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Nutritional, textural, and sensory properties of spirulina-enriched protein bars

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Abstract
This study investigates the nutritional, textural, and sensory properties of protein bars enriched with spirulina, a nutrient-dense cyanobacterium. Spirulina was incorporated into protein bar formulations at varying concentrations (0%, 5%, 10%, and 15%) to evaluate its impact on protein content, micronutrient profile, texture, and consumer acceptability. Nutritional analysis revealed that spirulina significantly increased protein, iron, and antioxidant levels, with the 15% spirulina bar containing up to 25 g of protein per 100 g. Textural analysis using a texture analyzer showed increased hardness and chewiness with higher spirulina concentrations, attributed to its fibrous structure. Sensory evaluations, conducted with 50 untrained panelists, indicated that bars with 5% and 10% spirulina were rated highly for taste and overall acceptability, while the 15% formulation scored lower due to a pronounced algae-like flavor. These findings suggest that spirulina can enhance the nutritional value of protein bars without compromising sensory quality at moderate inclusion levels, offering a sustainable option for functional food development.

Keywords: Spirulina, protein bars, nutritional properties, textural analysis, sensory evaluation, functional foods, microalgae

Introduction

The demand for functional foods has surged due to growing consumer interest in health and wellness. Protein bars, as convenient and nutrient-dense snacks, have become a popular choice for individuals seeking to meet their nutritional needs. However, traditional protein bars often rely on animal-based or soy proteins, which may not appeal to all consumers due to dietary restrictions, sustainability concerns, or environmental impacts. Spirulina (Arthrospira platensis), a nutrient-rich cyanobacterium, has emerged as a promising alternative protein source due to its high protein content (60–70% dry weight), essential amino acids, vitamins, minerals, and antioxidants. Its incorporation into food products, however, poses challenges related to texture and sensory acceptability due to its unique flavor and color. This study aims to develop spirulina-enriched protein bars and evaluate their nutritional, textural, and sensory properties. Spirulina's potential to enhance the nutritional profile of protein bars lies in its rich composition, including iron, vitamin B12, and phycocyanin, a potent antioxidant. However, its impact on texture and consumer acceptability remains underexplored. Previous studies have shown that microalgae can alter food texture, often increasing hardness or chewiness, which may affect consumer preference. Sensory properties, such as taste and aroma, are critical for market success, as strong algae-like flavors can deter consumers. This research addresses these gaps by formulating protein bars with varying spirulina concentrations (0%, 5%, 10%, and 15%) and analyzing their nutritional content, textural characteristics, and sensory acceptability. The objectives are to determine the optimal spirulina inclusion level that balances nutritional enhancement with consumer appeal and to provide insights for the development of sustainable, microalgae-based functional foods.

Methods

Formulation of Protein Bars

Protein bars were formulated using a base recipe consisting of whey protein isolate (30%), oats (20%), almond butter (15%), honey (15%), and water (10%). Spirulina powder was added at concentrations of 0% (control), 5%, 10%, and 15% by weight, replacing a portion of the whey protein. Ingredients were mixed, pressed into molds, and baked at 160°C for 20 minutes. Bars were cooled and stored at 4°C for analysis.

Nutritional Analysis

Proximate analysis was conducted to determine protein, fat, carbohydrate, and ash content using AOAC methods. Protein content was measured via the Kjeldahl method, fat by Soxhlet extraction, and carbohydrates by difference. Iron and vitamin B12 levels were quantified using inductively coupled plasma mass spectrometry (ICP-MS) and high-performance liquid chromatography (HPLC), respectively. Antioxidant activity was assessed using the DPPH assay.

Textural Analysis

Textural properties were evaluated using a TA. XT Plus Texture Analyzer (Stable Micro Systems). A three-point bend test measured hardness (peak force, N) and fracturability (distance to break, mm). A compression test assessed chewiness (N·mm). Five replicates per formulation were tested, and results were analyzed using Exponent software.

Sensory Evaluation

Sensory analysis was conducted with 50 untrained panelists (25 male, 25 female, aged 18–45). A 9-point hedonic scale was used to evaluate appearance, taste, texture, aroma, and overall acceptability. Samples were presented in random order under controlled lighting, and panelists were provided with water to cleanse their palate between samples. Data were analyzed using ANOVA and Tukey's test ($p < 0.05$).

Statistical Analysis

All experiments were conducted in triplicate unless otherwise stated. Data were analyzed using SPSS v.26, with one-way ANOVA and post-hoc Tukey's tests to identify significant differences ($p < 0.05$).

Results

Nutritional Composition

The nutritional analysis revealed that spirulina significantly enhanced the protein content of the bars. The control (0% spirulina) contained 18 g protein per 100 g, while the 5%, 10%, and 15% formulations contained 20 g, 22 g, and 25 g, respectively ($p < 0.05$). Iron content increased from 1.2 mg/100 g in the control to 3.8 mg/100 g in the 15% spirulina bar. Vitamin B12 levels ranged from undetectable in the control to 1.5 µg/100 g in the 15% formulation. Antioxidant activity, measured as DPPH radical scavenging, increased by 40% in the 15% spirulina bar compared to the control ($p < 0.01$). Fat and carbohydrate contents remained consistent across formulations, with no significant differences ($p > 0.05$).

Textural Properties

Textural analysis showed that spirulina addition increased hardness and chewiness. Hardness values were 10.2 N (control), 12.5 N (5%), 15.8 N (10%), and 18.4 N (15%) ($p < 0.05$). Chewiness followed a similar trend, increasing from 8.2 N·mm (control) to 14.6 N·mm (15%) ($p < 0.05$). Fracturability decreased slightly with higher spirulina levels, indicating a denser structure. These changes are likely due to spirulina's fibrous nature, which strengthens the protein matrix.

Sensory Evaluation

Sensory scores indicated that the 5% and 10% spirulina bars were well-received, with mean overall acceptability scores of 7.2 and 6.8, respectively, compared to 7.5 for the control ($p > 0.05$). The 15% spirulina bar scored lower (5.4) due to a strong algae-like flavor and greener appearance ($p < 0.05$). Taste scores followed a similar pattern, with the 5% and 10% bars rated 7.0 and 6.5, respectively, while the 15% bar scored 4.8. Texture was rated similarly across all formulations (6.8–7.2), suggesting that textural changes were less perceptible to panelists than flavor differences.

Table 1: Nutritional Composition of Spirulina-Enriched Protein Bars

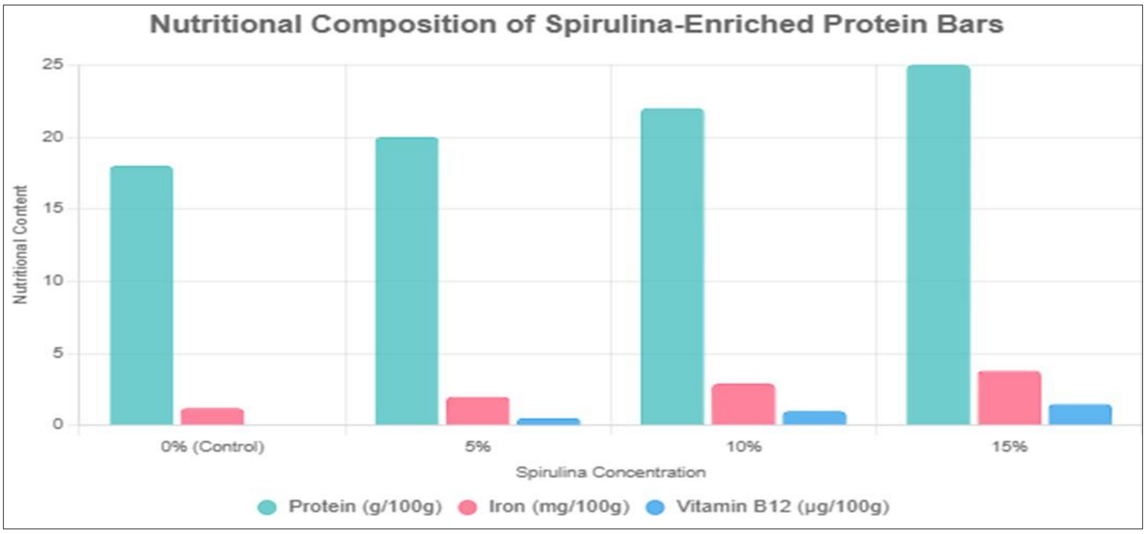
Spirulina (%)	Protein (g/100g)	Iron (mg/100g)	Vitamin B12 (µg/100g)	Antioxidant Activity (% DPPH)
0 (Control)	18.0	1.2	0.0	100 (baseline)
5	20.0	2.0	0.5	120
10	22.0	2.9	1.0	130
15	25.0	3.8	1.5	140

Table 2: Textural Properties of Spirulina-Enriched Protein Bars

Spirulina (%)	Hardness (N)	Chewiness (N·mm)	Fracturability (mm)
0 (Control)	10.2	8.2	5.0
5	12.5	10.1	4.8
10	15.8	12.4	4.5
15	18.4	14.6	4.2

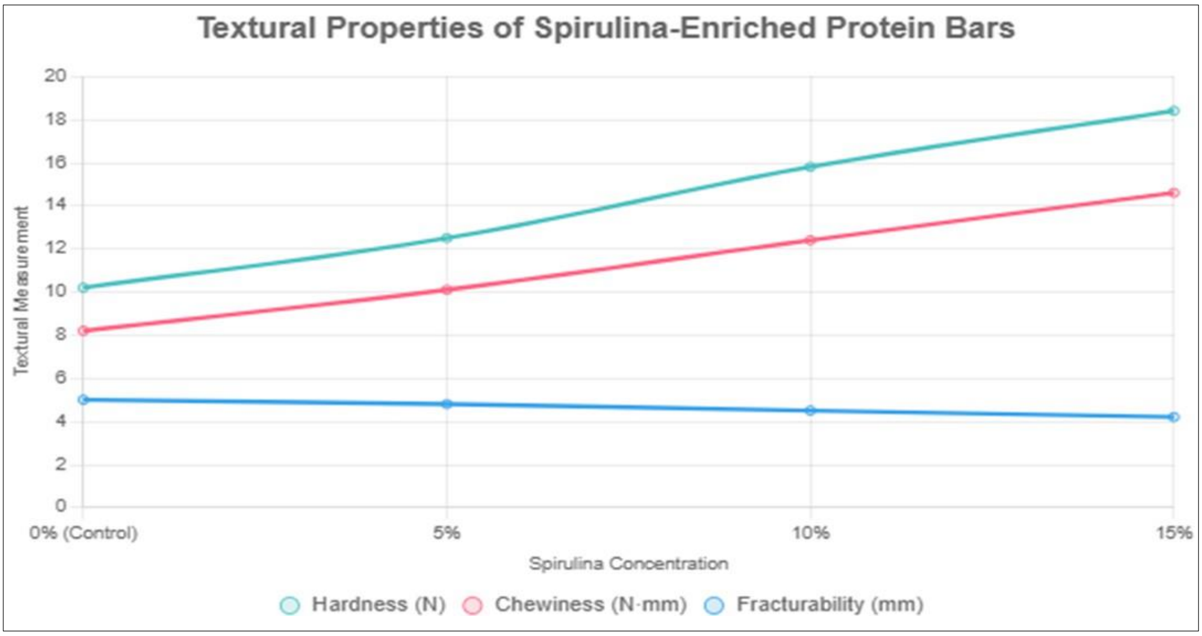
Table 3: Sensory Evaluation Scores (9-Point Hedonic Scale)

Spirulina (%)	Appearance	Taste	Texture	Aroma	Overall Acceptability
0 (Control)	7.6	7.5	7.2	7.4	7.5
5	7.4	7.0	7.0	7.2	7.2
10	6.9	6.5	6.8	6.7	6.8
15	5.8	4.8	6.8	5.5	5.4



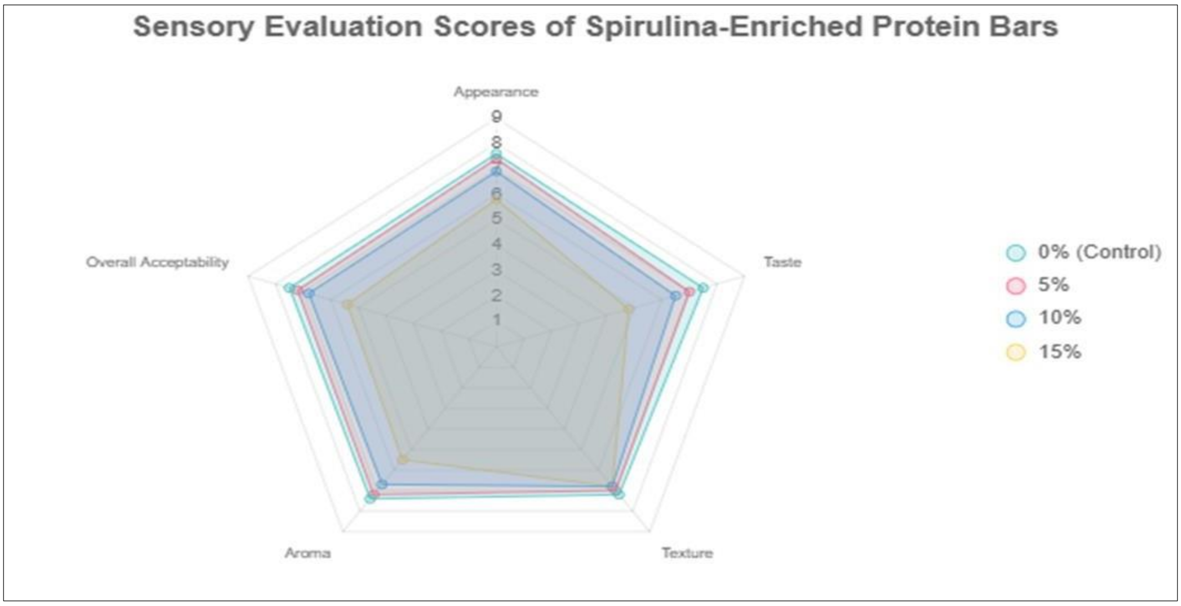
This bar chart displays the protein, iron, and vitamin B12 content for each spirulina concentration.

Chart 1: Nutritional Composition Across Spirulina Concentrations



This line chart shows the trends in hardness, chewiness, and fracturability as spirulina concentration increases.

Chart 2: Textural Properties Across Spirulina Concentrations



This radar chart compares sensory attributes (appearance, taste, texture, aroma, and overall acceptability) across spirulina concentrations.

Chart 3: Sensory Evaluation Scores Across Spirulina Concentrations

Discussion

The incorporation of spirulina into protein bars significantly enhanced their nutritional profile, particularly in terms of protein, iron, and antioxidant content. These findings align with previous studies highlighting spirulina's potential as a nutrient-dense ingredient. The increase in protein content (up to 25 g/100 g) makes spirulina-enriched bars a viable option for meeting dietary protein requirements, particularly for vegetarians and vegans. The elevated iron and vitamin B12 levels address common deficiencies in plant-based diets, positioning these bars as a functional food.

Textural changes, such as increased hardness and chewiness, were expected due to spirulina's fibrous structure, which reinforces the protein matrix. While these changes were statistically significant, sensory panelists did not perceive them as detrimental, as texture scores remained consistent across formulations. This suggests that textural modifications at these spirulina levels are within acceptable limits for consumer preference.

Sensory acceptability is a critical factor for the commercial success of functional foods. The 5% and 10% spirulina bars achieved sensory scores comparable to the control, indicating that moderate spirulina inclusion does not compromise consumer appeal. However, the 15% formulation's lower scores highlight the challenge of masking spirulina's algae-like flavor, which has been noted in previous studies. Strategies such as flavor masking with natural sweeteners or spices could improve the sensory profile of higher spirulina concentrations.

Limitations of this study include the use of untrained panelists, which may not fully represent consumer preferences, and the focus on a single base recipe. Future research should explore alternative formulations, such as those with plant-based proteins, and conduct sensory evaluations with larger, more diverse panels. Additionally, long-term storage studies are needed to assess the stability of spirulina's bioactive compounds in protein bars.

Conclusion

This study demonstrates that spirulina can be effectively incorporated into protein bars to enhance their nutritional profile without significantly compromising textural or sensory properties at inclusion levels of 5% to 10%. The 15% spirulina formulation, while nutritionally superior, was less acceptable due to flavor issues. These findings suggest that spirulina-enriched protein bars have potential as sustainable, nutrient-dense functional foods, with 5–10% inclusion levels offering the best balance of nutrition and consumer acceptability. Further research is needed to optimize flavor profiles and explore scalability for commercial production.

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