STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 13, Special Issue 6, 2025
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Review JoPC

Polymer Chemistry in Nutraceutical Composites: Exploring Natural Polymers and Binding Systems in a Bamboo-Enhanced Formulation

Amar Mohite[1,*], Rohan Sharadanand Phatak[2], Jayant Rajaram Pawar[3]

Abstract

Polymer chemistry underpins the development of advanced nutraceutical composites, blending natural polymers with functional ingredients for health benefits. This study examines a novel nutraceutical formulation comprising ragi (16.39 g/100g), wheat (12.29 g/100g), soybean (12.29 g/100g), buffalo milk (16.39 g/100g), buffalo butter (4.13 g/100g), bamboo extract (0.90 g/100g), and auxiliary components (37.61 g/100g, including fats, sugars, and proteins). Natural polymers—proteins from soybean and milk, polysaccharides from ragi and wheat—form a macromolecular matrix, stabilized by hydrophobic and hydrogen bonding interactions. The formulation's process involves homogenization at 500 rpm and 1000 rpm, enhancing polymer chain entanglement and dough uniformity, followed by thermal processing at 180°C to cross-link protein and starch networks. Bamboo extract, rich in polyphenolic compounds, introduces antioxidant properties and potential polymer-ligand interactions, reinforcing the composite's stability. The auxiliary components—fats (20.49 g/100g), sugars (16.39 g/100g), and protein powder (0.73 g/100g)—act as plasticizers and cross-linkers, tailoring the matrix's mechanical properties and shelf life (6 months). Physicochemical analysis reveals optimal moisture (2.93%), ash values (7.5% total ash), and nutritional content (e.g., 9.80% crude protein), reflecting a robust polymer network. This work highlights polymer chemistry's role in designing stable, nutrient-rich composites, with proteins and polysaccharides providing structural integrity and bamboo extract enhancing bioactivity. Future directions include synthetic polymer additives (e.g., pectin) or nano-composites to further optimize texture and stability, showcasing polymer science's potential in nutraceutical innovation.

Keywords: Polymer chemistry, natural polymers, nutraceutical composites, protein-polysaccharide matrix, bamboo extract, homogenization, thermal cross-linking

***Author for Correspondence**
Amar Mohite

[1]Research Associate, Department of Research, Krishna Vishwa Vidyapeeth Deemed to be University, Karad, Maharashtra, India
[2]Assistant Professor, Department of Pharmacognosy, Krishna Institute of Pharmacy, Krishna Vishwa Vidyapeeth Deemed to be University, Karad, Maharashtra, India
[3]Associate Professor, Department of Biotechnology, Krishna Vishwa Vidyapeeth Deemed to be University, Karad, Maharashtra, India

Received Date: March 12, 2025
Accepted Date: April 15, 2025
Published Date: August 22, 2025

Citation: Amar Mohite, Rohan Sharadanand Phatak, Jayant Rajaram Pawar. Polymer Chemistry in Nutraceutical Composites: Exploring Natural Polymers and Binding Systems in a Bamboo-Enhanced Formulation. Journal of Polymer & Composites. 2025; 13(Special Issue 6): S878–S884p.

INTRODUCTION

Nutraceuticals are food-based products that offer health benefits beyond basic nutrition, playing a significant role in disease prevention and overall well-being.[1] The increasing demand for functional foods has led to extensive research into the development of novel formulations that incorporate bioactive compounds from natural sources. Polymer composites derived from plant-based materials have emerged as a promising approach for enhancing the nutritional value and stability of food products.

Bamboo, ragi, wheat, soybean, and dairy products are rich in essential nutrients and bioactive compounds that contribute to human health.[2] Bamboo extracts, in particular, contain polyphenols and antioxidants that help in reducing oxidative stress and improving immune function. Ragi and

wheat provide dietary fiber and complex carbohydrates, which are essential for maintaining gut health and energy levels. Soybean serves as an excellent source of plant-based protein and essential amino acids, while buffalo milk and butter contribute healthy fats necessary for metabolic functions.[3]

This study aims to develop and evaluate a nutraceutical formulation that integrates these polymer composites to create a stable and nutritious food supplement. The research focuses on optimizing ingredient composition, assessing physicochemical properties, and evaluating consumer acceptability through sensory analysis. By investigating the synergistic effects of these natural components, this study provides valuable insights into the potential of polymer-based nutraceuticals in promoting human health and enhancing food quality.

MATERIALS AND METHODS

This section outlines the materials and methodologies utilized in developing the nutraceutical formulation. The selection of natural polymer composites was based on their nutritional benefits and bioactive properties.[4] Each ingredient was sourced to maintain high quality and ensure consistency in formulation. Various analytical techniques were applied to assess physicochemical and sensory characteristics. These methods included standard drying techniques, Soxhlet extraction, and homogenization processes aimed at achieving optimal texture, stability, and bioavailability. The comprehensive approach ensures a robust evaluation of the formulation's nutritional impact and long-term stability.

Ingredients and Their Sources

The key ingredients used in this formulation include

The formulation incorporates a carefully selected range of natural ingredients, each contributing specific nutritional and functional properties.[5] These ingredients were chosen for their synergistic effects on health and their ability to enhance the stability of the final product. The primary components include:

- *Ragi (eleusine coracana):* A rich source of calcium, fiber, and essential minerals, ragi supports bone health and digestion.
- *Wheat (triticum aestivum):* Provides carbohydrates and dietary fiber essential for sustained energy release and gut health.[6]
- *Soybean (glycine max):* A high-protein legume containing all essential amino acids, making it a crucial component for muscle maintenance and metabolic health.
- *Buffalo milk and butter (bubalus bubalis):* Serve as sources of essential fats, proteins, and bioactive peptides, contributing to enhanced nutrient absorption and product texture.
- *Bamboo extract (bambusa vulgaris):* Known for its antioxidant properties, bamboo extract is a potent source of polyphenols that help in reducing oxidative stress and improving immune function.[7]

These ingredients were procured from verified sources to ensure quality, consistency, and efficacy in the final nutraceutical formulation. Additionally, their processing methods were optimized to retain maximum bioavailability of nutrients while ensuring food safety and product stability.

- *Ragi (eleusine coracana)* - Rich in calcium and fiber
- *Wheat (triticum aestivum)* - A primary carbohydrate source
- *Soybean (glycine max)* - High in protein and essential amino acids
- *Buffalo milk and butter (bubalus bubalis)* - Provide essential fats and proteins
- *Bamboo extract (bambusa vulgaris)* - Contains antioxidants and polyphenols

Formulation Process

The nutraceutical formulation consists of the following key steps

1. *Preparation of product 1:* Buffalo milk is heated to 180°C, and ragi, wheat, soybean, and auxiliary components are added. The mixture is homogenized at 500 rpm and filtered.

2. *Preparation of product 2:* Bamboo leaves undergo Soxhlet extraction for 8 hours at 62°C using petroleum ether. The extracts are dried at 45°C and mixed with buffalo butter.
3. *Mixing and homogenization:* Products 1 and 2 are combined and homogenized at 1000 rpm for 1 minute to form a uniform dough.[8]
4. *Moulding and baking:* The dough is rolled into 1-inch spherical units and heated at 180°C for 15 minutes.

Storage Stability and Shelf-Life Estimation

Shelf-life was estimated based on ambient storage stability studies conducted over a six-month period. Samples were stored at room temperature (25 ± 2°C) and evaluated at regular monthly intervals for sensory acceptability, moisture content, color change, and odor. The endpoint was determined as the time at which noticeable sensory degradation or physicochemical instability occurred. This method followed conventional storage study protocols, rather than accelerated or predictive modeling.

DISCUSSION

This section presents the evaluation of the developed nutraceutical formulation, highlighting its physicochemical, nutritional, and sensory characteristics. The results demonstrate the effectiveness of polymer-based composites in enhancing product stability and consumer acceptability.[9] Comparative analysis with alternative formulations provides insights into the advantages of the optimized composition.

The study also examines the interactions between the bioactive compounds present in bamboo extract and other ingredients. Bamboo-derived polyphenols contribute significantly to the antioxidant potential of the formulation, which plays a crucial role in preventing oxidative degradation and extending shelf life.[10] The incorporation of high-protein soybean flour and ragi further fortifies the formulation, ensuring an optimal balance of macronutrients.

Physicochemical Analysis

The formulated product was evaluated for moisture content, ash value, pH stability, and other physical properties to ensure consistency and long-term quality.[11] The analysis focused on:

- *Moisture content:* The optimized formulation exhibited a loss on drying of 14%, which falls within acceptable limits for enhanced shelf stability. Maintaining low moisture content helps prevent microbial growth and prolongs product usability.
- *Ash values:* Total ash (7.5%), acid-insoluble ash (1.05%), and water-soluble ash (2.5%) were measured to ensure purity and minimal contamination. These values confirm that the formulation remains within standard quality guidelines.[12]
- *pH stability:* The product maintained a pH level between 6.2 and 6.8, ensuring compatibility with human digestion and reducing the likelihood of rapid degradation.
- *Bulk density:* Measured to evaluate the compactness of the product, influencing packaging, transport, and consumer handling.
- *Water activity (Aw):* The product exhibited an Aw value of 0.55, which is below the threshold for bacterial growth, further enhancing its stability.[13]

Nutritional Analysis

The developed formulation demonstrated superior nutritional composition, ensuring optimal macronutrient and micronutrient balance for improved health benefits. The nutritional profile of the formulation was analyzed based on its protein, fat, carbohydrate, and mineral content:

- *Crude protein:* 9.8% - A crucial component for muscle repair, metabolic function, and immune system support.
- *Crude fat:* 14.35% - Provides essential fatty acids necessary for brain function, hormone production, and cellular integrity.
- *Carbohydrate content:* 64.71 kcal/100g - Serves as a primary energy source, supporting sustained physical and cognitive activities.[14]

- *Calcium content:* 140.58 mg/100g - Essential for bone health, muscle contractions, and nerve signaling.
- *Dietary fiber:* 3.5% - Improves digestion, regulates blood sugar levels, and promotes gut health.
- *Iron content:* 6.2 mg/100g - Plays a vital role in oxygen transport and energy metabolism.[15]
- *Vitamin B complex:* Significant amounts detected, supporting brain health, energy metabolism, and red blood cell formation.

The formulation's balanced macronutrient composition ensures an ideal mix of protein, fat, and carbohydrates to promote overall well-being. Additionally, the presence of essential micronutrients such as calcium, iron, and B vitamins enhances its functional food potential. The combination of plant-based and dairy-derived ingredients contributes to the high bioavailability of these nutrients, making this formulation an effective dietary supplement.

Sensory and Stability Studies

Sensory evaluation showed high scores for appearance, taste, and overall acceptability over six months. Microbiological stability testing confirmed the absence of microbial contamination, ensuring product safety. Sensory evaluation plays a crucial role in determining consumer acceptance of a nutraceutical product. The developed formulation underwent a detailed sensory analysis over six months, assessing key attributes such as appearance, texture, taste, aroma, and overall acceptability. [16] A structured sensory panel, consisting of trained evaluators and potential consumers, was employed to gather qualitative and quantitative data on sensory characteristics.

Sensory evaluation

The sensory panel evaluated the product using a 9-point hedonic scale, where scores ranged from 1 (extremely disliked) to 9 (extremely liked). The evaluation was conducted at regular intervals, specifically at baseline (0 months), 1 month, 3 months, and 6 months, to track any variations in sensory perception over time. The following attributes were analysed:

- *Appearance:* The colour and surface texture of the product remained visually appealing throughout the study. The golden-brown hue, derived from ragi and wheat, was stable, indicating no significant colour degradation.
- *Texture:* The product maintained its crispness and structural integrity, demonstrating minimal changes in hardness or softness. The homogenization and baking process ensured uniform texture distribution, contributing to a pleasant mouthfeel.[17]
- *Taste:* The formulation was well-received for its balanced flavor profile. The mild sweetness from dairy components, coupled with the nutty and earthy notes of ragi and soybean, contributed to an enjoyable taste. No off-Flavors were detected over the storage period.
- *Aroma:* The product's aroma, influenced by bamboo extract and dairy ingredients, remained consistent, with no signs of rancidity or undesirable Odors.[18]
- *Overall acceptability:* Sensory scores for overall acceptability ranged between 7.5 and 8.8 on the hedonic scale, reflecting a high level of consumer preference.

The results indicated that the product retained its desirable sensory attributes over six months, with no significant degradation in quality. This stability is essential for consumer satisfaction and market viability.

Microbiological stability

Ensuring microbiological safety is paramount for the commercial success of any nutraceutical formulation. The product underwent microbiological stability testing at 0, 1, 3, and 6 months to assess the presence of microbial contaminants. Standard microbiological assays were employed to evaluate the following parameters:

- *Total plate count (TPC):* TPC remained below the permissible limits throughout the study, indicating effective preservation and hygienic processing conditions.[19]

- *Yeast and mold count:* No detectable yeast or mold growth was observed, confirming that the moisture content and water activity were maintained at optimal levels.
- *Pathogenic bacteria testing:* The formulation was tested for the presence of Escherichia coli, Salmonella spp., and Staphylococcus aureus. Results confirmed the absence of these pathogens, ensuring product safety.[20]

The absence of microbial contamination over six months suggests that the applied processing and storage techniques effectively inhibited microbial growth, making the formulation safe for consumption.

Chemical stability

To assess chemical stability, key parameters such as pH, moisture content, and oxidative rancidity were monitored:

- *pH stability:* The pH values of the product ranged between 6.2 and 6.8, indicating minimal fluctuation. This stability ensures compatibility with human digestion and reduces the risk of rapid degradation.[21]
- *Moisture content:* The final product maintained a moisture content of 14%, which is within acceptable limits for shelf-stable food products. The low moisture level prevented microbial growth and ensured extended shelf life.
- *Oxidative rancidity:* The presence of antioxidants in bamboo extract contributed to lipid stability, preventing oxidation-related spoilage. Peroxide value and thiobarbituric acid reactive substances (TBARS) tests confirmed minimal lipid oxidation, reinforcing the product's chemical stability.[22]

Shelf-Life Estimation

Shelf-life estimation was performed under controlled storage conditions to simulate real-world environmental exposure.[23] The formulation was stored at ambient temperature (25±2°C) and monitored for physicochemical and microbiological stability. Results confirmed that the product remained nutritionally and organoleptically stable for at least six months, with no significant deterioration.

Based on monthly monitoring of key quality attributes, the formulation remained acceptable up to six months under ambient conditions. Hence, the shelf-life was estimated at six months. While advanced modeling was not applied, this estimate is grounded in observational stability and sensory thresholds.

CONCLUSION

This study successfully developed a nutraceutical formulation with enhanced nutritional benefits and stability. The combination of natural polymer composites from bamboo, ragi, wheat, soybean, and dairy products resulted in a functional food product suitable for consumer health. Future research may explore additional bioactive compounds for improved health benefits. Sensory evaluation was conducted to assess the overall consumer acceptability of the developed nutraceutical formulation over a six-month period. The study evaluated key attributes such as appearance, texture, taste, aroma, and overall palatability using a structured sensory panel. The formulation received consistently high scores across all categories, with minimal variations over time, indicating its sustained quality and consumer preference. In terms of stability, microbiological testing was performed at regular intervals to detect potential contamination. The results confirmed the absence of microbial growth, including pathogenic bacteria, Molds, and yeasts, ensuring product safety. Additionally, chemical stability studies assessed changes in pH, moisture content, and oxidative rancidity. The pH remained stable within the acceptable range, and the moisture content was controlled to prevent spoilage. Oxidative stability tests indicated that the presence of antioxidants in bamboo extract effectively prevented lipid oxidation, thereby maintaining product freshness. Furthermore, shelf-life estimation was conducted under controlled storage conditions, simulating real-world environments. Future studies may explore extended stability

assessments beyond six months to validate long-term storage viability. These findings suggest that the developed nutraceutical formulation is not only highly palatable but also microbiologically and chemically stable, making it a viable functional food product for commercial production.

REFERENCES

1. Vlaicu PA, Untea AE, Varzaru I, Saracila M, Oancea AG. Designing nutrition for health—Incorporating dietary by-products into poultry feeds to create functional foods with insights into health benefits, risks, bioactive compounds, food component functionality and safety regulations. Foods. 2023 Nov 1;12(21):4001.
2. Jhamb V, Swaminathan P. Role and importance of lactic acid bacteria in different Indian fermented foods. Biologia. 2023 Dec;78(12):3609-23.
3. Vashisht P, Sharma A, Awasti N, Wason S, Singh L, Sharma S, Charles AP, Sharma S, Gill A, Khattra AK. Comparative Review of Nutri-functional and Sensorial Properties, Health Benefits and Environmental Impact of Dairy (Bovine milk) and Plant-Based Milk (Soy, Almond, and Oat milk). Food and Humanity. 2024 Apr 12:100301.
4. Sergi R, Bellucci D, Cannillo V. A review of bioactive glass/natural polymer composites: State of the art. Materials. 2020 Dec 6;13(23):5560.
5. Tanwar R, Panghal A, Chaudhary G, Kumari A, Chhikara N. Nutritional, phytochemical and functional potential of sorghum: A review. Food Chemistry Advances. 2023 Oct 21:100501.
6. Saini P, Islam M, Das R, Shekhar S, Sinha AS, Prasad K. Wheat bran as potential source of dietary fiber: Prospects and challenges. Journal of Food Composition and Analysis. 2023 Mar 1;116:105030.
7. Noremylia MB, Aufa AN, Ismail Z, Hassan MZ. An overview of the potential usage of bamboo plants in medical field. Bamboo Science and Technology. 2023 Mar 15:55-66.
8. Premi M, Sharma V. Mixing and forming. InAgro-Processing and Food Engineering: Operational and Application Aspects 2022 Mar 23 (pp. 253-305). Singapore: Springer Singapore.
9. Dey N, Mohan M, Malarvizhi Dhaswini R, Roy A, Alam MM, Al-Sehemi AG, Govindarajan RK, Fazle Rabbee M, Sundaram T, Lackner M. Recent trends and advancements in the utilization of green composites and polymeric nanocarriers for enhancing food quality and sustainable processing. Green Processing and Synthesis. 2024 Dec 9;13(1):20240161.
10. Liu HC, Hsieh CY, Tsai PW, Chou TY, Yang SC, Chang CH, Huang YP, Chien CC, Lee SC, Shih HD, Liu YC. Development and Applications of Bambusa stenostachya Leaf Extract in Personal Care Products. Processes. 2025 Jan 15;13(1):233.
11. Awol SM, Kuyu CG, Bereka TY, Abamecha N. Physicochemical stability, microbial growth and sensory quality of refined wheat flour as affected by packaging materials during storage. Journal of Stored Products Research. 2024 Feb 1;105:102217.
12. Baste N, Gangurde H, Nemade C, Shahare H, Bihani M. Enhanced Bioavailability of Valsartan through Mucoadhesive Pellets Fabricated via Fluidized Bed Processor: A Novel Drug Delivery Approach. Ind. J. Pharm. Edu. Res. 2024;58(2s):s453-67.
13. Wei X, Lau SK, Chaves BD, Danao MG, Agarwal S, Subbiah J. Effect of water activity on the thermal inactivation kinetics of Salmonella in milk powders. Journal of Dairy Science. 2020 Aug 1;103(8):6904-17.
14. Rastello L, Gasco L, Lussiana C, Gerbelle M, Coppa M, Vernetti-Prot L, Galli A, Guidou C, Trespeuch C, Torsiello B, Renna M. Insect oil (Hermetia illucens) in dairy cow nutrition: effects on milk fatty acid profile. InCongress Proceedings-28th Congress of the European Society of Veterinary and Comparative Nutrition 2024 (pp. 141-141). Ilias Kyriazakis.
15. Akinbo D. *Ferric pyrophosphate fortified extruded rice increased iron status in rats* (Doctoral dissertation).
16. Ngume LS, Katalambula L, Munyogwa M, Mongi RJ. Sensory properties, preference mapping and shelf-life stability of linear programmed quelea meat based instant complementary food for children aged 6–23 months in Tanzania. Journal of Agriculture and Food Research. 2022 Dec 1; 10:100412.
17. Kutlu N, Pandiselvam R, Saka I, Kamiloglu A, Sahni P, Kothakota A. Impact of different microwave treatments on food texture. Journal of Texture Studies. 2022 Oct;53(6):709-36.

18. Hu MY, Zhao L, Sun HH, Xue Y, Mao XZ, Cao R. Recent advances on shrimp paste: key flavor components and biochemical formation pathway, biogenic amine formation, microbial functions, and innovative process strategies. Trends in Food Science & Technology. 2024 Aug 30:104694.
19. Ajay Gaikwad, Saurabh Swamy, Shivsagar Tewary, Pronob Kumar Sanyal, Shubha Joshi, Abhijeet Kore. Influence of Polymeric Materials on Osseointegration and Stability of Dental Implants: An In-vivo Resonance Frequency Analysis. Journal of Polymer and Composites. 2024; 13(01):1051-1057.
20. Naveena BM, Muthukumar M, Muthulakshmi L, Anjaneyulu AS, Kondaiah N. Effect of different cooking methods on lipid oxidation and microbial quality of vacuum-packaged emulsion products from chicken. Journal of food processing and preservation. 2014 Feb;38(1):39-47.
21. Aishwarya Digvijay Mohite, G.R. Pathade. Polymer Use in Soilless Farming Systems with A Comparative Study on Hydroponics and Aquaponics. Journal of Polymer and Composites. 2024; 13(01):868-874.
22. Nusrat N, Ahmad Zahra M, Ahmed A, Haque F. Assessment of potential pathogenic bacterial load and multidrug resistance in locally manufactured cosmetics commonly used in Dhaka metropolis. Scientific Reports. 2023 May 13;13(1):7787.
23. Shi C, Zhao Z, Jia Z, Hou M, Yang X, Ying X, Ji Z. Artificial neural network-based shelf life prediction approach in the food storage process: A review. Critical Reviews in Food Science and Nutrition. 2024 Dec 20;64(32):12009-24.

