g bar)	17.51 (45 g bar)	10.35 (45 g bar)
Glycemic load	10.1 ± 3.3[a]	5.9 ± 2.6[b]	2.2 ± 0.7[c]
Portion administered to each patient	37.4g/2 bars	76.2g/1.7 bars	219.3g/4.9 bars

a, b, c - statistically significant differences (p < 0.05)

3.4 Glycemic Response and Metabolic Impact

The postprandial glycemic response curves (Fig. 2a) clearly illustrate the differences in glucose metabolism among the tested snack bars. CBS induced the highest and most rapid glucose spike, whereas NPSB showed a lower and more gradual glycemic response, maintaining more stable blood glucose levels over time. The incremental area under the curve (iAUC) analysis (Fig. 2b) confirmed these differences, with CBS presenting the highest glycemic impact. ABPS exhibited an intermediate response, likely due to its moderate carbohydrate content and higher protein composition, while NPSB showed the lowest iAUC, reinforcing its suitability for glycemic control.

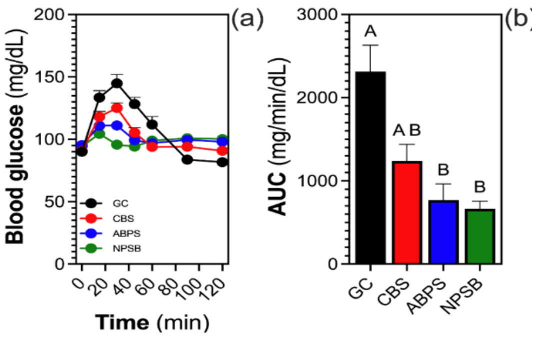

Fig. 2 Postprandial glycemic response to the tested snack bars and GC. (a) Blood glucose levels (mg/dL) over time (min) after consuming the GC, CBS, ABPS, and the NPSB. (b) The incremental area under the curve (iAUC) is calculated using the glycemic responses in (a). Data are presented as the mean ± SE (n = 10). Different letters indicate statistically significant differences (p < 0.05).

The exploratory analysis allowed for the selection of snack bars with contrasting nutritional profiles, facilitating a precise assessment of their glycemic impact. The results indicate that nutritional composition, particularly fiber content and carbohydrate type, plays a key role in metabolic response [17]. CBS exhibited the highest glycemic index (GI = 83.7) and glycemic load (GL = 10.1), indicating rapid glucose absorption and a high metabolic burden. This is likely due to its high available carbohydrate content (66.8 g/100 g) and low dietary fiber levels (4.9 g/100 g), which contribute to a rapid postprandial glycemic spike [18]. Previous studies have shown that high-GI foods can trigger sharp fluctuations in blood glucose levels, leading to excessive insulin responses and increasing the risk of metabolic disorders [19].

Additionally, lower-cost snacks like CBS, which often contain refined carbohydrates and minimal functional ingredients, are more accessible to a broader consumer base. This economic barrier limits access to healthier alternatives, reinforcing the importance of reformulating snacks to enhance their nutritional quality without significantly increasing costs.

In contrast, NPSB demonstrated the most favorable glycemic profile, characterized by lower GI (42.9) and GL (2.2) values. This effect can be attributed to its high total dietary fiber content (23.1 g/100 g), particularly its high proportion of low-molecular-weight soluble fiber (18.6 g/100 g), which modulates glucose absorption by slowing carbohydrate digestion and prolonging metabolic response [20]. The glycemic response curve of NPSB revealed a more gradual rise in blood glucose levels, avoiding sharp peaks and maintaining a more stable metabolic profile over time. Low-molecular-weight soluble fiber has been associated with delayed gastric emptying and reduced postprandial glycemic excursions, contributing to improved glucose homeostasis and enhanced satiety [21].

Furthermore, the presence of isomaltulose in NPSB may have played a crucial role in its glycemic response. Isomaltulose, a slowly digestible disaccharide with a glycemic index of approximately 32, undergoes hydrolysis primarily in the small intestine through the action of isomaltase (EC 3.2.1.10), promoting a more gradual release of glucose and fructose [22-24].

ABPS presented intermediate GI (39.9) and GL (5.9) values, suggesting a more controlled glycemic response compared to CBS but not as optimized as NPSB. Its higher protein content (34.5 g/100 g) likely contributed to a slower glucose absorption rate, as proteins can modulate postprandial glucose responses by stimulating insulin secretion and delaying gastric emptying [25].

However, its lower fiber content (7.7 g/100 g) relative to NPSB indicates that further improvements could be achieved by incorporating additional sources of dietary fiber. Previous research has shown that increasing fiber intake, particularly soluble fiber, enhances glycemic control by modifying carbohydrate digestion and absorption kinetics [26].

These findings highlight the importance of developing snack products with a lower GL by incorporating ingredients that slow carbohydrate absorption and promote sustained energy release. Reformulating snacks with slow-digesting carbohydrate sources, such as isomaltulose, and increasing soluble fiber content could be an effective strategy for expanding the availability of healthier options in the market.

Moreover, considering the high prevalence of obesity and type 2 diabetes in Chile (12.3% of the population diagnosed with diabetes and over 74% classified as overweight or obese), snack reformulation strategies could play a crucial role in public health interventions [8]. Targeted nutritional policies should encourage the development of products with optimized macronutrient compositions and functional properties to mitigate the risk of metabolic disorders.

Future research should evaluate these effects in populations at risk of type 2 diabetes and explore new formulations incorporating other slowly metabolized carbohydrates to further enhance glycemic control and satiety. Additionally, sensory evaluation studies should be conducted to ensure that reformulated snack products maintain consumer acceptance while optimizing nutritional benefits.

4. Conclusion

This research work discussed that NPSB, a snack bar with high fiber content and slow-digesting carbohydrates, resulted in a lower GL, promoting a more stable metabolic response. This type of product represents a healthier snack alternative by reducing glycemic fluctuations, which may help mitigate the risk of metabolic disorders.

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Institutional Review Board Statement

The study was conducted in accordance with the Declaration of Helsinki and approved by Ethical Committee of Research in Human Subjects (CEISH, by its Spanish acronym) of the School of Medicine, University of Chile.

Informed Consent Statement

Informed consent was obtained from all subjects involved in the study.

Data Availability Statement

The data supporting the findings of this study are available from the corresponding authors upon reasonable request. Due to ethical restrictions and participant confidentiality, raw data, including participant

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glucose measurements and demographic details, are not publicly accessible. Processed data used for statistical analyses and graphical representations can be provided in anonymized form upon request.

Conflicts of Interest

The authors declare no conflicts of interest.

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