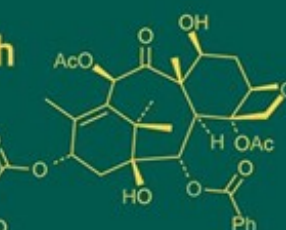
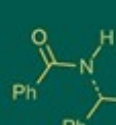


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Development and quality evaluation of *Spirulina* (*Arthrospira platensis*)-fortified peanut chikki as a protein-rich functional snack

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ABSTRACT

The present study was undertaken to develop and evaluate a protein-enriched functional snack by incorporating *Arthrospira platensis* (spirulina) powder into traditional peanut chikki. *Spirulina* powder was evaluated for its nutritional and bioactive characteristics and showed a high protein content of $67.00 \pm 0.28\%$. It also contained phycocyanin (160.00 ± 0.28 mg/g), total carotenoids (502.00 ± 0.72 mg/100 g), antioxidant activity (15.82 ± 0.32 mg TE/g), total phenolic content (14.25 ± 0.35 mg GAE/g), total flavonoid content (4.85 ± 0.14 mg QE/g), and tannin content (1.62 ± 0.05 mg TAE/g). Five formulations of peanut chikki were prepared by incorporating spirulina powder at 0, 2, 4, 6, and 8 g per 100 g peanut and were evaluated for sensory acceptability using a 9-point hedonic scale by ten semi-trained judges. Among the formulations, T_3 containing 6 g spirulina powder per 100 g peanut recorded the highest scores for appearance and color (8.5), flavor (8.3), taste (8.3), texture (8.5), and overall acceptability (8.4), and was selected for further evaluation. The selected T_3 formulation showed higher protein ($18.23 \pm 0.21\%$), ash ($2.46 \pm 0.06\%$), and crude fibre ($3.16 \pm 0.08\%$) contents compared with the control, which contained $14.23 \pm 0.19\%$, $1.90 \pm 0.05\%$, and $2.20 \pm 0.07\%$, respectively. In contrast, carbohydrate content decreased from $56.76 \pm 0.31\%$ in the control to $49.23 \pm 0.28\%$ in T_3 . The results demonstrated that incorporation of spirulina powder at an optimized level improved the nutritional composition of peanut chikki while maintaining good sensory acceptability. Overall, spirulina-enriched peanut chikki, particularly the T_3 formulation, showed potential as a protein-rich, value-added traditional snack with enhanced nutritional and functional attributes.

Keywords: *Arthrospira platensis*, Spirulina-enriched peanut chikki, Functional snack, Protein enrichment, Bioactive compounds, Antioxidant activity

Introduction

The increasing prevalence of lifestyle-related health concerns and micronutrient deficiencies has intensified the demand for foods that provide adequate nutrients along with biologically active components. In recent years, functional foods have received considerable attention because they can combine nutritional value with naturally occurring bioactive compounds. This has encouraged researchers to explore nutrient-dense ingredients for the development of convenient, acceptable, and value-added food products. Among the ingredients of increasing interest, spirulina has gained attention because of its high protein content and diverse range of bioactive constituents (Becker, 2007; Gohara-Beirigo *et al.*, 2022) [1, 2].

Arthrospira platensis, commonly known as spirulina, is a filamentous, photosynthetic cyanobacterium that has been widely investigated as a nutrient-rich food ingredient. Its dried biomass is characterized by a high protein content, generally reported in the range of approximately 55–70%, along with essential amino acids, minerals, vitamins, essential fatty acids, pigments, and other bioactive compounds (Habib *et al.*, 2008; Becker, 2007) [3, 1]. *Spirulina* is particularly recognized for its phycocyanin, chlorophyll, carotenoids, phenolic compounds, and other antioxidant constituents. These components contribute to its nutritional and functional potential and make spirulina a promising ingredient for nutritional enrichment of conventional food products (Karkos *et al.*, 2011; Fernandes *et al.*, 2023) [5, 4].

The nutritional importance of spirulina extends beyond its protein content. Phycocyanin is one of the characteristic pigments of spirulina and has been extensively studied because of its antioxidant and other biological properties. Carotenoids, chlorophyll, phenolic compounds, and flavonoids may also contribute to the antioxidant potential of spirulina. Consequently, incorporation of spirulina into food products may improve their nutritional density and provide additional bioactive components (Fernandes *et al.*, 2023; Gohara-Beirigo *et al.*, 2022) [4, 2]. However, the characteristic blue-green color and distinctive flavour of spirulina can influence the sensory properties and consumer acceptability of food products. Therefore, optimization of the incorporation level is essential to achieve a balance between nutritional enhancement and sensory quality.

Peanut (*Arachis hypogaea* L.) is an important oilseed legume widely consumed as a food ingredient and is valued for its protein, fat, energy, minerals, and characteristic sensory properties. Its high energy density, pleasant flavour, crunchy texture, and broad consumer acceptance make it suitable for the preparation of traditional and value-added snack products. Peanut also provides a complementary protein and energy source that can be combined with spirulina to develop nutritionally enriched foods. The successful incorporation of protein-rich ingredients into peanut-based traditional products has previously been investigated, demonstrating the potential of peanut as a suitable food matrix for nutritional enhancement (Pallavi *et al.*, 2014) [6].

Jaggery is a traditional non-centrifugal sugar commonly used in Indian food preparations and traditional confectionery products. It functions primarily as a sweetening and binding ingredient and contributes to the characteristic color, flavor, and texture of products such as chikki. Unlike refined sugar, jaggery retains certain mineral constituents and naturally occurring components derived from sugarcane juice (Jaffé, 2015) [7]. The combination of peanut and jaggery therefore provides a familiar and widely accepted traditional food matrix suitable for incorporation of nutritionally valuable ingredients.

Chikki is a traditional Indian confectionery product generally prepared using peanuts and jaggery. It is valued for its characteristic crisp texture, pleasant taste, convenience, and energy density. Conventional peanut chikki provides protein and energy; however, its nutritional quality can potentially be enhanced through the incorporation of nutrient-dense functional ingredients. Previous research has demonstrated the feasibility of nutritional enrichment of peanut chikki with protein, mineral, and vitamin sources (Pallavi *et al.*, 2014) [6]. Incorporating spirulina into peanut chikki may therefore provide an opportunity to combine the nutritional advantages of spirulina with the desirable sensory characteristics and consumer familiarity of traditional peanut chikki.

The combination of spirulina, peanut, and jaggery provides complementary nutritional and technological characteristics. *Spirulina* contributes concentrated protein and bioactive compounds, peanut contributes protein, fat, energy, and desirable sensory properties, while jaggery acts primarily as a sweetening and binding agent. However, increasing the level of spirulina may alter the color, flavor, taste, and texture of the final product. Thus, sensory evaluation is an important step in determining an appropriate level of spirulina incorporation that provides nutritional enrichment without compromising product acceptability.

Spirulina has been investigated for incorporation into several food applications, including beverages, bakery products, pasta, snacks, and other value-added foods. The growing interest in microalgae-based food products is associated with their potential contribution of pro-

teins, pigments, minerals, and other bioactive compounds (Gohara-Beirigo *et al.*, 2022) [2]. However, comparatively limited attention has been given to the incorporation of spirulina into traditional Indian confectionery products such as peanut chikki. In addition, optimization of the spirulina incorporation level based on sensory acceptability and subsequent evaluation of the nutritional characteristics of the selected product remain important areas for product development.

The present study was undertaken to develop and standardize spirulina-enriched peanut chikki using different levels of *Arthrospira platensis* powder. The developed formulations were evaluated for sensory acceptability to identify the most acceptable level of spirulina incorporation. The selected formulation was further evaluated for its proximate composition and other nutritional and functional characteristics, including phytochemicals, phytopigments, and essential amino acid composition. The study aimed to assess the potential of spirulina as a value-added ingredient for improving the nutritional quality of traditional peanut chikki while maintaining desirable sensory acceptability.

2 Materials and Methods

2.1 Materials

The present investigation was carried out during the academic year 2025–2026 at the Department of Food Chemistry and Nutrition, College of Food Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani, Maharashtra, India, in collaboration with the Department of Food Process Technology, Department of Food Microbiology and Safety, and Department of Food Engineering, College of Food Technology, and Department of Soil Science, College of Agriculture. *Spirulina* powder (*Arthrospira platensis*) was procured from the local market of Parbhani. Peanuts, jaggery, liquid glucose and cardamom were procured locally. Analytical-grade chemicals and reagents were used for chemical and instrumental analyses. LDPE, HDPE and PET packaging materials were used for storage studies.

2.2 Formulation and preparation of spirulina peanut chikki

Preliminary trials were conducted to standardize the level of spirulina powder incorporation in peanut chikki. Five formulations were prepared, namely T₀ (control), T₁, T₂, T₃ and T₄. The control formulation (T₀) was prepared without spirulina powder, while T₁, T₂, T₃ and T₄ contained 2, 4, 6 and 8 g of spirulina powder, respectively, per 100 g of peanut. The quantity of jaggery was gradually reduced from 170 g in the control to 162 g in T₄ to obtain an appropriate consistency and taste. Liquid glucose was incorporated to improve the binding, texture and consistency of the chikki, while cardamom powder was added for flavor enhancement.

Table 1. Formulation for preparation of peanut chikki by using spirulina powder

Ingredients (g)	T ₀ (Control)	T ₁	T ₂	T ₃	T ₄
Peanut	100	100	100	100	100
Jaggery	170	168	166	164	162
Liquid Glucose	10	10	10	10	10
<i>Spirulina</i> powder	-	2	4	6	8
Cardamom	0.5	0.5	0.5	0.5	0.5

Where,

T₀ (Control): Peanut 100 g + jaggery 170 g + liquid glucose 10 g + cardamom 0.5 g.

T₁: Peanut 100 g + jaggery 168 g + liquid glucose 10 g + *Spirulina* 2 g + cardamom 0.5 g.

T₂: Peanut 100 g + jaggery 166 g + liquid glucose 10 g + *Spirulina* 4 g + cardamom 0.5 g.

T₃: Peanut 100 g + jaggery 164 g + liquid glucose 10 g + *Spirulina* 6 g + cardamom 0.5 g.

T₄: Peanut 100 g + jaggery 162 g + liquid glucose 10 g + *Spirulina* 8 g + cardamom 0.5 g.

2.3 Methodology for preparation of spirulina peanut chikki

Raw materials ↓ Roasting peanuts (120–130 °C, 10–15 min) ↓ Preparation of jaggery–glucose syrup (140–145 °C) ↓ Drop test for hard-ball stage

↓ Addition of roasted peanuts + cardamom ↓ Cooling of syrup (60–80 °C) + addition of spirulina powder ↓ Pouring, rolling and sheeting

↓ Cutting into squares and setting ↓ Cooling and packaging in LDPE packets

↓ Storage (room temperature)

Flow Chart 1. Process for preparation of spirulina peanut chikki

2.4 Sensory evaluation

Sensory evaluation of the developed spirulina peanut chikki was conducted using a 9-point hedonic scale as described by Amerine *et al.* (1965) [8]. Ten semi-trained judges evaluated the samples for appearance and color, flavor, taste, texture and overall acceptability. The samples were coded and presented to the judges under similar conditions. The judges independently evaluated each sample using the following hedonic scale: 9 = like extremely, 8 = like very much, 7 = like moderately, 6 = like slightly, 5 = neither like nor dislike, 4 = dislike slightly, 3 = dislike moderately, 2 = dislike very much and 1 = dislike extremely. The scores obtained from the ten judges were averaged for each sensory attribute and treatment. The treatment receiving the highest overall acceptability score was considered the most acceptable formulation and was selected for further quality evaluation.

2.5 Proximate analysis

The proximate composition of spirulina powder and spirulina peanut chikki was determined using standard AOAC methods. Moisture was estimated by hot air oven drying at 105 ± 1 °C, ash by muffle furnace incineration at 550–600 °C, protein by the Kjeldahl method using a conversion factor of 6.25, fat by soxhlet extraction using petroleum ether, and crude fibre by acid–alkali digestion. Carbohydrate content was calculated by difference. All analyses were carried out in triplicate and expressed as percentage of the sample (AOAC, 1984; AOAC, 2000) [9].

2.6 Phytochemical and phytopigment analysis

The phytochemical constituents of spirulina powder were evaluated for total phenolic content, total flavonoid content and tannin content. Total phenolic content was determined by the Folin-Ciocalteu method using gallic acid as standard, total flavonoids by the aluminium chloride colorimetric method using quercetin as standard, and tannins by the Folin-Denis method using tannic acid as standard. The results

were expressed as mg GAE/g, mg QE/g and mg TAE/100 g, respectively (Singleton *et al.*, 1965) [10].

Phytopigments including chlorophyll, phycocyanin, total carotenoids and β -carotene were determined by spectrophotometric and chromatographic methods. Chlorophyll was extracted with 90% acetone and measured at 630, 647 and 664 nm (Jeffrey *et al.*, 1975) [11]. Phycocyanin was estimated spectrophotometrically at 620 nm following phosphate-buffer extraction. Total carotenoids were determined at 450 nm, while β -carotene was quantified by reverse-phase HPLC at 450 nm.

2.7 Amino acid profile

The amino acid profile of spirulina powder was determined by HPLC following acid hydrolysis, derivatization and chromatographic separation. Tryptophan was analysed separately using alkaline hydrolysis. Essential amino acids including isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, histidine and valine were identified by comparison with authentic standards and quantified using calibration curves. Results were expressed as g/100 g sample on a dry-weight basis (AOAC, 1984).

2.8 Color analysis

Color characteristics of spirulina powder and spirulina peanut chikki were measured using a Hunter color difference meter. The color values L^* , a^* , b^* , chroma (C^*) and hue angle (h°) were recorded. L^* represented lightness, a^* represented redness/greenness and b^* represented yellowness/blueness. Three readings were taken for each sample and mean values were reported (Pankaj *et al.*, 2013).

2.9 Statistical analysis

All experiments were conducted in triplicate. The data were statistically analysed using a Completely Randomized Design (CRD) and ANOVA. Significant differences among treatments were determined at the 5% level of significance ($P < 0.05$). Standard error (SE) and critical difference (CD) were calculated wherever applicable, following Panse *et al.* (1967) [12].

3 Result and Discussion

3.1 Sensory evaluation of spirulina peanut chikki

Table 2. Sensory evaluation of prepared food product spirulina added peanut chikki

Treatments	Parameters				
	Appearance and color	Flavour	Taste	Texture	Overall Acceptability
T ₀	7.8	8	8	8.2	8
T ₁	7.5	7.8	7.5	7.8	7.7
T ₂	7.2	7.5	7.2	7.5	7.4
T ₃	8.5	8.3	8.3	8.5	8.4
T ₄	7	7.2	7	7.5	7.2
SE ($\pm$)	0.090	0.085	0.089	0.087	0.088
CD at 5 %	0.262	0.247	0.259	0.253	0.256

- Each value is average of three determinations

Sensory evaluation of the spirulina peanut chikki samples was carried out using a 9-point hedonic scale as described by Maynard A. Amerine *et al.* (1965) [8]. Ten semi-trained judges evaluated the samples for appearance and color, flavor, taste, texture and overall acceptability. The sensory scores ranged from 9 (like extremely) to 1 (dislike extremely). Each treatment was evaluated under identical conditions, and the mean scores obtained for each sensory attribute were used for statistical analysis.

Among the five formulations, T₃ (6 g spirulina powder/100 g peanut) recorded the highest scores for appearance and color (8.5), flavor (8.3), taste (8.3), texture (8.5) and overall acceptability (8.4). The control (T₀) also showed good acceptability, with an overall acceptability score of 8.0. The incorporation of spirulina at 2 and 4 g levels (T₁ and T₂) resulted in comparatively lower sensory scores. However, T₄ (8 g spirulina) received the lowest scores, particularly for appearance and color (7.0) and taste (7.0), indicating that higher incorporation of spirulina negatively affected the sensory characteristics of chikki. Therefore, T₃ was selected as the most acceptable formulation for further quality evaluation.

3.2 Phytonutrients and phytopigments composition of spirulina powder

Table 3. Phytonutrients and Phytopigments composition of spirulina powder

Phytonutrients and Phytopigments	Value
Chlorophyll (%)	1.52 ± 0.03
β- Carotene (mg/100g)	6.4 ± 0.08
Phycocyanin (mg/g)	160 ± 0.28
Total carotenoids (mg/100g)	502 ± 0.72
Antioxidant activity (mg TE/g)	15.82 ± 0.32
Total phenolic content (mg GAE/g)	14.25 ± 0.35
Total flavonoid content (mg QE/g)	4.85 ± 0.14
Tannin content (mg TAE/g)	1.62 ± 0.05

- Each value is average of three determinations

The spirulina powder showed appreciable levels of bioactive pigments and phytochemicals. Chlorophyll, β-carotene, phycocyanin and total carotenoids were found to be 1.52 ± 0.03%, 6.40 ± 0.08 mg/100 g, 160 ± 0.28 mg/g and 502 ± 0.72 mg/100 g, respectively. The antioxidant activity was 15.82 ± 0.32 mg TE/g, while total phenolic, flavonoid and tannin contents were 14.25 ± 0.35 mg GAE/g, 4.85 ± 0.14 mg QE/g and 1.62 ± 0.05 mg TAE/g, respectively. The appreciable pigment content, particularly phycocyanin and carotenoids, indicates the potential of spirulina as a source of natural bioactive compounds. Similar studies have reported that phycocyanin, carotenoids and chlorophyll contribute significantly to the antioxidant potential of *Spirulina*, while phenolic and flavonoid compounds may also contribute to its antioxidant activity.

3.3 Chemical composition of spirulina peanut chikki

Table 4. Chemical composition of spirulina peanut chikki

Chemical Component (%)	Control	Selected (T ₃)
Moisture	2.26 ± 0.08	3.16 ± 0.09
Fat	23.06 ± 0.22	23.80 ± 0.24
Carbohydrate	56.76 ± 0.31	49.23 ± 0.28
Protein	14.23 ± 0.19	18.23 ± 0.21
Ash	1.9 ± 0.05	2.46 ± 0.06
Crude Fibre	2.2 ± 0.07	3.16 ± 0.08

- Each value is average of three determinations

The data presented in Table 4 revealed that incorporation of spirulina powder improved the nutritional composition of peanut chikki. The moisture content increased from 2.26 ± 0.08% (T₀) to 3.16 ± 0.09% (T₃), while fat content increased from 23.06 ± 0.22% to 23.80 ± 0.24%. The protein content showed a marked increase from 14.23 ± 0.19% (T₀) to 18.23 ± 0.21% (T₃). Similarly, ash content increased from 1.90 ± 0.05% to 2.46 ± 0.06%, and crude fibre increased from 2.20 ± 0.07% to 3.16 ± 0.08%. In contrast, carbohydrate content decreased from 56.76 ± 0.31% (T₀) to 49.23 ± 0.28% (T₃). The increase in protein, ash and fibre can be attributed to the nutrient-rich composition of spirulina, which is recognized as a valuable source of protein, minerals and dietary components. Similar nutritional improvements have been reported in spirulina fortified food products (Becker, 2007; Khanra *et al.*, 2018) [1, 13].

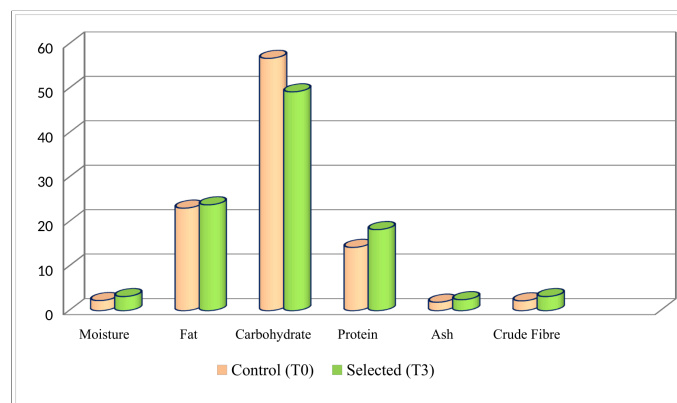


Figure 1. Chemical composition of spirulina peanut chikki

3.4 Essential amino acids composition of spirulina powder

Table 5. Essential amino acids composition of spirulina powder

Amino acid	Value (g/100g)
Isoleucine	5.40 ± 0.05
Leucine	7.65 ± 0.06
Lysine	4.42 ± 0.04
Methionine	2.12 ± 0.02
Phenylalanine	8.48 ± 0.07
Threonine	5.20 ± 0.05
Tryptophan	1.02 ± 0.01
Histidine	1.54 ± 0.02
Valine	5.45 ± 0.05

- Each value is average of three determinations

The amino acid composition of the sample is presented in Table 5. The results of the present study revealed variation in the concentration of the analysed amino acids. Phenylalanine showed the highest concentration (8.48 ± 0.07 g/100 g), followed by leucine (7.65 ± 0.06 g/100 g), valine (5.45 ± 0.05 g/100 g), isoleucine (5.40 ± 0.05 g/100 g), and threonine (5.20 ± 0.05 g/100 g). Lysine, methionine, and histidine were recorded at 4.42 ± 0.04, 2.12 ± 0.02, and 1.54 ± 0.02 g/100 g, respectively, while tryptophan showed the lowest concentration (1.02 ± 0.01 g/100 g). The relatively higher levels of leucine, isoleucine, and valine indicate a good contribution of branched-chain amino acids (BCAAs) to the amino acid profile. Overall, the present study demonstrated a diverse essential amino acid composition, indicating the potential nutritional value of the sample. Essential amino acid composition is considered an important parameter for evaluating the nutritional quality of dietary proteins (WHO *et al.*, 2007) [14].

Conclusion

The present study demonstrated the potential of *Arthrospira platensis* (spirulina) powder as a nutritionally enriching ingredient in traditional peanut chikki. *Spirulina* powder exhibited a high protein content along with appreciable levels of phycocyanin, carotenoids, phenolic compounds, flavonoids, tannins and antioxidant activity, indicating its nutritional and functional potential. Incorporation of spirulina at different levels influenced the sensory characteristics of peanut chikki, with the 6% incorporation level (T₃) showing the highest sensory scores for appearance and color, flavor, taste, texture and overall acceptability. The selected T₃ formulation also demonstrated improved protein, ash and crude fibre contents compared with the control, while carbohydrate content was comparatively reduced. The amino acid profile of spirulina further indicated the presence of several essential amino acids, particularly phenylalanine, leucine, valine, isoleucine and threonine. Overall, incorporation of spirulina at an optimized level of 6 g per 100 g peanut resulted in a nutritionally enhanced chikki with good sensory acceptability. The developed spirulina-en

riched peanut chikki may therefore serve as a promising value-added, protein-enriched traditional snack. Further studies on shelf life, storage stability, bioavailability and consumer acceptance at a larger scale are recommended to establish its potential for commercial application.

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