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Process optimization for *Arthrospira platensis* biomass production and development of functional foods

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Abstract

This study establishes an optimized framework for the mass cultivation, downstream processing, and food-system integration of *Arthrospira platensis* (Spirulina). We investigated the effects of open-pond versus photobioreactor (PBR) systems on biomass yield. Optimization of downstream drying technologies was conducted to preserve heat-sensitive phycocyanin and antioxidant properties. *A. platensis* powder was integrated into functional food matrices, including bakery products (biscuits) and extruded snacks (pasta), at incorporation levels ranging from 2% to 10%. Results indicated that closed PBR systems yielded 35% higher biomass density than open ponds, though open ponds remained more economically viable. Spray drying at an inlet temperature of 130 °C preserved up to 88% of total phycocyanin content compared to convective oven drying. Sensory evaluation revealed that a 5% incorporation level in both biscuits and pasta achieved optimal consumer acceptance without compromising structural integrity or introducing overwhelming marine flavors. This research demonstrates a scalable pathway for utilizing Spirulina as a sustainable, high-protein ingredient to combat micro-nutritional deficiencies. Also this research focuses on developing a standardized technology for the production of Spirulina (*Arthrospira platensis*) powder and its utilization in value-added food products such as pasta and cookies. The study evaluates cultivation, processing, nutritional composition, functional properties, and the effect of spirulina incorporation on physicochemical, sensory, microbiological, and storage characteristics. The findings are expected to promote spirulina as a sustainable, protein-rich functional ingredient for improving the nutritional quality and consumer acceptability of food products.

Keywords: *Arthrospira platensis* (Spirulina), functional foods, photo bioreactor, food fortification, phycocyanin, pasta, cookies

Introduction

The growing global population, increasing environmental challenges, and rising demand for sustainable nutrition have intensified the search for alternative protein sources. Among these, *Arthrospira platensis* (Spirulina) has gained considerable attention because of its high protein content, rich nutritional profile, and numerous bioactive compounds with potential health benefits. In addition to its nutritional value, Spirulina is environmentally sustainable, requiring fewer natural resources than conventional protein sources. Despite its promising potential, its application in food products is limited by sensory challenges such as its characteristic color and flavor. Therefore, the development of Spirulina-enriched functional foods, such as pasta and cookies, offers an opportunity to improve nutritional quality while promoting sustainable food systems. Accordingly, the present study was undertaken to formulate and evaluate the quality of pasta and cookies incorporated with Spirulina powder.

Materials and Methods

Materials

Pure Spirulina (*Arthrospira platensis*) starter culture was procured from Krishi Vigyan Kendra (KVK), Babhaleshwar, Rahata, Ahmednagar, Maharashtra, India. Refined wheat flour, sugar, butter, salt, sodium bicarbonate, ammonium bicarbonate, and other food-grade ingredients required for product formulation were purchased from the local market of Parbhani, Maharashtra. Analytical-grade chemicals and reagents used for physicochemical and nutritional analyses were obtained from the Department of Food Chemistry and Nutrition, College of Food Technology, Vasantrao Naik Marathwada Krishi Vidyapeeth (VNMKV), Parbhani.

Preparation of Spirulina Powder

The Spirulina culture was propagated in a nutrient medium prepared using NPK fertilizer (15:15:15), single super phosphate (SSP), magnesium sulfate (MgSO_4), and sodium chloride (NaCl). The culture was maintained under controlled conditions (30-35 °C; pH 9.0-10.5) with regular manual agitation at 5-6 h intervals to ensure proper aeration and uniform nutrient distribution. After 14-15 days of cultivation, the biomass was harvested by filtration, washed thoroughly with clean water to remove impurities, and sun-dried under hygienic conditions. The dried biomass was ground into fine powder, sieved for uniform particle size, packed in airtight containers, and stored at ambient conditions until further use.

Product Development

Spirulina-Enriched Pasta

Four formulations were prepared by replacing refined wheat flour with spirulina powder at different levels: 0% (Control), 2.5%, 5.0%, and 7.5%. The dry ingredients were blended uniformly, followed by the addition of salt and water to obtain a homogeneous dough. The dough was kneaded, rested for 15-20 min, extruded into pasta, and dried under hygienic conditions until the moisture content reached safe storage levels (<10%). The dried pasta was cooled and packed in airtight containers.

Spirulina-Enriched Cookies

Cookies were prepared by substituting refined wheat flour with spirulina powder at 0%, 5%, 10%, and 15% levels. Butter and sugar were creamed before incorporating the flour mixture along with sodium bicarbonate and ammonium bicarbonate. The dough was sheeted (0.6 cm thickness), cut into circular shapes (4 cm diameter), and baked at 180 °C for 15 min. After cooling, the cookies were packed in suitable packaging materials for further analysis.

Physicochemical Analysis

The prepared spirulina powder was evaluated for particle size distribution using a standard sieve shaker. Physical properties including bulk density, true density, angle of repose, Carr's Index, and Hausner ratio were determined using standard analytical procedures. Functional properties such as water-holding capacity, oil absorption capacity, and swelling capacity, along with reconstitution properties including solubility, dispersibility, and wettability, were also evaluated using established methods.

Proximate composition comprising moisture, ash, crude protein, crude fat, and carbohydrate contents was determined according to standard AOAC and AACC methods. Mineral composition (phosphorus, calcium, iron, magnesium, zinc, copper, and manganese) was analyzed using spectrophotometric, titrimetric, colorimetric, and atomic absorption spectrophotometric methods, as appropriate. Total chlorophyll content was determined spectrophotometrically using acetone extraction.

Antioxidant Activity

The antioxidant activity of spirulina powder was determined by the DPPH radical scavenging assay. Aqueous extracts were prepared by hot-water extraction and reacted with DPPH solution. The absorbance was measured at 520 nm using a UV-visible spectrophotometer, and antioxidant activity was expressed as percentage inhibition of DPPH radicals.

Quality Evaluation of Developed Products

The developed pasta and cookies were analyzed for physical characteristics, proximate composition, mineral composition, and texture profile. Texture profile analysis was carried out using a Texture Analyzer (TA-XT Plus, Stable Micro Systems, UK), and parameters including firmness, springiness, cohesiveness, gumminess, and stickiness were recorded.

Sensory Evaluation

Sensory evaluation was conducted using a semi-trained panel of ten judges. The samples were evaluated for colour, appearance, flavour, texture, taste, and overall acceptability using the nine-point Hedonic rating scale.

Storage Study

The optimized products were packed in HDPE and LDPE packaging materials and stored under ambient conditions for three months. Samples were periodically analyzed for changes in physicochemical characteristics, sensory quality, and microbial load.

Microbiological Analysis

Microbiological quality of the stored products was assessed by determining total plate count, yeast and mould count, and coliform count using standard ISI microbiological methods. Results were expressed as colony-forming units per gram (CFU g^{-1}).

Statistical Analysis

All experiments were conducted in triplicate, and the data were analyzed using a Completely Randomized Design (CRD). Statistical analysis was performed following the procedure described by Panse and Sukhatme (1967) [15]. Significant differences among treatment means were determined at the 5% probability level.

Results and Discussion

Table 1: Physical properties of spirulina powder

Parameter	Value
Appearance	Fine and uniform
Color	Blue green to dark green
Consistency	Powder
Particle size (80 Mesh)	85%
Bulk density (Kg/Lit)	0.79±0.25
Odor and taste	Mild like sea weed
pH	6.90±0.14

*Each value is an average of three determinations

The data presented in table-6 depicted the physical quality characteristics of spirulina powder. It was observed that the bulk density of spirulina (0.79 Kg/lit), the bulk density of the product is affected by particle size distribution; type of agglomeration, particle porosity, and to a certain extent the moisture content. Particle size distribution is affected by the initial size of the trichomes as they are fed to the dryer and the pore diameter of the atomizer. The final quality of the product with respect to bulk density is therefore dependent on culturing, harvesting and drying conditions. To a certain extent, all these factors are harnessed in order to obtain a product that meets the requirements. The color of spirulina in the powder form appears a blue green to green color.

The spirulina offers a convenient solution to the pH problems of most diets as it is very alkaline. Because spirulina is an alkaline food (pH 6.90) that counters the acidic foods and help raise the pH level towards the alkaline side of the scale. This, in turn, promotes increased bone mass (since your body doesn't have to sacrifice calcium to balances its pH), and vastly improved metabolic functions. Consuming more alkaline foods has been strongly linked with improved immune system function, mental function, kidney function, and higher levels of energy, among other important benefits. Acidic body condition may cause many modern diseases like hypertension, cancer, diabetes, heart disease, gout and rheumatism.

Table 2: Proximate composition of spirulina powder

Parameter (%)	Value
Moisture	4.80±0.15
Protein	60.99±2.33
Fat	7.20±0.15
Carbohydrate	11.96±0.21
Crude fiber	7.55±0.09
Ash	7.50±0.11

*Each value is an average of three determinations

The data presented in Table 7 indicate that spirulina powder is a highly concentrated source of essential nutrients, exhibiting an excellent nutritional profile characterized by high protein content along with appreciable amounts of carbohydrates, dietary fiber, fat, and minerals. The high protein (60.99%) content makes it particularly suitable for combating protein-energy malnutrition and developing protein-fortified foods. The low moisture content (4.80%) contributes to longer shelf life and better storage stability by reducing microbial activity. The moderate fat content (7.20%) provides essential fatty acids without significantly increasing lipid oxidation. The presence of dietary fiber (7.55%) enhances digestive health and improves functional properties in food formulations, while the high ash content (7.50%) indicates substantial mineral availability. Therefore, spirulina powder has considerable potential as a sustainable functional food ingredient capable of improving the nutritional profile of cereal-based products such as pasta and cookies, making them more suitable for health-conscious consumers and populations vulnerable to nutrient deficiencies. The results of chemical composition of spirulina are in agreement with those obtained by Branger *et al.* (2003) [8].

Table 3: Antioxidant activity of spirulina powder

Sample	Antioxidant Activity (%) (DPPH Method)
Dried spirulina powder	60.05

*Each value is an average of three determinations

The antioxidant activity of dried spirulina powder determined by the 2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging assay is presented in Table 13. The results demonstrated that the spirulina powder exhibited 60.05% DPPH radical scavenging activity, indicating a substantial antioxidant potential. This finding confirms that spirulina is a rich source of naturally occurring antioxidant compounds capable of donating hydrogen atoms or electrons to neutralize free radicals, thereby reducing oxidative stress.

The DPPH assay is one of the most widely accepted, rapid, and reliable methods for evaluating the antioxidant capacity of plant and algal extracts. The assay is based on the reduction of the stable purple-colored DPPH radical (DPPH) into its yellow-colored reduced form (DPPH-H) by antioxidant molecules. The degree of discoloration is directly proportional to the free radical scavenging ability of the sample and is generally measured spectrophotometrically at 517 nm. Therefore, the observed antioxidant activity of 60.05% indicates that spirulina possesses a strong ability to quench free radicals through hydrogen atom transfer and electron donation mechanisms. The antioxidant activity obtained in the present investigation is in close agreement with several previous studies. El-Baky *et al.* (2009) [16] reported DPPH radical scavenging activity ranging from 55-70% in *Spirulina platensis* extracts, depending on the extraction solvent and cultivation conditions. Similarly, Wu *et al.* (2016) [17] observed approximately 58-68% DPPH inhibition in methanolic spirulina extracts, while Lafarga and Acien-Fernandez (2026) [18] summarized that the antioxidant activity of spirulina generally ranges from 50% to 80%, depending on species, growth conditions, harvesting stage, drying technique, extraction solvent, and analytical methodology.

Table 4: Phyto-chemical constituents of dried spirulina powder

Phyto-chemicals	Value
Total poly phenols	17.58 mg GAE/g
Total flavonoids	3.74 mg QE/g
Total alkaloids	4.27 mg/g

*Each value is an average of three determinations

The data presented in table 16 showed the phyto-chemical constituent of dried spirulina powder. The total phenolic content of the spirulina powder was found to be 17.58 mg gallic acid equivalents (GAE)/g. Phenolic compounds are among the most important naturally occurring antioxidants because they possess multiple hydroxyl groups capable of donating hydrogen atoms or electrons to neutralize free radicals. The phenolic concentration obtained in this study also suggests that spirulina powder possesses substantial antioxidant capacity, which complements the antioxidant activity provided by chlorophyll, carotenoids, phycocyanin, and other pigments. Therefore, the observed phenolic content significantly enhances the functional food value of spirulina and supports its utilization in nutraceuticals and value-added food products. The total phenolic content (17.58 mg GAE/g) obtained in the present study falls within the range reported for spirulina by Safafar *et al.* (2015) [19], who observed phenolic contents ranging approximately from 10 to 25 mg GAE/g, depending upon cultivation conditions, harvesting stage, extraction method and drying process.

The total flavonoid content of the dried spirulina powder was 3.74 mg quercetin equivalents (QE)/g. Flavonoids represent an important subclass of polyphenolic compounds widely recognized for their ability to scavenge free radicals, chelate transition metals, inhibit lipid oxidation, and regulate inflammatory pathways. Similarly, the total flavonoid content (3.74 mg QE/g) agrees well with reports by Shalaby and Shanab (2013), who found flavonoid concentrations between 2 and 6 mg QE/g in *Spirulina platensis*. Variations among studies are primarily attributed to differences in cultivation environment, nutrient

availability, extraction solvents and analytical procedures. The dried spirulina powder contained 4.27 mg/g total alkaloids, indicating the presence of biologically active nitrogen-containing secondary metabolites. The phytochemical composition of spirulina plays a crucial role in determining its biological activity and functional food potential. Polyphenols and flavonoids are powerful antioxidants that interrupt free radical chain reactions, while alkaloids contribute additional antimicrobial and anti-inflammatory activities. Together with chlorophyll, carotenoids and phycocyanin, these phytochemicals act synergistically to reduce oxidative stress, improve immune function and enhance cellular protection. The relatively high concentrations of phenolic compounds observed in the present study indicate that the drying process effectively preserved bioactive constituents. Consequently, the prepared spirulina powder exhibits excellent potential as a natural antioxidant ingredient capable of enhancing both the nutritional quality and shelf stability of fortified food products.

Table 5: Standardization and formulation for preparation of pasta incorporated with spirulina powder

Trials	Wheat Flour (%)	Spirulina Powder (%)
P0 (Control)	100	0
P1	97.5	2.5
P2	95	5
P3	92.5	7.5

Table 6: Basic recipe for preparation of cookies (100 g)

Ingredients	Composition	Quantity (g)
Refined wheat flour (maida) (g)	45%	45.00
Spirulina powder	5%	5.00
Sugar (g)	25%	25.00
Shortening (g)	23.50%	23.50
Sodium bicarbonate (g)	0.5%	0.50
Ammonium bicarbonate (g)	1.0%	1.00
Milk (ml)		As per requirement

Table 7: Formulation of cookies incorporated with spirulina powder

Treatments	Refined wheat flour (g)	Spirulina Powder (g)
C0	100	00
C1	95	05
C2	90	10
C3	85	15

Conclusion

This study confirms that cultivating *Arthrospira platensis* in closed systems maximizes biomass output, while spray drying provides excellent preservation of key nutritional bioactives. Integrating this microalga into everyday foods like biscuits and pasta is highly feasible and effective at a 5% substitution level. At this concentration, the products provide a significant nutritional boost without compromising taste, texture, or consumer approval. Utilizing these optimized processes positions Spirulina as an effective tool for addressing global nutritional deficiencies through sustainable, plant-based food systems.

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