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Nutritional, Antioxidant, Anti-Obesity, and Sensory Evaluation of *Garcinia parvifolia*-Fortified Fitness Bars

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ABSTRACT

Southeast Asia, including Malaysia, is facing a prevalence concern with obesity. Functional foods containing natural bioactive compounds are widely studied for their potential use in dietary interventions for obesity and weight management. This study developed a low-calorie fitness bar enriched with *Garcinia parvifolia*, which contains bioactive compounds that might display antioxidant and anti-obesity properties. Four different formulations of *G. parvifolia* powder: Control (0%), F1 (1%), F2 (3%), and F3 (5%) were prepared together with rolled oats, puffed rice, honey, chia seeds, canola oil, and xanthan gum. Nutritional composition, total phenolic content, antioxidant activity, pancreatic lipase inhibition, and sensory acceptance were analysed. The results showed that the energy values ranged from 371.73 to 377.76 kJ/100 g, with sample F3 (5%) showing the lowest sugar content (1.43%) and fat content (2.64%). Additionally, F3 also recorded the highest content of phenolic (49.43 mg GAE/g) and lipase inhibition activity (59.21%), demonstrating strong potential as a functional food. However, sensory evaluation indicated that 1% formulation (F1) was most preferred, while 3% formulation (F2) offered the best compromise between functionality and palatability. F3 was less favoured due to its sourness despite its higher bioactivity. Overall, *G. parvifolia* shows potential as a useful ingredient in snack bar formulations, boosting antioxidant activity and anti-obesity effects while retaining consumer preferences.

Keywords: *Garcinia parvifolia*, Functional foods, Snack bar formulation, Antioxidant activity, Anti-obesity potential

Introduction

Snack bars, particularly fitness bars, have become more popular due to their convenience, nutritional value, and health advantages. They are regarded as functional foods that provide physiological advantages beyond simple nutrition. With rising obesity rates, researchers are looking into healthier snack options as nutritional tools to address this global issue.[1] Snack bar composition plays a crucial role in influencing obesity-related factors.[2] There are varieties of snack bars, such as energy, protein, and cereal bars. They provide a portable source of carbohydrates, proteins, and fats, often enhanced with beneficial bioactive compounds. These bars support multiple purposes, from providing quick energy to filling nutritional gaps and supporting specific diets.[3] The Federal Food, Drug, and Cosmetic Act (FDCA) regulates the marketing of products in the United States, which are often marketed for their potential health benefits and low-fat content.

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Fitness bars are classified under the category of functional foods or nutraceuticals, which have advantages such as better nutrient absorption and digestion, as well as a potential role in weight management.[2,4] To further enhance their functional value, researchers have been using natural bioactive compounds derived from plants, herbs, and fruits. Among these, *Garcinia* species have drawn attention due to their high amount of phenolic and flavonoid content, which are known to exhibit anti-lipogenic and antioxidant properties that support weight control and fat metabolism.[5,6] Some naturally occurring bioactive compounds, such as hydroxycitric acid, which is present in some *Garcinia* species, are believed to inhibit fat production by blocking adenosine triphosphate ATP citrate lyase, a key enzyme involved in fatty acid synthesis, potentially aiding in weight loss.[7]

Obesity, a complex metabolic disorder marked by excessive fat accumulation, has tripled its prevalence since 1975 and is now a global health concern, which causes morbidity, mortality, and healthcare costs.[51] Functional foods, including plant-based and bioactive-enriched products, have shown their effectiveness in promoting weight control and combating obesity by influencing energy balance and lipid metabolism.[8] It is a complex condition linked to metabolic disorders such as type 2 diabetes and cardiovascular disease,[9] and poses challenges in effective treatment. While changes in lifestyle remain the most common approach, pharmaceutical and surgical options are also being considered due to the minimal success of conventional methods.[10] Snack bars have gained popularity as a nutrient-rich, portable option for versatile consumption.[11] In response to rising obesity concerns, researchers are looking for healthier alternatives. Functional foods such as fitness bars, enriched with bioactive compounds, show potential as a functional food for obesity management strategies.

Malaysia records the highest rates of obesity in Southeast Asian countries.[12] According to recent studies, approximately 19.7% of

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Malaysian adults are obese, with projections showing a 4.7% annual increase through 2035.[13,14] The impact of obesity extends beyond individual health, negatively affecting societal wellbeing and causing a significant burden on healthcare systems.[15] Despite pharmaceutical interventions being one of the conventional treatments used, they often cause adverse effects such as headaches, nausea, gastrointestinal disturbances, and organ-specific complications.[16,17]

Despite the growing market for functional foods and the documented potential of *Garcinia* species in weight management,[5] there are no previous studies on using *G. parvifolia* in food products. *G. parvifolia*, a native tropical fruit species in Southeast Asia, locally known as "takob akob," "asam kandis," or "asam aur-aur," was selected for its high phenolic content, antioxidant activity, and lipase inhibition, which potentially support fat metabolism and obesity prevention. In addition, this superfruit is well known to have many bioactive potentials, including antibacterial, antifungal, anti-cancer, anti-aging, anti-inflammation, and anti-allergenicity.[54,55] Maintaining the stability and bioavailability of its active compounds, during processing and storage, is one of the key challenges in food handling[18] as it is prone to heat and light degradation, reducing its therapeutic efficacy.[19]

By integrating *G. parvifolia* into food matrices, formulation is one of the challenges that requires careful balance. Previous studies on functional foods highlight the challenges of incorporating bioactive compounds while preserving product nutritional quality.[20] Although *G. parvifolia* exhibits promising anti-obesity effects, particularly through lipase inhibition,[21] the optimal formulation for therapeutic efficacy without affecting palatability is yet unknown. This gap limits the development of effective and palatable functional foods as natural alternatives for weight management.[22]

This study aims to develop fitness bars enriched with *G. parvifolia* extracts, evaluating the nutritional composition, focusing on protein, fat, carbohydrate, and fibre content. In vitro assays such as total phenolic content and lipase inhibition were further evaluated as key indicators of anti-obesity activity. Consumer acceptance is also evaluated through sensory analysis, recognizing its importance for the commercial success of functional foods. Collectively, these objectives fill in the current research gaps and provide novel insights for developing commercially functional food products based on *Garcinia* extract to support natural approaches in managing obesity. Moreover, integrating local fruits into food development helps to strengthen and promote the local agricultural economy while encouraging the conservation of indigenous fruit species that are currently underutilized.

Materials and Methods

Sample and materials collection

Samples of *G. parvifolia* were obtained from a local market in Sabah, specifically sourced from Penampang, Sabah, Malaysia, and stored at -20°C freezer (SINCOOL, China) for identification purposes. The specimen was examined prior to further analysis for morphological and taxonomical characteristics and compared with existing taxonomic references. Additional verification was performed through consultation with botanical experts and comparison with herbarium specimens. The unique accession number BORH 20201 was assigned to the specimen. Rolled oats (Pristine brand, Australia), cereal rice, chia seeds, honey, and canola oil were purchased from various retailers through the Shopee e-commerce platform.

Preparation of a Fitness Bar

The *G. parvifolia* fruit peel was dried using the oven-drying method at a temperature of 40–60°C (Memmert UN110PA, Germany) until the moisture content was reduced to a stable level to prevent microbial growth.[53] The dried peel was ground into a fine powder using a high-speed blender (Panasonic MX-GM1011, Japan). The resulting powder was stored in an airtight container and refrigerated at 4–10°C (SINCOOL, China) to preserve its nutritional and bioactive properties over time. This method ensures reproducibility and stability of the powder under controlled conditions.

The fitness bars were formulated using rolled oats, puffed rice, chia seeds, honey, canola oil, and *G. parvifolia* peel powder at three different concentrations (Table 1). Rolled oats and puffed rice were roasted, while honey, canola oil, and xanthan gum were heated to form a binding solution.[23,24] The ingredients were mixed thoroughly, moulded into 12 × 2.5 × 2.0 cm bars, and cooled at -17°C for 20 minutes to set before finally shaped into 25 g portions.

Table 1: The formulation of the Fitness Bar

Raw Material	Formulation Control (0%) (g)	F1 (1%) (g)	F2 (3%) (g)	F3 (5%) (g)
G. parvifolia powder	-	0.75	2.25	3.75
Rolled Oat	22.33	22.33	22.33	22.33
Puffed rice	14.53	14.53	14.53	14.53
Honey	7.26	7.26	7.26	7.26
Chia seed	5.81	5.81	5.81	5.81
Canola oil	2.91	2.91	2.91	2.91
Xanthan gum	0.73	0.73	0.73	0.73

Nutritional Composition of a Fitness Bar

Ash content

Ash content was determined using the dry ash method in a muffle furnace (Carbolite AAF 11/7, United Kingdom). A 5g homogenized fitness bar sample was placed in a muffle furnace at 575°C for 3 hours.[25] The ash's weight was recorded, and ash content was estimated using Equation (2.1):

$$\text{Ash Content (\%)} = \frac{W3-W1}{W2-W1} \times 100\%, \quad (2.1)$$

where W_1= weight of the crucible with lid (g), W_2= weight of the crucible with lid and sample (g), W_3= weight of the crucible with lid and ash (g).

Moisture analysis

Moisture content was determined using a moisture analyser (A&D MX-50, Japan) set at 140°C and analysed until completion. The moisture percentage displayed on the machine's screen was recorded.[26]

Fat content

Fat content was determined using the Soxhlet extraction method with petroleum ether as the solvent and heated for approximately 8 hours[25]. Fat percentage was calculated using Equation (2.2):

$$\text{Lipid Content (\%)} = \frac{W3-W1}{W2} \times 100\%, \quad (2.2)$$

where W_1= weight of the empty flask (g), W_2= weight of the sample (g), W_3= weight of the flask with extracted fat (g).

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Protein content
Protein content was measured using the Micro-Kjeldahl method[25] involving digestion, distillation, and titration processes[26]. The nitrogen percentage was converted to protein content using Equation (2.3):

$$\text{Protein (\%)} = \text{\% Nitrogen} \times 6.25. \quad (2.3)$$

Fibre content
Crude fibre content was determined using AOAC 978.10, involving acid and alkaline digestion followed by ashing at 550°C in a muffle furnace[27] (Carbolite AAF 11/7, United Kingdom). Fibre percentage was calculated using Equation (2.4):

$$\text{Crude Fibre (\%)} = \frac{W2-W3}{W1} \times 100\%, \quad (2.4)$$

where W_1: weight of sample (g), W_2: weight after drying (g), and W_3: weight after ashing (g).

Carbohydrate content
Carbohydrate content was calculated by the difference method, subtracting the sum of protein, moisture, fat, fibre, and ash contents from 100%.[27]

Total sugar
Total sugar content was measured using a digital refractometer (Atago PAL-BX/RI, Japan), and the Brix value was converted to sugar percentage.[28]

Energy value calculation
Energy content was estimated based on macronutrient caloric values: 4 kcal/g for protein and carbohydrate, 9 kcal/g for fat, and 2 kcal/g for fibre.[27]

Functional Properties
Total phenolic content
The Total Phenolic Content (TPC) of the fitness bars was determined using a modified Folin-Ciocalteu method.[29] A 20 µL aliquot of sample solution was mixed with 100 µL of Folin-Ciocalteu reagent (Sigma Aldrich, USA), followed by 100 µL of 7.5% weight over volume (w/v) sodium carbonate (Chemiz, United Kingdom) in a volumetric flask and incubated in the dark at room temperature for 90 minutes. After incubation, absorbance was measured at 765 nm using a spectrophotometer (Jenway 7200, United Kingdom). TPC was calculated based on a standard gallic acid (Merck, Germany) calibration curve (ranged from 20-100 µg/mL), and results were expressed as milligrams of Gallic Acid Equivalent (GAE) per gram of sample. The regression equation used for quantification is $y = 0.0054x - 0.0031$ ($R^2 = 0.9997$), ensuring accuracy in phenolic content determination.

Pancreatic lipase inhibition assay
The pancreatic lipid inhibition assay was conducted using plant material that had been dried and ground into small particles.[30] The Pancreatic Lipase (PL) inhibition assay was performed following a standardized procedure.[31, 32] A 5 mg/mL solution of porcine Pancreatic Lipase (PL) (Sigma Aldrich, USA) was prepared in Tris-HCl buffer (2.5 mmol Tris, 2.5 mmol NaCl, pH 7.4) (Chemiz, United Kingdom). Stock solutions of the Control, F1, F2, and F3 were prepared in dimethyl sulfoxide (DMSO) (Chemiz, United Kingdom) at concentrations ranging from 3.125 to 1000 µg/mL. Orlistat (Sigma Aldrich, USA) was prepared separately in DMSO at concentrations ranging from 1.5625 to 200 µg/mL.
Each reaction mixture (1 mL) consisted of 875 µL of buffer, 100 µL of enzyme solution, and 20 µL of inhibitor solution. Then, the mixture was pre-incubated at 37°C for 5 minutes, respectively. Subsequently, 10 µL of substrate solution (10 mM 4-nitrophenyl butyrate in acetonitrile) (Sigma Aldrich, USA) was added, and the reaction was allowed to proceed for 5 minutes. The absorbance of the product (4-nitrophenol) was measured at 405 nm using a microplate spectrophotometer (Synergy HTx BioTek, USA). The percentage of inhibition was calculated relative to the enzyme control using the formula presented in Equation (2.5):

$$\text{Inhibitory activity (\%)} = \left[\frac{(AE-AT)}{(AE)}\right] \times 100, \quad (2.5)$$

where AE: the absorbance of the enzyme control (without inhibitor), and AT: the absorbance of the test sample.

Sensory Evaluation of Fitness Bar
A 9-point hedonic scale has been widely used as a sensory evaluation tool to quantify food acceptability. A total of 30 untrained panellists participated in the sensory evaluation.[52] Each panellist evaluated four formulations under controlled conditions. The sensory assessment comprised a descriptive evaluation of attributes, including appearance, texture, aroma, taste, and overall acceptance, alongside a hedonic test to assess overall liking or preference. To minimize bias, the fitness bar samples were labelled with three-digit random codes and presented in a randomized order. Each sample, cut into small pieces, was served on white plates at room temperature. Data were collected using the 9-point hedonic scale and analysed using one-way Analysis of Variance (ANOVA) to identify significant differences in sensory parameters among the formulations. A spiderweb chart was constructed using Microsoft Excel (version 2021) to visualise the sensory evaluation of the fitness bars.

Statistical Analysis
All experiments were conducted in triplicate (n=3), and results were expressed as mean ± Standard Deviation (SD). The mean and SD values were calculated using Microsoft Excel (version 2021). For statistical analysis, ANOVA was performed using Minitab software (version 22.1.0), with a significance level set at $p \leq 0.05$. A post-hoc Tukey's test was used to identify significant differences between groups when ANOVA indicated statistical significance. Data are presented as mean ± SD from three independent experiments, and any p-value ≤ 0.05 was considered statistically significant. This approach ensures the reliability and reproducibility of the results. Past studies recommend reporting data as mean ± SD to accurately reflect experimental variability.[33]

Results and Discussion

Nutritional Composition Analysis
The nutritional data (Table 2) for fitness bars enriched with varying concentrations of *G. parvifolia* (Control, F1, F2, and F3) revealed significant differences in several key parameters, particularly in moisture, protein, fat, ash, total sugar, and caloric content, whereas carbohydrate and fibre content showed no significant variation among formulations. These variations were directly influenced by the amount of *G. parvifolia* incorporated into the formulations. The Control bar contained no *G. parvifolia*, while F1, F2, and F3 included 1%, 3%, and 5%, respectively.
Fat content declines significantly with increasing levels of *G. parvifolia*, with F3 showing the lowest fat content (2.66%) compared to Control (3.29%). Reduced fat content is crucial for obesity prevention since high fat intake is associated with increased calorie density and weight gain.[34] Furthermore, carbohydrate and total sugar levels decreased with *G. parvifolia* enrichment, with F2 exhibiting the lowest sugar concentration (1.43%) compared to the Control (1.87%). The reduced sugar content in F2 makes it a suitable option for regulating energy intake, as excessive sugar consumption is a significant contributor to obesity.[35]
F2 exhibited moderate energy content (374.74 kJ/100g) compared to Control (376.27 kJ/100g) and F3 (371.73 kJ/100g). Although F3 recorded the lowest energy level, F2's slightly reduced protein content and higher moisture levels made it the superior choice overall. F2 offers an optimal balance of protein, fat, and sugar while maintaining appropriate energy levels that promote satiety and reduce the risk of overeating.[36] Thus, 3% of *G. parvifolia* formulation (F2) can be considered the most suitable formulation for obesity prevention, combining reduced calorie density, lower sugar content, and improved protein levels.

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Table 2: Nutritional Composition of Fitness Bar (per 100g)

Composition	Formulation Control (0%)	F1 (1%)	F2 (3%)	F3 (5%)
Moisture content, %	$5.58^{c} \pm 0.04$	$6.32^{b} \pm 0.06$	$6.54^{b} \pm 0.10$	$7.10^{a} \pm 0.11$
Protein, %	$10.27^{d} \pm 0.05$	$11.36^{b} \pm 0.05$	$11.59^{a} \pm 0.05$	$11.28^{c} \pm 0.05$
Fat, %	$3.29^{a} \pm 0.05$	$2.95^{b} \pm 0.05$	$2.74^{c} \pm 0.05$	$2.66^{d} \pm 0.05$
Ash, %	$3.15^{a} \pm 0.98$	$1.63^{b} \pm 0.47$	$1.92^{ab} \pm 0.06$	$2.00^{ab} \pm 0.01$
Fiber, %	$1.32^{a} \pm 0.05$	$1.29^{b} \pm 0.05$	$1.29^{b} \pm 0.05$	$1.28^{b} \pm 0.05$
Carbohydrates, %	$76.41^{a} \pm 1.02$	$76.45^{a} \pm 0.42$	$75.92^{a} \pm 0.17$	$75.68^{a} \pm 0.11$
Total sugar	$1.87^{b} \pm 0.12$	$1.70^{b} \pm 0.00$	$1.43^{c} \pm 0.05$	$2.27^{a} \pm 0.05$
Energy (KJ/100g)	$376.27^{ab} \pm 4.12$	$377.76^{a} \pm 1.66$	$374.74^{ab} \pm 0.59$	$371.73^{b} \pm 0.42$
Energy per serving (25g)	94.06	94.44	93.69	92.93

*Result was expressed in mean ± standard deviation
**The letters in the same row indicate a significant difference (a, b, c, d)

Moisture content gradually increases significantly with higher *G. parvifolia* incorporation, from 5.58% (Control) to 7.10% (F3). The higher moisture level in F3 contributes to a softer texture, which may improve sensory appeal but may also shorten the product's shelf life due to increased susceptibility to microbial development.[37] Protein content, an important macronutrient for satiety and energy management, was higher in F2 (11.59%) than in the Control (10.27%). This indicates that F2 is beneficial for weight management because higher protein intake is related to increased satiety and lower calorie intake.[38]
Overall, *G. parvifolia* incorporation has significantly modified the macronutrient composition of the fitness bars. The enriched formulations with *G. parvifolia* showed higher protein, lower fat, and slightly varied reduced sugar content, contributing to improving nutraceutical properties, which support obesity prevention and consumer health. Higher protein levels help increase satiety, reducing hunger and supporting muscle maintenance, which aids in weight control.[38] The reduction in fat, particularly in F3, lowers overall calorie intake, making the bars a better option for managing body weight. Although sugar content is slightly higher in F3 than in Control, it remains within an acceptable range[12,50], minimising the risk of excessive sugar consumption. Overall, these nutritional adjustments create a more balanced, functional snack that supports weight management and healthier eating habits.

Total phenolic and lipase inhibition activity of fitness bar

Based on the experimental results, TPC and lipase inhibition were identified as critical parameters in evaluating the functionality of the fitness bars as potential functional food in obesity prevention. Four formulations, Control (0%), F1 (1%), F2 (3%), and F3 (5%) were analysed for these attributes. Table 3 showed a progressive increase in both TPC and lipase inhibition with higher levels of *G. parvifolia* incorporation. The addition of *G. parvifolia* to nutrition bars significantly enhanced their TPC and lipase inhibitory activity, emphasizing its potential impact on the development of functional foods for obesity management.

Table 3: Total Phenolic Content and Lipase Inhibition Fitness Bar

Nutrition Bar	Total Phenolic Content, mg GAE/g	Lipase Inhibition, %
Orlistat, O	-	$89.29^{a} \pm 0.57$
Control	$16.03^{d} \pm 0.75$	$44.40^{e} \pm 1.19$
F1	$25.29^{c} \pm 2.66$	$49.10^{d} \pm 1.28$
F2	$41.03^{b} \pm 0.88$	$54.59^{c} \pm 1.19$
F3	$49.43^{a} \pm 4.17$	$59.21^{b} \pm 0.64$

*Result was expressed in mean ± standard deviation
**The letters in the same row indicate a significant difference (a, b, c, d)

The TPC of the bars increases significantly from 16.03 mg GAE/g (Control) to 49.43 mg GAE/g (F3), indicating that *G. parvifolia* is a rich source of phenolic compounds. These compounds are known for their powerful antioxidant effects, which can help reduce oxidative stress, a key factor in metabolic disorders linked to obesity.[39,40] The rise in TPC from F1 (25.29 mg GAE/g) to F2 (41.03 mg GAE/g) and F3 (49.43 mg GAE/g) demonstrates the positive correlation between the concentration of *G. parvifolia* and antioxidant potential. Among the formulations, F3 offers the highest antioxidant effect, making it the most effective option against oxidative stress.
Previous studies have shown that higher TPC in functional foods correlates with improved lipid metabolism, reduced fat accumulation, and enhanced pancreatic lipase inhibition.[41] For instance, *Taraxacum officinale* extract with high TPC (contains 123.42 mg GAE/g), demonstrated strong lipase inhibition (IC_{50} = 146.49 µg/mL), supporting the correlation between phenolic content and anti-obesity effects.[42] In this study, similar trends were observed as increased TPC was associated with higher lipase inhibition, particularly in F2 and F3 formulations.
Lipase inhibition, expressed as a percentage, reflects the potential of fitness bars to regulate fat digestion, an essential mechanism in obesity prevention. The results indicate a progressive increase in lipase inhibition from 44.40% (Control) to 59.21% (F3), with intermediate values for F1 (49.10%) and F2 (54.59%). While F3 demonstrated the highest inhibition, it remained significantly lower than Orlistat (89.29%), a pharmaceutical lipase inhibitor commonly prescribed for obesity management. This suggests that while the fitness bars exhibit promising lipase-blocking potential, their inhibition levels may not completely suppress fat digestion, making them a safer alternative for long-term dietary intervention. Excessive lipase inhibition, as observed with Orlistat, can lead to gastrointestinal discomfort, including steatorrhea and nutrient malabsorption.[43] Therefore, the moderate inhibition in F2 (54.59%) presents a more balanced approach, offering functional benefits without the risk of digestive discomfort.
However, despite its superior bioactivity, F3 exhibited lower consumer preference due to its sourness, affecting taste and texture. Higher concentrations of polyphenols are known to cause bitterness and astringency,[44] which explains that F3 is less preferred compared to F2.

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This finding aligns with previous research on polyphenol-rich foods, where consumer acceptance tends to decline at higher TPC levels due to undesirable sensory attributes.[45] While F3 offers the greatest lipase inhibition, the balanced formulation of F2 (41.03 mg GAE/g TPC, 54.59% lipase inhibition) suggests that moderate polyphenol incorporation may optimize both functionality and consumer appeal.
Recent studies on Indonesian medicinal plants, such as *Curcuma xanthorrhiza*, have shown that extracts with high TPC not only inhibit lipase but also regulate adipogenesis and cholesterol metabolism.[46] These findings aligned with the formulation strategy of fitness bars incorporated with *G. parvifolia*, suggesting that optimizing both TPC and lipase inhibition can enhance functional food properties for obesity prevention. Given that F2 strikes a balance between bioactive functionality and consumer acceptance, it may serve as a viable candidate for further development as a functional snack aimed at metabolic health improvement.

Table 4: Descriptive Test Fitness Bar

Attribute	**Formulation**			
	Control	**F1**	**F2**	**F3**
Appearance	$6.81^a \pm 1.85$	$6.26^a \pm 1.90$	$6.26^a \pm 1.87$	$5.90^a \pm 1.74$
Flavour (Taste/Sourness)	$5.58^b \pm 2.43$	$4.93^c \pm 2.30$	$6.26^a \pm 1.95$	$5.55^b \pm 1.95$
Aroma	$5.55^a \pm 2.14$	$5.54^a \pm 2.10$	$5.65^a \pm 1.79$	$5.81^a \pm 2.24$
Texture	$6.19^a \pm 1.58$	$6.13^a \pm 1.84$	$5.87^b \pm 1.43$	$5.26^c \pm 2.08$
Aftertaste	$5.29^b \pm 2.20$	$4.81^c \pm 2.48$	$5.97^a \pm 1.78$	$5.55^b \pm 2.01$
Overall Acceptability	$5.97^b \pm 2.16$	$5.39^c \pm 2.05$	$6.19^a \pm 1.79$	$5.77^b \pm 2.13$

*Result was expressed in mean ± standard deviation
**The letters in the same row indicate a significant difference (a, b, c, d)

Sensorial Evaluation of a Snack Bar
A sensory analysis study was conducted using a 9-point hedonic scale, and the results were visualized using a spiderweb chart (Figure 2) to determine the optimal sensory qualities of snack bars based on panellists' preferences across various sensory attributes, including appearance, taste, texture, aroma, aftertaste, and overall acceptability. Figure 1 shows the visual appearance of nutrition bars enriched with *G. parvifolia* (Control, F1, F2, and F3).

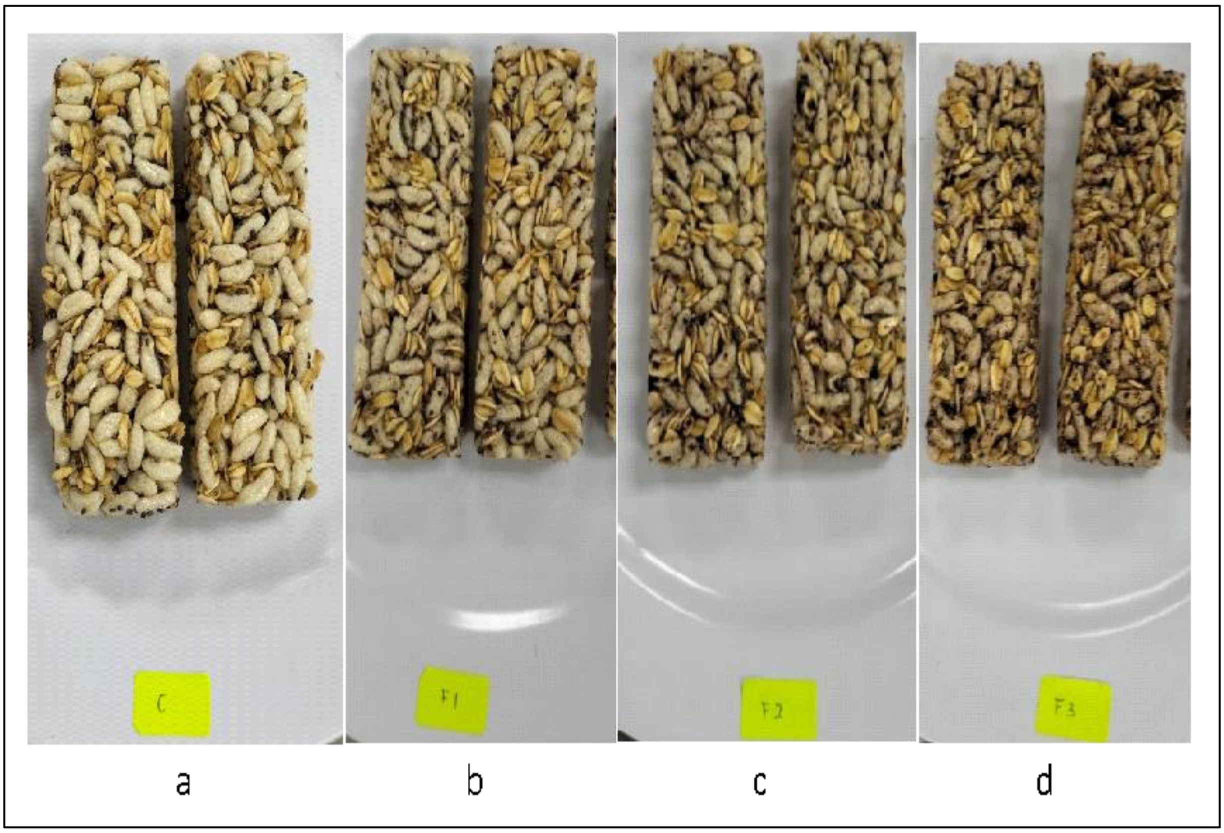

Figure 1: Appearance of Fitness Bars Control (a), Formulation 1 (b), Formulation 2 (c), and Formulation 3 (d)

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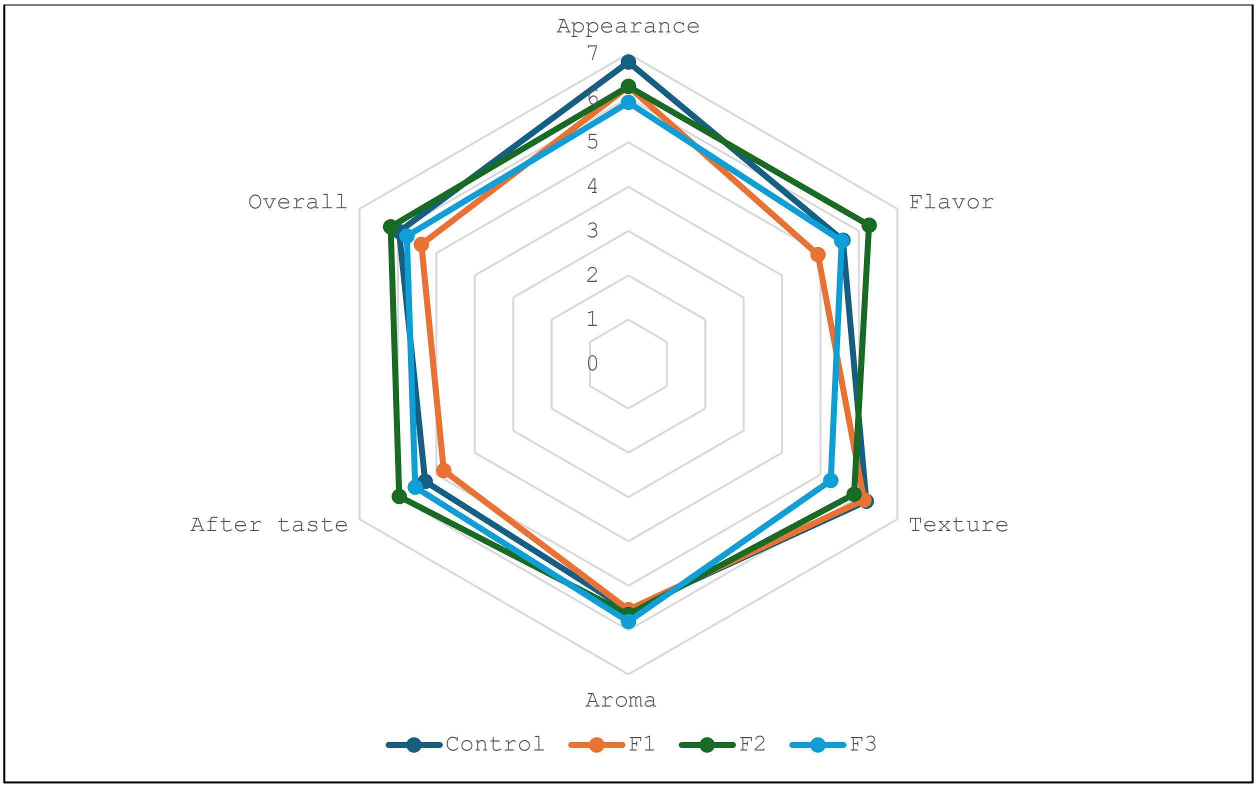

Figure 2: Spiderweb Diagram Showing Sensory Evaluation Results for Four Formulations.

The Control formulation received the highest mean score for appearance (6.81 ± 1.85), suggesting that the inclusion of *G. parvifolia* slightly affected the visual appeal of the bars, with F3 showing the lowest appearance score (5.90 ± 1.74) (Table 4). Nevertheless, this variation was not statistically significant (P = 0.262), showing that *G. parvifolia* inclusion had a minimal impact on appearance acceptability. For flavour (taste/sourness), F2 achieved the highest mean score (6.26 ± 1.95), comparable to the Control formulation with a mean score of 5.58 ± 2.43, but significantly higher than F3 with a mean score of 5.55 ± 1.95. This suggests that a moderate level of *G. parvifolia* enrichment enhances flavour without introducing pronounced bitterness or other undesirable taste characteristics observed at higher enrichment levels. This is due to the interaction of *G. parvifolia* with major food ingredients, which can alter flavour release from the food matrix and improve overall sensory perception.[47] Furthermore, aroma scores were highest for F2 (5.65 ± 1.79) in comparison to F3 (5.81 ± 2.24) and the Control (5.55 ± 2.14), although the differences were not statistically significant (P = 0.956).
Texture was another key aspect assessed, with the Control sample receiving the highest mean score (6.19 ± 1.58), followed by F1 (6.13 ± 1.84) and F2 (5.87 ± 1.43). However, F3 obtained the lowest texture mean score (5.26 ± 2.08), possibly due to higher moisture content at increased *G. parvifolia* levels, which may have softened the bar and adversely affected its texture firmness.[48] The aftertaste was rated most favourably for F2 (5.97 ± 1.78) compared to F1 (4.81 ± 2.48) and F3 (5.55 ± 2.01), suggesting that a moderate *G. parvifolia* inclusion improves the sensory aftereffects without overpowering the palate.
Overall acceptability scores showed that F2 achieved the highest rating (6.19 ± 1.79) among all samples, surpassing the Control (5.97 ± 2.16) and F3 (5.77 ± 2.13). This finding positions F2 as the most balanced and favoured sample, combining pleasant sensory features with the health advantages of *G. parvifolia* inclusion. The results suggest that F2 is the most ideal formulation for consumer preference, as it harmonizes sensory quality with functional benefits, making it a viable option for preventing obesity through better taste, moderate enrichment, and functional attractiveness.
The descriptive sensory evaluation of fitness bars enriched with *G. parvifolia* revealed that F1 was the most preferred formulation in terms of appearance, flavour, texture, and aroma. Both the Control and F1 samples maintained better visual appeal, with most panellists rating them as "slightly white," while F2 and F3 appeared darker, which reduced their visual acceptability. In terms of flavour (sourness), F1 achieved a balance with "moderate" and "weak" sourness, whereas F2 and F3 were perceived as more sour, likely due to higher phenolic content. The combination of moderate sourness and appealing appearance makes F1 more consumer-friendly while retaining functional benefits.
In terms of texture and aroma, F1 performed better with a "moderate" texture and "strong" aroma, while F2 and F3 were marked down for "soft" textures and "overpowering" aroma. F1's ability to balance sensory appeal with the functional properties of *G. parvifolia* makes it the optimal choice for a functional snack targeting obesity prevention. Recent research consistently demonstrates that moderate enrichment of foods with antioxidant-rich ingredients or bioactive compounds enhances antioxidant capacity while maintaining or improving sensory acceptability, an important consideration in functional food development. For example, fortifying cookies with 6% *Clitoria ternatea* flower extract significantly increased phenolic content and antioxidant activity while maintaining good overall sensory scores and consumer acceptance.[49]

Conclusion

This study underscores the potential of *G. parvifolia*-enriched nutrition bars as functional foods for obesity management. The formulations exhibited increased phenolic content and significant lipase inhibition, supporting fat digestion regulation and antioxidant benefits. F1 (1%) emerged as the most consumer-preferred due to its balanced sensory appeal and functionality, while F2 (3%) offered greater anti-obesity benefits but slightly lower sensory scores. F3 (5%) demonstrated the strongest functional properties but reduced consumer acceptance due to sourness and soft texture.
Moderate enrichment levels, particularly F1 and F2, represent the ideal balance between health benefits and consumer appeal. *G. parvifolia* demonstrates potential for developing functional foods targeting obesity. The F2 formulation, with its optimal balance of anti-obesity benefits and acceptable sensory properties, could be commercialized as

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a health-focused snack bar. Its incorporation into widely accessible snack bars offers a natural, convenient approach to obesity prevention, appealing to health-conscious consumers and those undergoing weight management. In addition to its potential in weight management, the widespread distribution of F2-based products could contribute significantly to improving public health by providing a functional, convenient alternative to traditional snacks.

For successful commercialization, further steps should include clinical validation, approval from regulatory agencies, and consumer education on the health benefits of *G. parvifolia*. Moreover, future research should focus on evaluating the shelf stability and sensory performance of F2 over time, ensuring that the product maintains both its functional properties and consumer acceptance throughout its shelf life. Additional studies on standardizing bioactive components and exploring other types of functional food products could potentially expand the potential application of *G. parvifolia* in the nutraceutical industry.

Conflict of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims relating to the content of this article will be borne by them.

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