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Formulation and development of a high-fiber snack bar with baobab and lupin flour

Baobab ve acı bakla unu ile yüksek lifli bir atıştırmalık barın formülasyonu ve geliştirilmesi

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Abstract

High protein, high energy, and nutritious snack bars are considered great supplemental meals. The purpose of this study was to develop a nutritionally balanced, high fiber, antioxidant-rich snack bar using baobab powder and lupin flour. Healthy snack bar formulations containing lupin flour alone and containing 10%, 30%, and 50% baobab instead of lupin flour were evaluated, and their sensory, textural and color properties were analyzed. Sensory analysis identified the snack bar with 10% baobab as the best formulation, achieving the highest ratings for sweetness, texture and overall acceptability. Further analyses were conducted to evaluate its composition, total phenolic content, and DPPH radical scavenging activity. The snack bar with 10% baobab demonstrated a well-balanced nutritional profile, with high protein content (19.11%), dietary fiber (20.6%), moderate fat content (12.42%), and low carbohydrate levels (48.95%). Additionally, it exhibited strong antioxidant properties, with a total phenolic content of 20.08 mg GAE/g and a DPPH radical scavenging activity of 50.66%. The results highlight the potential of incorporating baobab powder and lupin flour into snack bars to produce high-energy, nutrient-dense products with substantial health benefits, making them an appealing option for health-conscious consumers.

Keywords: Baobab powder, Sensory analysis, Lupin flour, Snack bar.

Öz

Yüksek proteinli, yüksek enerjili ve besleyici atıştırmalık barlar, harika ek öğünler olarak kabul edilmektedir. Bu çalışmanın amacı, baobab tozu ve acı bakla unu kullanarak besinsel olarak dengeli, yüksek lifli, antioksidan açısından zengin bir atıştırmalık bar geliştirmektir. Yalnızca acı bakla unu içeren ve acı bakla ununun yerine sırasıyla %10, %30 ve %50 oranında baobab tozu içeren sağlıklı atıştırmalık bar formülasyonları değerlendirilmiş ve bunların duyusal, tekstürel ve renk özellikleri analiz edilmiştir. Duyusal analiz sonuçları, tatlılık, doku ve genel kabul edilebilirlik açısından en yüksek puanı alan %10 baobab içeren atıştırmalık barın en iyi formülasyon olduğunu ortaya koymuştur. Kompozisyon, toplam fenolik içeriği ve DPPH radikal bağlama aktivitesini değerlendirmek için ek analizler gerçekleştirilmiştir. %10 baobab içeren atıştırmalık bar, yüksek protein (%19,11), diyet lifi (%20,6), orta düzeyde yağ (%12,42) ve düşük karbonhidrat (%48,95) içeriği ile dengeli bir besin profili sergilemiştir. Ayrıca, 20,08 mg GAE/g toplam fenolik bileşik içeriği ve %50,66 DPPH radikal bağlama aktivitesi ile güçlü antioksidan özellikler göstermiştir. Sonuçlar, baobab tozu ve acı bakla ununun atıştırmalık barlara dahil edilmesinin yüksek enerjili, besin açısından zengin ve önemli sağlık faydaları sunan ürünler üretme potansiyelini vurgulayarak, bunları sağlık bilincine sahip tüketiciler için cazip bir seçenek haline getirmektedir.

Anahtar kelimeler: Baobab tozu, Duyusal analiz, Acı bakla unu, Atıştırmalık bar.

1 Introduction

Increasing awareness of health and wellness among consumers has driven demand for convenient, nutrient-dense food products that align with contemporary dietary needs. Snack bars, particularly those enriched with functional ingredients, have emerged as a popular choice due to their portability, energy content, and ability to deliver essential nutrients in a compact form. These products cater to the growing interest in plant-based and sustainable diets, offering an alternative to traditional snack foods often high in artificial additives and calories [1]. The integration of underutilized natural resources, such as baobab and lupin, into snack formulations presents an opportunity to develop innovative products that combine superior nutritional benefits with consumer appeal [2-4]. Baobab and lupin are recognized for their high fiber, protein, and antioxidant content, which can significantly enhance the health-promoting properties of snack bars while supporting sustainable food systems [5, 6].

Baobab (*Adansonia digitata* L.), a fruit native to Africa and other arid regions, is valued for its unique nutritional profile [6]. The fruit pulp is rich in dietary fiber, vitamin C, and polyphenols, offering antioxidant and functional health benefits. Baobab fruit pulp contains high amount of vitamin C (280-300 mg/100 g), almost ten times that of oranges, calcium (293 mg/100 g), phosphorus (96-118 mg/100 g) and soluble and insoluble dietary fibers (52%) [6]. Furthermore, baobab is highly sustainable due to its drought-tolerant nature, making it an appealing ingredient for addressing global food security concerns in dry regions [7]. Despite this potential, baobab remains underutilized in modern food applications, with limited research exploring its incorporation into ready-to-eat snack products. Its natural acidity and high pectin content make it a promising component for innovative formulations,

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particularly in snacks designed to provide functional health benefits [8].

Similarly, lupin (*Lupinus* spp.) seeds are emerging as a sustainable and nutrient-dense food source. With a protein content of approximately 40%, lupin is one of the most protein-rich legumes. Lupin seeds contain 30–40% dietary fiber, primarily consisting of insoluble fiber and they have a fat content in the range of 8% to 11.5% with a fat profile predominantly consists of mono- and polyunsaturated fats, omega 3, 6 and 9 fatty acids. They are also rich in minerals such as iron, magnesium, zinc, calcium and potassium; they contain vitamin A, B vitamins and vitamin E [5, 9]. These nutritional attributes make lupin suitable for various food applications, including baking and as a substitute for animal proteins in products such as meat, egg, or cheese analogues [5, 9, 10]. Additionally, its prebiotic properties support gut health by fostering beneficial microbiota, while its low glycemic index and bioactive compounds make it suitable for managing weight, blood glucose levels, and cardiovascular health risks [5, 11]. Despite these advantages, lupin remains underrepresented in mainstream food products, particularly in snack formulations. Combining lupin with complementary ingredients such as baobab could therefore significantly enhance the functional and sensory properties of snack bars.

Unlike conventional protein-enriched snack bars, this study focuses on the synergistic effects of baobab and lupin, two underutilized yet highly nutritious ingredients, in a single formulation. In this study, three distinct snack bar formulations were chosen to create various combinations of these components. Sensory evaluation, along with texture and color analysis, was conducted to assess taste, structural integrity, and visual appeal, ensuring alignment with consumer preferences. The results of these assessments guided the selection of the optimal formulation for the final product.

2 Materials and methods

2.1 Raw materials

Baobab powder was supplied from Naturiga, Türkiye (origin: Ghana). Apple juice concentrate was generously provided by Tasargem Company in Kozan, Adana, Türkiye. Flaxseed and pistachio powder purchased from a local market in Gaziantep, Türkiye, White Lupin was purchased from a local market in Denizli, Türkiye.

2.2 Preparation of snack bars

Three snack bar formulations were prepared by incorporating baobab powder at concentrations of 10%, 30%, and 50% (by weight of lupin flour and baobab powder). The control snack bar was prepared without any baobab powder. The proportions of the ingredients used in each formulation are presented in Table 1.

Fresh lupin seeds were first soaked in water to facilitate the removal of their outer skins. The peeled lupin seeds were then dried for 4 h using a 10 kW, 27.12 MHz free-swinging transitional field electrode radio frequency (RF) drying system with a hot air (45 °C) heating unit (Sonar, İzmir, Türkiye). After drying, the lupin seeds were ground into flour using a high-speed grinder (Isolab Laboratory Mill 602, Interlab, Istanbul, Türkiye). Next, apple juice concentrate was combined with flaxseed at concentration of 15% (w/w) and mixed for different durations to evaluate the Brix value. Apple juice concentrate with flaxseed mucilage and flaxseeds were combined with baobab, lupin, and pistachio powders in the specified proportions (Table 1). The total weight of each snack bar was 25.74 g. The images of the formulated snack bars are given in Figure 1.

Table 1. Formulations of the snack bars.

Ingredients	Control	Snack bar with 10% baobab	Snack bar with 30% baobab	Snack bar with 50% baobab
Baobab powder (g)		1.01	3.04	5.06
Lupin flour (g)	10.12	9.11	7.08	5.06
Flaxseed (g)	2.70	2.70	2.70	2.70
Pistachio powder (g)	2.60	2.60	2.60	2.60
Apple juice concentration (g)	10.32	10.32	10.32	10.32

2.3 Soluble solids content

To evaluate the soluble solids content of the flaxseed-apple juice concentrate mixture, Brix values were measured using an ABBE refractometer (Atago, NAR-1T Liquid Model, Saitama, Japan). The mixture, containing 15% flaxseed (w/w), was analyzed at 0, 15, 30, 45, and 60-min intervals to assess the effect of mixing time on the soluble solid content.

2.4 Sensory analysis

The sensory quality of snack bars was evaluated using the nine-point hedonic scale. Plain water was provided to participants for palate cleansing between samples. The scale ranged from 1 (extremely dislike) to 9 (extremely like) [7]. A total of 30 untrained panelists (19 females and 11 males) participated in the sensory evaluation. The panel consisted of undergraduate and graduate students, as well as academic staff from the Food Engineering Department, Gaziantep University, Türkiye, aged between 20 and 60 years. Although the panelists were not formally trained in sensory analysis, they received brief instructions on the evaluation procedure prior to testing. Each participant received four different snack bar formulations in a randomized order under controlled testing conditions (uniform lighting and neutral background). Participants rated the snack bars on the hedonic scale based on the following attributes: sweetness, sourness, fruitiness, appearance, texture, and overall acceptability.

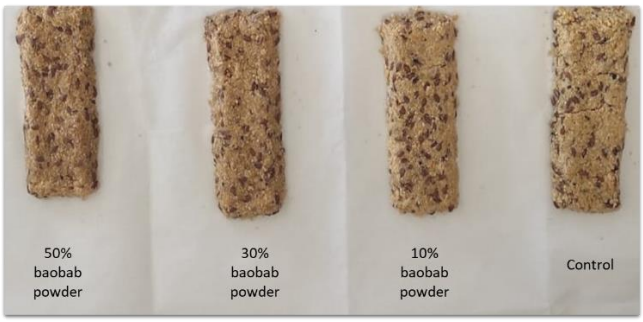

Figure 1. Images of formulated snack bars

2.5 Texture evaluation

The texture profile analysis (TPA) of the snack bars was done using the approach given by Mildner-Szkudlarz et al. [12], with minor modifications. A TA.XTplus Texture Analyzer (Stable Micro System Co. Ltd., Surrey, UK) with a 5 kg load cell and a cylindrical plunger probe 36 mm in diameter was used. Pre-test speed was set at 0.5 mm/s and 50% strain was applied during the measurement. Samples were prepared in a cylindrical shape with a diameter of 3.7 cm and sample thickness of 1.5 cm. Each sample was compressed twice to 50% of its original height. A total of 3 replicates per sample were analyzed to ensure statistical reliability. During the test, hardness, cohesiveness and chewiness were recorded.

2.6 Color Analysis

The color measurements of the snack bars were performed using a HunterLab ColorFlex (A60-1010-615 Model Colorimeter, HunterLab, and Reston VA, USA) with the different snack bar formulations. The samples were crushed, filled ¾ into the measuring head, and the color values were determined [20]. The L*a*b* color space, commonly known as CIELAB, was used to express the color changes. The color values were represented by the a* (greenness/redness), b* (blueness/yellowness), and L* (darkness/whiteness) values. Calibration was provided using the reference white tiles (L*= 93.41, a* = -1.12, b* = 1.07), the device was calibrated.

2.7 Analysis of nutritional composition and calculation of caloric value of the snack bar

The moisture, protein, and ash contents of the sample were analyzed following the standard procedures outlined by AOAC [13]. Fat content was measured by Soxhlet extraction using n-hexane as the solvent, in accordance with the AOCS method [14], without prior hydrolysis, over a period of 8 hours. Crude fiber content of the snack bar samples was evaluated using the standard procedure described in AOAC 991.43 [15]. Total sugar content was determined using the 3,5-dinitrosalicylic acid (DNS) method developed by Miller [16]. Total carbohydrate content of the snack bar was calculated by subtraction of the sums of the total fat, moisture, protein and ash from 100.

The total caloric value of the snack bar was calculated by multiplying the grams of fat, protein, and carbohydrates by their corresponding calorie values (4 calories per gram for protein and carbohydrates, and 9 calories per gram for fat) [17].

$$Total\ energy\ (kcal/100g) = (carbohydrates\ (g) \times 4) + (protein\ (g) \times 4) + (fat\ (g) \times 9) \quad (1)$$

2.8 Determination of Total Phenolic Content

The total phenolic content of the samples was determined using the Folin–Ciocalteu colorimetric method, as described by Özbek et al. [18], with slight modifications. Briefly, 2 g of the snack bar sample was mixed with 20 mL of 70% methanol, and the mixture was shaken in an incubator at room temperature and 150 rpm for 60 min. The mixture was then centrifuged at 6000 x g for 15 min, and the supernatant was carefully collected. 0.2 mL aliquot of the extract was transferred into a 10 mL test tube, followed by the addition of 1 mL of 10-fold diluted Folin–Ciocalteu reagent (2N). After a 5-min incubation, 1.5 mL of 6% (w/v) sodium carbonate solution was added to the reaction mixture. The mixture was incubated in the dark at room temperature for 90 minutes. Absorbance was measured at 725 nm against a blank using a spectrophotometer (Optima SP 3000 Nano, Tokyo, Japan). The total phenolic content was expressed as gallic acid equivalents per gram of extract (mg GAE/g extract).

2.9 Antioxidant activity

The antioxidant activity of the 10% baobab snack bar extract was evaluated using the DPPH radical assay, following the method described previously [19]. Briefly, 0.1 mL of the snack bar extract in 70% methanol, was added to test tubes containing 3.9 mL of DPPH solution (6×10^{-5} mol/L) in methanol. The mixture was vortexed and incubated in the dark at 37°C for 30 min. After incubation, the absorbance of each sample was measured at 517 nm against a methanol blank. A control, containing 70% methanol instead of the bar extract, was used for comparison. The scavenging activity (%) was calculated using the following formula:

$$Scavenging\ activity\ (\%) = \frac{A_{control} - A_{sample}}{A_{control}} \times 100 \quad (2)$$

2.10 Statistical Analysis

All experiments conducted in triplicate. The findings of analysis were presented as mean values ± standard deviation. The significance between the bar samples were statistically analyzed by using one-way analysis of variance (ANOVA) and compared by Tukey multiple range tests by using SPSS software (SPSS Inc., Chicago, IL, USA-Version 25).

3 Results and discussion

3.1 Evaluation of soluble dry matter in mucilage extraction

Flaxseeds at a concentration of 15% (w/w) were added into the apple juice concentrate to determine the optimal time of mucilage extraction. The Brix values of the mixture were measured at different time intervals. Since the mucilage concentration in apple juice concentrate directly impacts on the consistency, it plays a crucial role in determining textural properties of the final product.

The soluble solid content of the mixture was influenced by both the sugar content of the apple juice concentrate and the mucilage from the flaxseed. As mucilage was gradually extracted into the apple juice, a gel-like structure formed, contributing to increased soluble solids. This interaction not only enhances the sweetness of the snack bar but also improves its consistency. Similar findings have been reported in previous studies, where the incorporation of plant mucilages, such as flaxseed and chia seed, has been shown to increase the soluble

solids content in various food products by contributing to water retention and gel formation [21, 22].

The Brix value of the mixture increased from 67.8 ± 0.28% and reached into the equilibrium (72.4 ± 0.50%) at 60 minutes of mixing. This trend aligns with earlier studies indicating that mucilage extraction efficiency improves over time due to progressive hydration and diffusion process [23, 24]. Additionally, in a previous study on a snack bar formulation, which included an investigation of flaxseed mucilage extraction, reported that increasing extraction time enhanced polysaccharide solubilization, leading to a higher soluble solids content [25]. These findings further support the observed relationship between mixing time and soluble solid content in this study.

3.2 Sensory Evaluation

The sweetness, sourness, fruitiness, chewiness, hardness, general acceptability, and appearance of three distinct snack bar formulations (10%, 30%, and 50% baobab powder) were evaluated and compared to a control snack bar (without baobab) during sensory analysis. These parameters were assessed to analyze and characterize the sensory attributes of the formulations, as presented in Table 2. The results showed that the snack bar with 10% baobab and 90% lupin flour received the highest ratings for sweetness, texture, appearance, and overall acceptability, while the snack bar with 50% baobab and 50% lupin flour received the lowest ratings in these parameters.

Statistical analysis revealed significant differences among formulations ($p<0.05$), particularly in sweetness and hardness. The control sample exhibited the highest chewiness and hardness, whereas increasing the baobab content resulted in a significant decrease in these textural properties ($p<0.05$). Sweetness increased with 10% baobab addition but declined at higher concentrations. Sourness and fruitiness were significantly enhanced with increasing baobab levels ($p<0.05$). However, overall acceptability was highest for the 10% baobab formulation, suggesting that moderate baobab addition provides an optimal balance between flavor and texture. These findings highlight the impact of baobab powder concentration on both sensory and consumer preference.

The sensory results were influenced by interactions between varying ratios of baobab powder and lupin flour. The snack bars with the highest sweetness ratings were the control and the 10% baobab snack bars, as sweetness was moderated by the baobab content. The sourness parameter was notably low in both the control and 10% baobab snack bars, likely due to the reduced influence of organic acids in baobab and the higher proportion of lupin flour, which can counteract sour flavors. As observed in the 50% baobab snack bar, the pronounced sourness is directly linked to the high content of baobab powder, known for its organic acid and vitamin C composition. This aligns with the findings of Netshishivhe et al. [26], who highlighted the influence of the baobab on enhancing the nutritional quality and sensory properties of snacks. The increased fruitiness in this formulation results from the synergistic effect of baobab powder and apple concentrate, creating a more pronounced citrus-like flavor.

The 10% baobab bar also received the highest ratings for chewiness, hardness, and appearance. These attributes were largely due to the smooth and cohesive texture contributed by lupin flour, which enhanced the bar's overall sensory appeal. In contrast, the snack bar with 50% baobab exhibited a fibrous or sandy texture, leading to its lower ratings in texture and overall acceptability. This result is consistent with the study by You et al. [27], which demonstrated that higher fiber content increases hardness, a key factor in sensory evaluations. Higher baobab content also affected hardness, as seen in the 50% baobab snack bar, which had the highest hardness scores among all formulations. This is in line with findings by Netshishivhe et al. [26], who noted that higher baobab concentrations contribute to increased hardness while enhancing specific nutritional benefits. However, the high fiber content likely diminished consumer preference for this texture. Sensory analysis confirmed that the 10% baobab snack bar achieved an optimal balance among the evaluated parameters, combining higher sweetness and texture ratings with favorable sourness and fruitiness levels. These results are consistent with those reported by Bergman [28], who found that moderate baobab concentrations could improve sweetness and overall acceptability without overwhelming sourness or altering the texture of the product negatively. Based on the combined sensory evaluations, the snack bar containing 10% baobab was identified as the most preferred formulation.

Table 2. The statistical evaluation of various sensory parameters of a snack bar formulated with lupin flour and baobab powder

	Control (without baobab)	Snack bar with 10% baobab	Snack bar with 30% baobab	Snack bar with 50% baobab
Sweetness	5.66 ± 0.57^{b}	7.13 ± 0.89^{a}	5.3 ± 0.95^{b}	3.36 ± 1.47^{c}
Sourness	1.33 ± 0.68^{d}	3.43 ± 1.54^{c}	5.96 ± 0.96^{b}	7.5 ± 1.38^{a}
Fruitiness	7.66 ± 0.92^{a}	3.83 ± 1.45^{c}	5.1 ± 1.15^{b}	7.16 ± 1.20^{a}
Chewiness	7.54 ± 0.57^{a}	8.13 ± 0.95^{a}	6.73 ± 1.08^{b}	4.96 ± 1.29^{c}
Hardness	2.53 ± 0.84^{b}	2.04 ± 0.71^{c}	4.56 ± 0.57^{a}	7.22 ± 1.06^{a}
Overall Acceptability	5.33 ± 1.02^{b}	7.1 ± 0.95^{a}	6.46 ± 1.35^{b}	4.86 ± 1.47^{c}
Appearance	5.66 ± 0.57^{b}	7.16 ± 1.05^{a}	5.73 ± 1.00^{b}	4.23 ± 1.38^{c}

Values are presented as mean ± standard deviation. Superscript letters (a, b, c, d) indicate statistically significant differences between the samples for each parameter in lines ($p < 0.05$).

3.3 Textural profile of snack bars

The textural properties of snack bars prepared with varying proportions of baobab powder, and lupin flour were evaluated based on hardness, cohesiveness, and chewiness, as summarized in Table 3. These parameters were significantly influenced by the composition of the formulations.

The snack bar containing 50% baobab exhibited significantly higher hardness (269.52 ± 1.15 N) compared to all other formulations. This increase in hardness is attributed to the higher fiber content of baobab powder, which also contributed to its fibrous and sticky structure. These findings are consistent with previous research [20], which reported that snack bars enriched with dietary fiber tend to exhibit higher levels of chewiness and hardness. However, the excessive hardness and chewiness of the 50% baobab snack bar likely diminished its sensory appeal, as reflected in the low ratings for texture, appearance, and overall acceptability in the sensory analysis.

In contrast, the snack bar containing 10% baobab demonstrated a balanced textural profile, with moderate hardness (121.39 ± 1.11 N) and chewiness (13.42 ± 1.12 N). Its cohesiveness (0.250 ± 0.01) suggests an appropriate structural integrity that complements consumer preferences for a smooth and consistent mouthfeel. These characteristics were reflected in the sensory analysis, where the 10% baobab snack bar received the highest ratings for texture, appearance, and overall acceptability. The sensory preferences for the 10% baobab snack bar were influenced by its textural balance, with chewiness and hardness contributing positively to the eating experience. These favorable textural attributes contributed to the overall consumer acceptance of the 10% baobab snack bar. Considering both sensory and textural evaluations, this formulation emerged as the most suitable option. Its balanced texture, moderate hardness, and cohesive structure provided an enjoyable mouthfeel, complementing its high scores in sweetness, appearance, and overall acceptability during sensory analysis. These findings are consistent with those of Santiago-Ramos et al. [29], who reported that moderate hardness enhances consumer acceptance.

Table 3. Texture profile evaluation of snack bars

Formulations	Hardness (N)	Cohesiveness	Chewiness (N)
Control	100.95±0.19^{a}	0.236±0.004^{b}	9.69±0.01^{c}
Snack bar with 10% baobab	121.39±1.11^{b}	0.250±0.010^{b}	13.42±1.12^{b}
Snack bar with 30% baobab	167.18±0.63^{c}	0.293±0.001^{a}	26.58±0.35^{a}
Snack bar with 50% baobab	269.52±1.15^{d}	0.317±0.020^{a}	61.86±1.18^{a}

Results mean ± standard deviation of triplicate analyses. Values in columns with different letters are significantly different ($p < 0.005$).

3.4 Color Analysis

Color analysis was conducted for all four snack bar formulations, and the corresponding color parameter values are presented in Table 4.

The ratio of lupin flour to baobab powder plays a significant role in the lightness (L*), redness (a*), and yellowness (b*) values of snack bars. Formulations containing 30% and 50% baobab powder exhibited lower L* values and higher a* and b* values compared to the control and the 10% baobab formulation. The L* values indicated that the addition of 10% baobab powder increased the lightness of the snack bar compared to the control, likely due to the naturally light beige color of baobab powder. However, at higher concentrations, the L* values decreased. This trend may be related to the changes in water retention properties and possible Maillard reactions during processing, which could contribute to a darker appearance. These results highlight the complex interplay between ingredient composition and color development in snack bars. Furthermore, the snack bar with 10% product had the greatest value (34.97) of yellowness (b*), while the control, snack bar with 30%, and snack bar with 50% product had lower values, respectively. These findings are related to the lack or amount of lupin flour and baobab powder in the components of the snack bars. Color and sensory analysis findings are strongly correlated. Color is an important factor in sensory analysis in the consumer group. The overall acceptability and appearance perception of the items are significantly influenced by parameters including lightness (L*), redness (a*), and yellowness (b*). It has been found that the snack bar with 10% baobab had a high acceptance rate due to its bright and balanced color tone. The snack bar with 50% baobab has a lower acceptance and image criteria due to its deeper color tone.

These findings are consistent with the results of Netshishivhe et al. [26], who reported significant color changes with increasing baobab content. Additionally, the color values of the snack bar with %10 baobab were observed to be lighter and brighter than the color values of the baobab-containing snacks in the literature [30]. This may be attributed to the combined use of baobab powder, lupin flour, and pistachio powder in the formulation. The light and bright tone of the snack bar with 10% baobab may represent this product to the consumer group as a light, healthy, and nutritious snack bar. These findings highlight the importance of integrating sensory evaluation with instrumental data such as texture and color analysis, when selecting the optimal formulation. The snack bar with 10% baobab demonstrates a balance between consumer preferences and key quality attributes, ensuring structural integrity, appealing appearance, and consistent texture.

Table 4. The experimental values of color parameters for snack bars

Samples	L*	a*	b*
Control	58.17±0.09^{b}	5.83±0.02^{b}	30.24±0.09^{b}
Snack bar with 10% baobab	61.71±0.34^{a}	7.74±0.34^{ab}	34.97±1.21^{a}
Snack bar with 30% baobab	53.94±0.37^{c}	8.71±0.37^{a}	29.37±0.03^{b}
Snack bar with 50% baobab	56.04±1.45^{bc}	7.17±1.45^{ab}	28.19±0.56^{b}

Results mean ± standard deviation of triplicate analyses. Values in columns with different letters are significantly different ($p < 0.05$).

3.5 Proximate composition analysis and energy value of the snack bar

Based on the preliminary sensory, texture and color analyses, the snack bar with 10% baobab and 90% lupin flour (by weight of lupin flour and baobab powder) was selected as the optimal

formulation for further nutritional and antioxidant evaluations. This concentration was found to best balance consumer acceptability and textural properties, and thus was chosen for detailed compositional analysis. The results obtained are presented in Table 5.

The snack bar with 10% baobab contained 12.42% fat, primarily due to the inclusion of pistachio powder and flaxseed. A similar fat content (10%) was reported by Mridula et al. [31] in a snack bar formulation containing 15% flaxseed, supporting the findings of this study. Similarly, moisture content of 18.24% aligns with moisture levels in other high-protein snack bar formulations, where moisture levels ranged from 11.22-30.38% [32, 33]. The ash content, representing the mineral composition, was 1.28%, reflecting the contribution of mineral-rich ingredients such as baobab and lupin flours.

The dietary fiber content was notably high at 20.60%, placing this snack bar at the upper range of fiber-rich snack bars (15–22%) as reported in a previous study [32]. This higher fiber level is largely due to the combined effects of baobab powder (rich in pectin), lupin flour, and flaxseed, all of which are known for their fiber content. Such fiber levels support digestive health and promote satiety, making the product particularly suitable for health-conscious consumers. Moreover, the dietary fiber level surpasses those reported in other studies, where values ranged from 5.12% to 9.06% [20]. The results are consistent with Chiacchio et al. [34], who also reported a significant contribution of baobab powder to dietary fiber levels.

The carbohydrate content of 48.95% is relatively low compared to similar snack bars in earlier studies, where carbohydrate levels ranged from 55.24% to 69.03% [20, 33]. This can be attributed to the high inclusion of protein- and fiber-rich ingredients like baobab powder, lupin flour, and flaxseed. The addition of apple juice concentrate contributed to the carbohydrate content while enhancing energy density of the snack bar.

The total energy value of the snack bar was calculated as 384.02 kcal per 100 g, consistent with energy ranges reported by Alfheeaid et al. [33] (376–378 kcal/100 g). This makes the snack bar suitable for individuals seeking a nutritious and balanced energy source. Compared to Singh et al. [20], where the energy content were in the range of 316.14 - 332.78 kcal per 100 g, this snack bar offers higher energy content due to its well-balanced composition of protein, fat, and carbohydrates.

The snack bar with 10% baobab appeared that it provided similar levels of dietary fiber value, lower levels of carbohydrate value, and greater protein value as compared to previous studies [30]. The composition analysis of the snack bar with 10% baobab reveals a profile with high protein and sugar levels and moderate fat content, which is influenced by the contents of snack bar.

Table 5. Energy, composition and bioactive properties of snack bar with 10% baobab

Parameters	Snack bar with 10% baobab
Fat (%)	12.42±0.74
Moisture (%)	18.24±0.14
Ash (%)	1.28±0.05
Protein (%)	19.11±0.11
Total Sugar (%)	21.42±1.34
Dietary Fiber (%)	20.60±0.98
Carbohydrate (%)	48.95±0.63
Energy (kcal)	384.02
Total Phenolic Content (mg GAE/g sample)	20.08±0.29
DPPH Scavenging Activity (%)	50.66±0.40

Results mean ± standard deviation of triplicate analyses. The quantities of the ingredients are given on a wet basis.

3.6 Bioactive properties

The bioactive properties of the snack bar formulated with 10% baobab powder were evaluated in terms of total phenolic content and DPPH radical scavenging activity, as presented in Table 5. The total phenolic content was 20.08±0.29 mg GAE/g. The high levels of phenolic compounds in the snack bar are primarily due to the natural antioxidant sources of flaxseed, pistachio, lupin flour and baobab powder. These ingredients are known to significantly contribute to phenolic content, thereby enhancing the health-promoting properties of the snack bar. The DPPH radical scavenging activity was found to be 50.66±0.40%. This activity reflects the synergistic effects of baobab powder, flaxseed, lupin flour and pistachio nut in the formulation. These ingredients provide a robust antioxidant profile, making the snack bar an excellent choice for individuals seeking functional foods with health benefits, highlighting the significant contribution of the selected ingredients to its antioxidant properties. Moreover, the DPPH scavenging activity reported in this study exceeds the values found in previous studies [20, 35], confirming the superior antioxidant capacity of this formulation. The combination of high phenolic content and strong radical scavenging activity underscores the formulation's potential as a functional food product with considerable health benefits. These results demonstrate that the snack bar with 10% baobab not only offers nutritional advantages but also delivers enhanced antioxidant properties due to the carefully selected plant-based ingredients. In comparison with existing products in the literature, this formulation shows promise as a health-promoting and nutrient-rich snack option [20, 35].

4 Conclusions

This study evaluated the nutritional composition, antioxidant activity, and sensory properties of a healthy snack bar formulated primarily with baobab powder and lupin flour. The results demonstrated both the nutritional benefits and potential consumer appeal of this novel snack bar. The sensory evaluation, alongside texture and color analysis, showed that the snack bar with 10% baobab received the highest ratings for sweetness, texture, overall acceptability, and appearance, outperforming the formulations with 30% and 50% baobab, which scored lower in these attributes. The variations in sensory characteristics were attributed to the differing proportions of baobab and lupin flour in the formulations. Additionally, the bioactive properties of the snack bar, including its high phenolic compound content and antioxidant activity, were found to be significantly enhanced, with values surpassing those of similar products in the literature. The integration of sensory evaluation with instrumental texture and color analysis played a crucial role in identifying the

optimal formulation. The snack bar with 10% baobab demonstrated a well-balanced nutritional profile, with high fiber, protein, and mineral content, as well as moderate fat and low carbohydrate levels, making it a suitable option for health-conscious consumers. In addition to its nutritional composition, the snack bar's rich antioxidant activity and functional attributes underscore its potential as a nutrient-dense, health-promoting food. The findings contribute to the growing interest in plant-based snack bars, particularly those enriched with baobab powder, lupin flour, and flaxseed, as part of the emerging trend for nutritious, functional foods. Future studies should focus on optimizing the formulation by incorporating other functional ingredients and evaluating the shelf-life and stability of the snack bar. Further research on the relationships between the bioactive components and their health benefits will also be valuable in supporting the development of similar functional snack products.

5 Author contribution statements

Author 1: Data curation, Investigation, Writing - original draft, Visualization. Author 2: Methodology, Validation, Conceptualization, Writing - review & editing. Author 3: Methodology, Validation, Conceptualization, Writing - review & editing. Author 4: Conceptualization, Writing - review & editing. Author 5: Conceptualization, Methodology, Supervision, Writing - review & editing.

6 Ethics committee approval and conflict of interest statement

Ethical approval for the study was obtained from Gaziantep University Science and Engineering Ethics Committee dated 23 February 2024 and numbered E-87841438-050.99-459395.

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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