

RESEARCH STUDY

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Glycemic Index and Glycemic Load of a Steamed Sponge Cake Developed as a Novel Sport Food from Winged Bean (*Psophocarpus tetragonolobus* L.) Seed Flour and Arrowroot (*Maranta arundinacea* L.) Starch

Analisis Indeks Glikemik dan Beban Glikemik Inovasi Sport Food Bolu Kukus dari Tepung Biji Kecipir (*Psophocarpus tetragonolobus*. L) dan Tepung Pati Garut (*Maranta arundinaceae*. L)

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ABSTRACT

Background: Proper nutrition supports athlete performance and recovery. Winged bean seed flour provides protein, while Arrowroot starch contains amylose and amylopectin and is easily digestible. Their combination in a steamed sponge cake may provide complex carbohydrates and fiber that help regulate glycemic index and glycemic load, providing stable and sustained energy.

Objectives: This study aimed to evaluate the glycaemic index (GI) and glycaemic load (GL) of steamed sponge cake formulated from winged bean seed flour and arrowroot starch as an innovation in sports nutrition.

Methods: In vitro and in vivo experimental methods were applied to three formulations of steamed sponge cake: F1 (25:75), F2 (50:50), and F3 (75:25) ratios of winged bean flour to arrowroot starch. To measure the glycemic index and glycemic load in 10 students from UPN "Veteran" Jakarta, participants were given two test meals (pure glucose and steamed sponge cake), each containing 25 g of carbohydrates. Peripheral blood glucose was measured at 0, 15, 30, 45, 60, 90, and 120 minutes after a 10-hour fast using a glucometer. GI and GL were calculated based on the area under the blood glucose response curve (AUC).

Results: The glycemic index values of the steamed cakes were 79 (F1), 68.5 (F2), and 49.3 (F3), and were categorized as having a moderate glycemic index.

Conclusions: Steamed sponge cake formulated from winged bean flour and arrowroot starch shows potential as a sports food due to its favorable glycaemic characteristics for athletes.

INTRODUCTION

Muscle fatigue during prolonged, high-intensity physical activity is a common issue in sports, resulting from a decline in muscle strength. This condition is experienced by more than 90% of athletes¹. Muscle fatigue occurs due to an imbalance between muscle energy availability (ATP) and the supply of oxygen and glucose during strenuous activity². When this occurs, postural control and movement efficiency decrease, increasing the risk of injury in athletes, including muscle strain, cramps, and overuse injuries such as tendinitis³. Injury can further weaken muscle strength, particularly because 30%–60% of athletes do not achieve adequate energy intake. As a result, physiological muscle recovery is impaired⁴. Therefore, appropriate nutritional management for athletes is required.

Athlete nutrition management remains a weak aspect of sports development in Indonesia. Adequate

carbohydrate and protein intake contributes to improvements in strength, endurance, and recovery, thereby supporting performance during training and competition⁵. In sports with moderate to high intensity (>70% VO₂ max), energy requirements range from 2,064 to 3,660 kcal, with 55%–70% derived from carbohydrates⁶. To meet these energy needs, athletes' nutritional intake can be fulfilled through main meals and snacks consumed before, during, and after exercise⁷. Athletes are recommended to consume snacks every three hours to prevent daily energy deficits⁸. Sports food represents a form of snack specifically designed for this purpose, particularly those rich in complex carbohydrates and dietary fiber. One potential raw material for its development is winged bean seeds and arrowroot starch.

Winged bean seeds contain 34.1 g of carbohydrates per 100 g and a high protein content of 28.07%–35.17%, along with essential amino acids that

play a role in muscle protein synthesis, making them a potential ingredient for sports food products⁹. In addition to winged bean, arrowroot starch also has similar potential due to its low glycemic index (14), which supports blood glucose stability, combined with a complex carbohydrate content of approximately 85.2 g per 100 g and an amylose and amylopectin composition that produces a very smooth texture and is easily digested¹⁰. Based on their nutritional composition, winged bean seed flour and arrowroot starch have potential to be utilized as raw materials for various food products, including steamed cake. Soft-textured and easily digestible products such as steamed cake can support consumption efficiency and reduce the risk of gastrointestinal disturbances during intensive physical activity in athletes, particularly in endurance sports, as they are able to provide energy and nutrients according to requirements¹¹. In addition, the development of food products based on local resources such as winged bean seeds and arrowroot starch supports food diversification and national food security.

Food innovation in the form of cakes is an effective strategy to increase consumption appeal among athletes. Individuals with high levels of physical activity, including endurance athletes, tend to choose nutritious instant food products to support energy recovery and muscle cell repair¹². This study aims to analyze the glycemic index and glycemic load of steamed cake based on winged bean seed flour and arrowroot starch as an innovation in sports food. The findings of this study are expected to contribute to the development of healthy foods that support athletic performance, muscle recovery, and the prevention of health problems among physically active individuals.

METHODS

Study Design, Period, and Location

This study was conducted using an experimental design employing both *in vitro* and *in vivo* approaches. The *in vitro* analysis was performed to determine the nutrient composition of each steamed cake formulation sample (F1, F2, F3), including proximate analysis and dietary fiber analysis. The *in vivo* study was conducted to measure the glycemic index and glycemic load using a true experimental design with a crossover design.

During product preparation, all main and additional ingredients were weighed according to the predetermined formulations (F1 = 25%:75%, F2 =

50%:50%, F3 = 75%:25% between winged bean seed flour and arrowroot starch). Material specifications, processing stages, and the proportion of each component are described in detail in the subsequent sections. To ensure the reliability of the study results, all ingredients used were obtained from the same batch, and all equipment was calibrated prior to use. The steamed cake preparation process was conducted under consistent temperature and time settings to ensure uniformity across products. Each formulation was prepared in duplicate to ensure result consistency. In the *in vivo* study, each sample was administered with a minimum interval of one to three days between treatments to prevent carry-over effects. Throughout the study period, respondents were instructed to maintain their usual dietary patterns and physical activity levels to minimize external factors that could influence the results.

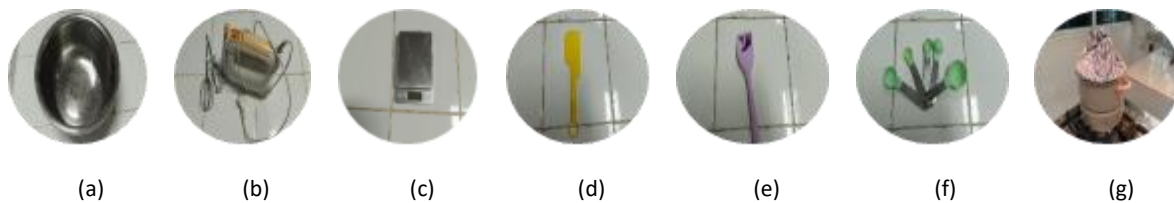
The study was conducted over three months, from June to September 2025. Product preparation and glycemic index and glycemic load testing were carried out at the Dietetics and Culinary Laboratory and the Biomedical Laboratory of Universitas Pembangunan Nasional “Veteran” Jakarta. Analysis of nutrient composition and dietary fiber was conducted at the Saraswanti Indo Genetech (SIG) Laboratory, Bogor. This study received ethical approval from the Research Ethics Committee of Universitas Prima Indonesia on 30 August 2025 (No. 065/KEPK/UNPRI/VIII/2025).

Production Process

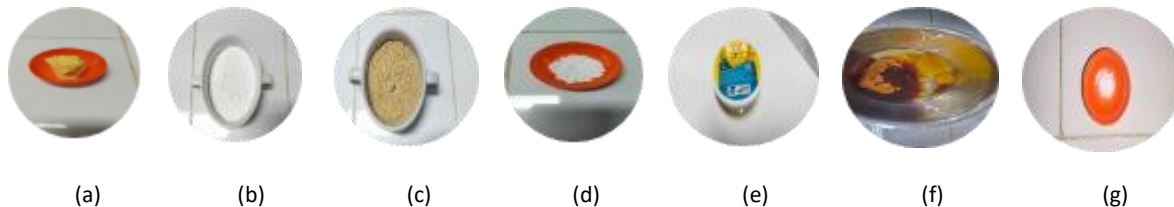
The steamed cake production process was conducted through several stages, beginning with steaming winged bean seed flour with cinnamon for 15 minutes to minimize the bitter taste of the flour¹³. The flour was then cooled to room temperature and sieved together with arrowroot starch to ensure uniform mixing and prevent clumping. In a separate container, eggs, palm sugar, emulsifier (SP), vanilla, baking powder, and salt were beaten using a high-speed mixer until the batter became pale, aerated, and thick. Margarine was melted and allowed to cool, then added to the batter and mixed again until evenly combined. The flour mixture was gradually incorporated while gently folding with a spatula until a homogeneous batter was obtained. The prepared batter was poured into aluminum molds lightly greased with margarine and steamed for approximately 15 minutes over medium heat without opening the steamer lid to allow optimal cake expansion.

Table 1. Steamed cake formulations

Composition (g)	F1	F2	F3
Winged Bean Seed Flour	15	25	35
Arrowroot Starch	35	25	15
Margarine	20	20	20
Egg	50	50	50
Palm Sugar	50	50	50
Vanilla	1	1	1
Emulsifier SP	2.5	2.5	2.5
Baking Powder	1	1	1
Salt	0.3	0.3	0.3
Total	174.8	174.8	174.8



(a) Basin, (b) Mixer, (c) Scale, (d) Spatula, (e) Brush, (f) Measuring Spoon, (g) Pot/Steamer
Figure 1. Equipment for preparing steamed cake with winged bean seed flour and arrowroot starch



(a) Margarine, (b) Arrowroot starch, (c) Winged bean seed flour, (d) Baking powder, (e) Emulsifier SP, (f) Palm sugar and eggs, (g) Vanilla
Figure 2. Ingredients for preparing steamed cake with winged bean seed flour and arrowroot starch

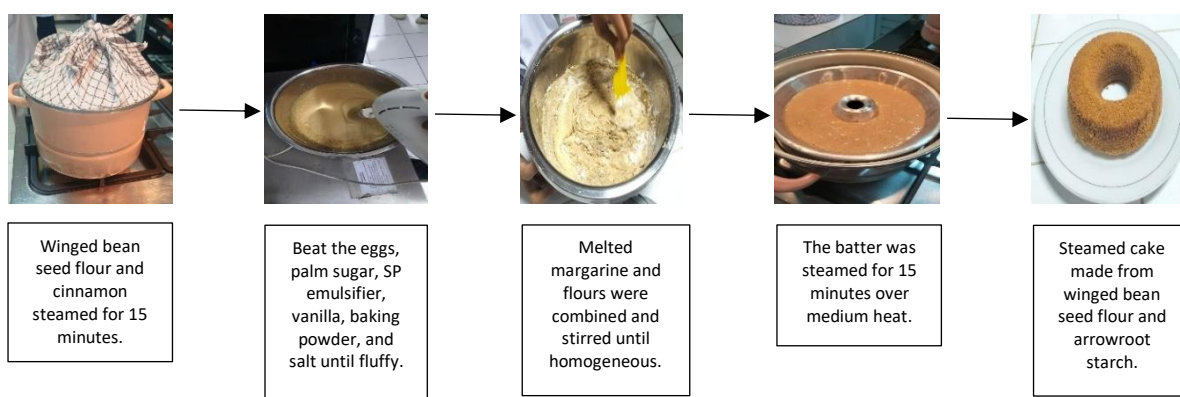


Figure 3. Preparation of steamed cake using winged bean seed flour and arrowroot starch.

Glycemic Index Test

The study population consisted of healthy adults meeting the inclusion criteria, specifically subjects aged 17–25 years with a body mass index (BMI) within the normal range (18.5–25 kg/m²). This age range was selected as it represents a group with stable metabolic function and glycemic response, without physiological changes associated with aging. The normal BMI criteria, according to the Indonesian Ministry of Health (KEMENKES), ensured that all subjects had balanced nutritional status and no metabolic disorders that could affect glycemic index and load measurements. Additional criteria included no regular medication use, non-smoking status, and no alcohol consumption. The study included four treatment groups with the same subjects, and sample size calculations using Federer's formula indicated a minimum of six subjects. The number of subjects was based on previous research indicating that ten respondents are adequate for glycemic index studies, providing high statistical power and precision¹⁴.

Data collection was conducted after respondents provided written informed consent. Each subject received two types of treatments: consumption of pure glucose as the reference food and consumption of steamed sponge

cake products from three different formulations (F1, F2, F3). Tests were conducted in the morning after a 10–12 hour fast. Blood samples were collected by healthcare personnel (nurses) via finger-prick capillary blood sampling at 0 minutes (pre-consumption) and subsequently at 15, 30, 45, 60, 90, and 120 minutes. Equipment used included a glucometer, glucose test strips, sterile lancets, and sterile alcohol swabs.

The pure glucose solution contained 25 g of carbohydrate dissolved in 250 mL of water, consumed within a maximum of 15 minutes. The steamed sponge cake samples were portioned to contain 25 g of carbohydrate per treatment, with product weights of 60.93 g, 73.66 g, and 86.06 g for F1, F2, and F3, respectively. A minimum one-day interval was provided between measurements to minimize residual effects from previous tests¹⁶. Glycemic index values were calculated by comparing the area under the curve (AUC) of the glycemic response for the steamed sponge cake products with the AUC of the pure glucose solution as the reference food¹⁵. All blood glucose data were systematically recorded by the researchers to ensure accuracy and consistency of the results.

Data Analysis

Glycemic index values were calculated by comparing the AUC of the glycemic response of the test products with the AUC of the reference food, and the result was multiplied by 100. Data were processed using Microsoft Excel 2021 for tabulation and construction of glycemic response curves, and IBM SPSS Statistics version 25 for statistical analysis. Comparisons between formulations were conducted using one-way ANOVA, and the optimal formulation was determined using the DeGarmo decision matrix method based on the lowest glycemic index and glycemic load values, while remaining within the medium glycemic load category according to FAO–WHO standards.

RESULTS AND DISCUSSIONS

Nutrient Content and Determination of Test Sample Weight

Table 2. Steam cake nutrition composition

Composition	Weight (gram)		
	F1	F2	F3
Ash (%)	1.63	1.91	2.14
Fat (%)	12.60	14.33	15.25
Moisture (%)	29.73	29.61	29.00
Protein (%)	6.66	8.73	10.91
Carbohydrate (by difference) (%)	49.39	45.42	42.71
Dietary fiber (%)	8.36	11.48	13.66
Available carbohydrate* (%)	41.03	33.94	29.05
Test food weight** (g)	60.93	73.66	86.06

*Available carbohydrate = Total carbohydrate (by difference) – Dietary fiber

**Test food weight = (25 g : Available carbohydrate) × 100

The amounts of steamed sponge cake provided to respondents, as determined in Table 1, were 60.93 g for Formula F1, 73.66 g for F2, and 86.06 g for F3. Test foods were administered after an 8–10 hour fast, with the exception that mineral water was permitted. Each administration was separated by a sufficient interval to allow blood glucose levels to return to baseline, thereby minimizing potential inter-treatment bias in glycemic index measurements.

Blood Glucose Response

Table 3 indicates that the highest increase in blood glucose occurred in the pure glucose group at 30 minutes (142 mg/dL), followed by a gradual decline from 60 to 120 minutes. ANOVA analysis indicated no

Glycemic index values were determined by repeated measurement of capillary blood glucose following administration of pure glucose as the reference food and three steamed sponge cake formulations as test foods, with weights adjusted to provide 25 g of available carbohydrate. Previous studies have indicated that the standard portion for glycemic index testing is 50 g of carbohydrate; however, 25 g may be used if the food portion is too large to be consumed in a short period¹⁶. Excessive intake of the test food in a single meal may cause gastrointestinal discomfort or excessive blood glucose spikes, particularly in sensitive individuals. The international standard ISO 26642:2010 similarly concludes that 25 or 50 g of carbohydrate is acceptable, depending on the requirements and characteristics of the food tested¹⁷. The following details the weights of the samples provided for testing:

significant differences in blood glucose levels between groups at 0, 60, 90, and 120 minutes (p -value > 0.005). However, significant differences were observed at 15 minutes (p -value = 0.034), 30 minutes (p -value = 0.002), and 45 minutes (p -value = 0.000), indicating variation in blood glucose response among treatments during the initial and peak phases. Based on the blood glucose change curves, the pure glucose group exhibited a sharper rise, reaching the highest peak at 30 minutes (142 mg/dL), followed by Formula 1 (132 mg/dL). Formulas 2 and 3 demonstrated more gradual increases with lower peaks, indicating a more stable glycemic response. After 45 minutes, all treatments showed a gradual decline in blood glucose until 120 minutes, approaching or slightly below baseline levels.

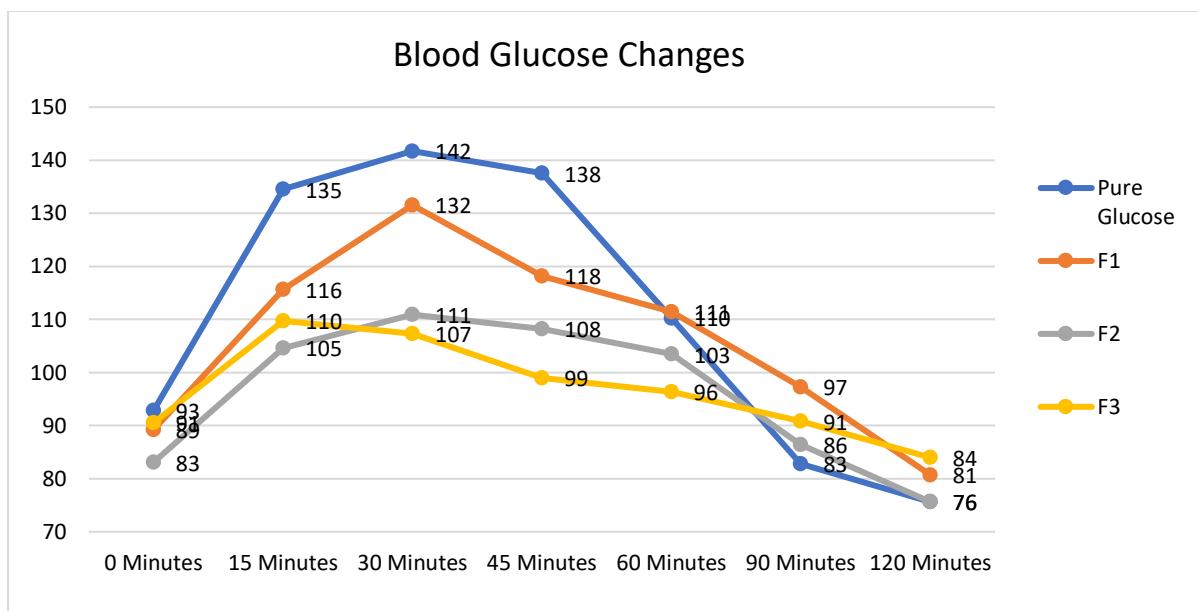


Figure 1. Blood glucose changes

Figure 1 presents changes in blood glucose levels for the pure glucose group, Formula 1, Formula 2, and Formula 3 across 10 respondents. Blood glucose levels for Formulas 1, 2, and 3 remained below those of the reference group, pure glucose. Pure glucose exhibited an increase from 0 minutes, reaching a peak at 30 minutes (142 mg/dL), whereas Formula 1 reached a slightly lower peak at 30 minutes (132 mg/dL). After peaking, all

treatments showed a gradual decline in blood glucose until 120 minutes, with the decrease in the pure glucose group being relatively steeper than in the other formulations. These differences indicate that each formulation elicited distinct glycemic responses, with Formulas 2 and 3 producing more stable blood glucose fluctuations.

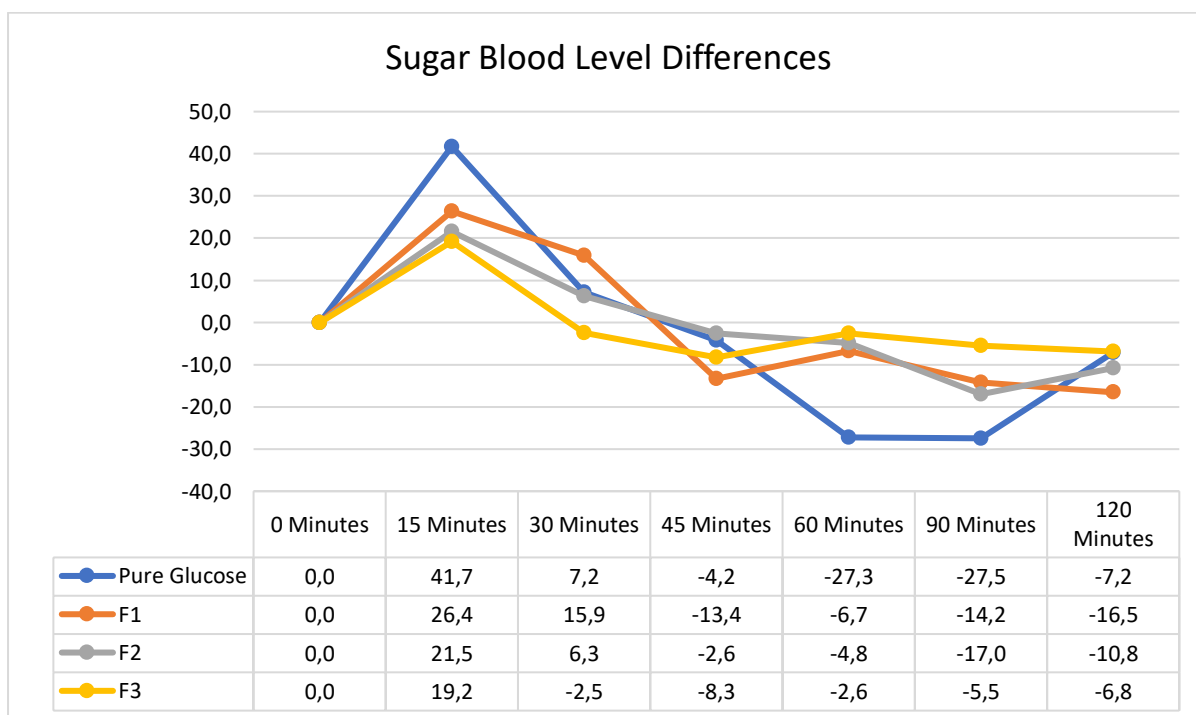


Figure 2. Differences in Blood Glucose Levels

Figure 2 presents the measured differences in blood glucose patterns between pure glucose and the three test formulations. Pure glucose elicited the highest

blood glucose increase at 15 minutes (41.7 mg/dL from baseline), followed by a continuous decline to -27.5 mg/dL at 90 minutes, and a slight rise to -7.2 mg/dL at

120 minutes. This pattern reflects the rapid postprandial glycemic response of pure glucose. For Formula 1, blood glucose increased at 15 minutes (26.4 mg/dL), then gradually declined to -5.5 mg/dL at 90 minutes and decreased slightly further at 120 minutes. Although all treatments exhibited an initial rise followed by a decline, fluctuations in the three test formulations were more gradual compared with pure glucose, which showed faster and sharper changes in blood glucose levels.

Glycemic Index and Glycemic Load

Glycemic Index Values

Glycemic index in this study was determined by comparing the area under the curve (AUC) of the glycemic response following consumption of the test products with the AUC obtained from the reference food¹⁵. The comparison of these two values was then used to calculate the glycemic index. The incremental Area Under the Curve (iAUC) method was applied to calculate the AUC. Calculation of the AUC and determination of glycemic index values were performed using blood glucose responses from pure glucose and the three test formulations as follows:

Table 3. Area under the curve (AUC) values

Respondent	AUC Glucose	AUC F1	AUC F2	AUC F3
R1	4747.5	7762.5	2715	0
R2	3495	1447.5	3210	1552.5
R3	5775	1560	2370	2887.5
R4	870	750	1365	795
R5	1200	240	480	1200
R6	2310	3457.5	1627.5	1582.5
R7	3225	3532.5	2655	1087.5
R8	1515	1515	832.5	570
R9	2962.5	2092.5	3120	1710
R10	2835	2872.5	1515	1665

$$AUC = (\Delta 15 \times 15/2) + (\Delta 15 + \Delta 30)/2 \times 15 + (\Delta 30 + \Delta 45)/2 \times 15 + (\Delta 45 + \Delta 60)/2 \times 15 + (\Delta 60 + \Delta 90)/2 \times 30 + (\Delta 90 + \Delta 120)/2 \times 30$$

Notes:

- The numbers 15 and 30 indicate the time intervals between blood sampling points (in minutes).
- $\Delta 15$, $\Delta 30$, $\Delta 45$, $\Delta 60$, $\Delta 90$, $\Delta 120$ represent the differences in blood glucose levels at the corresponding minutes compared to fasting blood glucose

Table 4. Glycemic index (GI) values

Product	Glycemic Index (%)	Category*
Formula 1	79	High
Formula 2	68.5	Medium
Formula 3	49.3	Low

*Category: Low GI: <55, Medium GI: 56–69, High GI: >70

$$\text{Glycemic Index (GI)} = \frac{\text{Area under the curve of the test food}}{\text{Area under the curve of the reference food}} \times 100\%$$

The glycemic index (GI) is used to assess the rate and magnitude of blood glucose increase following consumption of carbohydrate-containing foods. According to ISO standards, the GI scale can be referenced to either pure glucose or bread. Foods containing readily digestible, absorbable, and rapidly metabolized carbohydrates are classified as high GI (>70), whereas foods with slower digestion and absorption are classified as low GI (<55). The GI of a food can be influenced by cooking methods, processing, starch digestibility, and other nutrient contents such as protein and fat. For example, high-fiber foods generally have a lower GI because fiber slows carbohydrate absorption¹⁸. The GI of a food is determined by comparing the blood glucose response after consuming a test product providing 25 g of available carbohydrate with the response elicited by 25 g

of carbohydrate from a reference food, namely pure glucose.

The calculated GI values for the test foods were as follows: Formula 1 had a GI of 79, Formula 2 had a GI of 68.5, and Formula 3 had a GI of 49.3. These results indicate that Formula 1 is classified as high GI, Formula 2 as medium GI, and Formula 3 as low GI. Consumed carbohydrates elevate blood glucose and stimulate insulin release to regulate its utilization for energy, glycogen storage, or fat deposition. In low-GI foods, glucose absorption is slower, resulting in a more controlled blood glucose increase¹⁹.

The GI values obtained indicate that Formula 3 is lower compared with the other test formulations. This is attributable to higher contents of protein, dietary fiber, and fat in Formula 3, as indicated by nutrient analysis.

Fiber, protein, and fat slow digestion, delaying glucose absorption and preventing sudden blood glucose spikes. Fiber slows gastric emptying and inhibits digestive enzyme activity, while protein and fat require longer digestion time, delaying peak glucose levels by several hours. Additionally, antinutritional compounds in legumes, such as polyphenols, saponins, and phytic acid, inhibit carbohydrate digestion, contributing to lower GI in foods²⁰.

Foods with high or low GI can influence blood glucose levels, particularly within the first hour after eating. After carbohydrate intake, insulin acts in two phases: a rapid phase occurring approximately 10 minutes after the rise in blood glucose, and a slower phase lasting up to two hours. During the first hour, blood glucose may reach 160 mg/dL and then return to 120 mg/dL within 2–2.5 hours due to insulin facilitating

glucose uptake by cells for energy, glycogen storage, or conversion to fat. Consumption of high-GI foods immediately before competition can lead to rapid glucose and insulin spikes, potentially causing early exercise hypoglycemia, inhibiting fat utilization, accelerating muscle glycogen depletion, and reducing endurance. Therefore, high-GI foods should be avoided before competition^{21,22}.

Glycemic Load

Glycemic load describes the impact of a food on blood glucose, calculated based on the combination of its glycemic index and the amount of carbohydrate it contains. Glycemic load values are classified into three categories: low (<10), medium (>10 to <20), and high (>20)²³. The calculated glycemic load values for the products are as follows:

Table 5. Glycemic Load (GL) Values

Product	Glycemic Load	Category*
Formula 1	19,8	Medium
Formula 2	17,1	Medium
Formula 3	12,3	Medium

*Category: Low GL: <10, Medium GL: 11–19, High GL: >20

$$\text{Glycemic Load (GL)} = \frac{\text{Glycemic Index} \times \text{Available Carbohydrate}}{\text{Serving}} \times 100$$

The calculated glycemic load (GL) of the steamed cake made from winged bean seed flour and arrowroot starch falls within the medium category (11–19). Glycemic load measures the amount of carbohydrate in a food serving and its impact on blood glucose. Glycemic index and glycemic load do not always correspond; foods with a high glycemic index can have a low glycemic load if consumed in small portions, whereas foods with a low glycemic index can have a high glycemic load if consumed in large portions. The greater the carbohydrate content in a food, the higher its glycemic load²⁴. Foods with a medium glycemic load help maintain blood glucose stability and reduce drastic increases in blood glucose levels.

Differences in glycemic load categories among the formulas may be related to variations in available carbohydrate content and the glycemic index of each formula. Formula 1 has a higher glycemic load due to its greater available carbohydrate content, rapidly increasing blood glucose. Formula 2 has a lower glycemic load than Formula 1, providing a stable energy supply and helping to maintain muscle glycogen during activity. Formula 3, with the lowest glycemic load, produces a more gradual rise in blood glucose.

During pre-training and pre-competition periods, foods with low to medium glycemic loads tend to provide a stable glucose supply, helping maintain euglycemia and carbohydrate availability during the first 1–2 hours of activity, particularly if carbohydrate intake is restricted during training²⁵. Studies indicate that foods with a low glycemic index but medium glycemic load can benefit athletes by stabilizing blood glucose while supplying sufficient carbohydrate for glycogen synthesis²⁶. This glycogen serves as an energy source during training or competition, supporting performance. Moreover, during

the post-exercise recovery phase, consumption of foods with medium to high glycemic loads accelerates muscle glycogen replenishment, especially when combined with adequate protein intake.

Optimal Formulation

The selection of the optimal sport food formulation was performed using the DeGarmo decision matrix method, applying glycemic index and glycemic load criteria with equal weights of 50% each. The results indicated that Formula 3 achieved the highest score (1.000) compared to Formula 2 (0.357) and Formula 1 (0.000). This outcome is attributable to Formula 3 having the lowest glycemic index (49.3) and the lowest medium-range glycemic load (12.3). Therefore, Formula 3 was identified as the most suitable formulation for sport food development.

The low glycemic index of Formula 3 provides important advantages for endurance athletes. Foods with a low glycemic index are digested and absorbed more slowly, resulting in a gradual rise in blood glucose and a more stable energy supply throughout physical activity. Additionally, the relatively low glycemic load contributes to the overall control of postprandial glycemic response. Consumption of sport foods with a low glycemic index, such as Formula 3, can slow glycogen depletion, preserve energy reserves for longer durations, and ultimately delay the onset of muscle fatigue.

This study has strengths, including the utilization of locally available, nutrient-rich ingredients such as winged bean seed flour and arrowroot starch, which have potential for sport food innovation. Furthermore, the study successfully identified the formula with the lowest glycemic index, Formula 3, which could serve as a pre-exercise energy source by better maintaining blood

glucose stability compared to the other formulas. However, a limitation of this study is that it did not involve intervention in athletes; thus, the effects of product consumption on physical performance and muscle recovery in athletes have not yet been assessed.

CONCLUSIONS

The selection of foods with appropriate glycemic index and glycemic load plays a critical role in supporting blood glucose stability and athletic performance. The results of this study indicate that Formula 3 has a low glycemic index (49.3) and the lowest medium-range glycemic load (12.3) compared to the other formulas, making it the optimal formulation and a potential innovation in sport food based on winged bean seed flour and arrowroot starch. These characteristics support more efficient blood glucose stability and energy provision before exercise compared to Formula 1 (high GI: 79; GL: 19.8) and Formula 2 (medium GI: 68.5; GL: 17.1).

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CONFLICT OF INTEREST AND FUNDING DISCLOSURE

All authors declare no conflict of interest regarding this article. Funding was provided by the authors' personal resources.

AUTHOR CONTRIBUTIONS

TSNF: conceptualization, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, software, visualization, and writing the original draft; NN: methodology, supervision, validation, and writing review & editing.

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