Development and Quality Evaluation of Functional Cookies Fortified with Polysaccharide Powder Extracted from Tamarind (Tamarindus indica L.) Seeds

Pravin Chavan, K.S. Gadhe, P.U. Ghatge, Mohammed Ahmed Rayyan, Gunjan Sharma, Rohit Kondamgire

1. M.Tech, Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani
2. Head of Department, Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani
3. Assistant professor, Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani
4. M.Tech, Food Microbiology and Safety, College of Food Technology, VNMKV, Parbhani
5. M.Tech, Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani
6. M.Tech, Food Chemistry and Nutrition, College of Food Technology, VNMKV, Parbhani

Abstract

This study aimed to extract and characterize polysaccharide powder from tamarind (*Tamarindus indica* L.) seeds and evaluate its application in the development of functional cookies. The extraction was standardized using ethanol precipitation after cold water soaking and defatting, yielding 28.5% purified polysaccharide powder. Physicochemical analysis revealed that the extracted polysaccharide was rich in carbohydrates (74.5%) and protein (10.6%), with low fat (1.2%) and significant mineral content. Functional properties, including water absorption, solubility, and swelling index, were favorable for food application.

Cookies were formulated by partially replacing butter with tamarind seed polysaccharide powder (TSPP) at 20%, 25%, and 30% levels (TS1–TS3), while a control (T0) was maintained. The TS1 formulation showed the best sensory scores for appearance, texture, taste, and overall acceptability based on a 9-point hedonic scale. Physico-chemical evaluation of cookies indicated that TSPP increased diameter, spread ratio, and fiber content, while significantly

reducing fat (25.8% to 17.2%) and caloric value (581.4 to 500.8 kcal/100 g). The protein and mineral content also improved with increasing TSPP inclusion.

The study concludes that tamarind seed polysaccharide powder can be effectively utilized as a clean-label fat replacer and functional ingredient in cookies, offering improved nutritional value, acceptable sensory attributes, and reduced energy density. This novel approach promotes value addition to tamarind seed by-products and aligns with consumer demand for healthier bakery options.

Keywords

Tamarind seed polysaccharide powder, functional cookies, hydrocolloid, fat replacement, dietary fiber, sensory evaluation, techno-economic feasibility, clean-label food

Introduction

The growing interest in natural hydrocolloids and clean-label food ingredients has intensified the exploration of plant-based functional components, especially from agro-industrial by-products. Tamarind (*Tamarindus indica* L.), widely cultivated across India, produces significant quantities of seeds as a by-product during pulp extraction. These seeds, often underutilized, are rich in non-starch polysaccharides, primarily galactoxyloglucans, which possess thickening, stabilizing, and water-binding properties suitable for food applications.

The polysaccharide-rich endosperm of tamarind seeds has been studied for its potential as a natural hydrocolloid, showing functional properties comparable to commercial gums such as guar and xanthan (Bhattacharya et al., 1993). The Prathisthan variety of tamarind seeds, in particular, offers a high 1000-kernel weight (~690 g), moderate bulk density (~616 kg/m^3), and favorable flow characteristics (angle of repose: 32°), making it suitable for scalable processing and incorporation into food matrices.

Chemically, these seeds exhibit a carbohydrate-rich profile (62.5%) with appreciable levels of protein (13.3%), fat (6.5%), ash (3.8%), and crude fiber (5.6%), alongside essential minerals such as potassium (510 mg/100g), magnesium (248 mg/100g), calcium (145 mg/100g), and iron (15.5 mg/100g) (Adeleke et al., 2021; Singh et al., 2022). Extraction and characterization studies of tamarind seed polysaccharide powder have confirmed a high carbohydrate content (~74.5%), low fat (~1.2%), and dietary fiber (~2.4%) composition, suggesting its potential role as a fat replacer and fiber enhancer in bakery products (Gaur et al., 2019; Kumar & Prabhasankar, 2014).

Cookies, as popular ready-to-eat bakery items, serve as an ideal platform for the incorporation of functional ingredients. Substitution of conventional ingredients like butter or refined flour with tamarind seed polysaccharide powder can not only reduce fat content but also improve the protein, fiber, and mineral profile of the product. Prior research has demonstrated that hydrocolloids can modify cookie texture, spread, and moisture retention while maintaining sensory acceptability (Kumar et al., 2016; Chaudhary et al., 2023).

Hence, the present investigation was conducted to standardize the extraction process of polysaccharide powder from tamarind seeds, evaluate its physicochemical and functional properties, and assess its utilization in cookie formulation. The study also includes sensory evaluation, nutritional profiling, energy value estimation, and techno-economic feasibility to promote the sustainable utilization of tamarind seed by-products in health-oriented bakery applications.

2. Materials and Methods

2.1. Raw Materials

Tamarind seeds of the *Prathisthan* variety were procured from local markets in Maharashtra. All analytical-grade chemicals including petroleum ether, ethanol (95%), and standard reagents used in compositional analysis were sourced from certified suppliers. Common baking ingredients such as refined wheat flour (maida), sugar, butter, baking soda, ammonium bicarbonate, salt, and milk were used for cookie preparation.

2.2. Extraction of Polysaccharide Powder from Tamarind Seeds

The tamarind seeds were cleaned to remove debris and dried either in the sun or in an oven to reduce moisture. The dried seeds were dehulled to remove the seed coat, and the dehulled kernels were ground into coarse powder. This powder was defatted using petroleum ether to eliminate non-polar components and air-dried to remove residual solvent.

Cold extraction was carried out by soaking the defatted powder in distilled water at a 1:20 (w/v) ratio for 24 hours at room temperature (pH 7–8). The extract was filtered through muslin cloth, and polysaccharides were precipitated by adding chilled 95% ethanol (1:1 v/v) and storing the mixture at 4°C. The precipitate was collected either by centrifugation (5000 rpm, 20 minutes) or sedimentation overnight. The precipitate was washed 2–3 times with ethanol, dried in a vacuum oven at 45°C or air-dried, then ground to a fine powder and stored for further use.

2.3. Physical and Chemical Characterization of Tamarind Seeds and Extracted Powder

Physical properties such as 1000-kernel weight, bulk density, kernel volume, and angle of repose of raw tamarind seeds were measured using standard gravimetric and volumetric methods (Bhattacharya et al., 1993). The same properties (yield, true and bulk density, angle of repose) were also recorded for the extracted tamarind seed polysaccharide powder.

Chemical composition, including moisture, fat, carbohydrate, protein, ash, and crude fiber content, was analyzed using AOAC (2016) protocols. Micronutrient composition (Ca, P, K, Mg, Fe, Mn, Zn) was determined via standard titration and flame photometric methods (Singh et al., 2022).

2.4. Functional Properties of Polysaccharide Powder

The functional properties of the extracted powder, including solubility, swelling index, and water absorption capacity, were evaluated under varying soaking times (6–24 h) and extraction temperatures (35–65°C). Water absorption was measured by mixing known quantities of tamarind seed polysaccharide powder (TSPP) with water and recording the absorbed volume (Kumar & Prabhasankar, 2014).

2.5. Cookie Formulation and Preparation

Two sets of cookie formulations were developed:

- **Trial Formulation (T0–T3)**: TSPP partially replaced butter at levels of 12.5, 25, and 37.5 g.
- **Final Formulation (TS1–TS3)**: Optimized levels of TSPP (20–30 g) were used with reduced butter content.

All dry ingredients (maida, TSPP, baking soda, ammonium bicarbonate, salt) were sieved and mixed. In a separate bowl, butter and sugar were creamed. The dry mix and milk were combined with the creamed mixture to form a dough. The dough was shaped into cookies (20 g each), placed on greased trays, and baked at 160°C for 20 minutes. Cookies were cooled, packed in polyethylene bags, and stored at room temperature.

2.6. Physical and Chemical Evaluation of Cookies

The prepared cookies were analyzed for physical parameters—diameter, thickness, spread ratio, weight, and bake-loss—using vernier calipers and electronic weighing scales. Chemical composition (moisture, fat, carbohydrate, protein, ash, and crude fiber) was determined as per AOAC (2016).

2.7. Sensory Evaluation

Sensory attributes (appearance, color, texture, crispiness, taste, aftertaste, overall acceptability) were evaluated by a semi-trained panel of 10 judges using a 9-point Hedonic scale (9 = Like Extremely, 1 = Dislike Extremely). The evaluation focused on comparing control and TSPP-enriched cookie formulations.

2.8. Energy Value and Techno-Economic Analysis

Energy value was calculated using the Atwater conversion factors: Energy (kcal/100g) = (Fat × 9) + (Carbohydrate × 4) + (Protein × 4). Techno-economic feasibility was assessed by calculating the cost of raw materials, yield of the final product, and potential market viability based on cost per 100 g of cookies.

3. Results and Discussion

3.1. Standardization of Polysaccharide Powder Extraction from Tamarind Seeds

The optimized extraction method involved cleaning, dehulling, defatting, cold water soaking, ethanol precipitation, and vacuum drying. The process (detailed in Flowchart 1) yielded a consistent polysaccharide powder with a 28.5% yield from the *Prathisthan* variety. The efficiency and reproducibility of this method align with previous works (Bhattacharya et al., 1993) and confirm its suitability for pilot-scale application in functional food product development.

3.2. Physico-Chemical and Functional Properties of Extracted Polysaccharide Powder

3.2.1 Physical and Chemical Characteristics of Tamarind Seeds

As shown in Table 1, the 1000-kernel weight of *Prathisthan* tamarind seeds was 690 g, with a kernel volume of 480 mL and bulk density of 616 kg/m³. An angle of repose of 32° confirmed good flowability, making the seed powder ideal for processing and large-scale handling (Bhattacharya et al., 1993).

Table 1. Physical Properties of Tamarind Seeds (Prathisthan variety)

Parameter	**Value**
1000 Kernel Weight (g)	690
1000 Kernel Volume (ml)	480
Bulk Density (Kg/m³)	616
Angle of Repose (°)	32

Table 2 revealed the seed's composition: 62.5% carbohydrates and 13.3% protein indicated potential as a functional ingredient, while 8.2% moisture supported safe storage. The moderate fat (6.5%) and fiber (5.6%) contents contribute to flavor and textural attributes. These results are in line with Adeleke et al. (2021), highlighting the seed's value for polysaccharide extraction.

Table 2. Chemical Composition of Tamarind Seeds (Prathisthan variety)

Component (%)	**Value**
Moisture	8.2
Fat	6.5
Carbohydrate	62.5
Protein	13.3
Ash	3.8
Crude Fiber	5.6

3.2.2 Properties of Extracted Polysaccharide Powder

The extracted powder showed promising technological characteristics (Table 3): a yield of 28.5%, true density of 1.015 g/cm³, and good flow behavior with an angle of repose of 29.5°. The bulk density (0.651 g/cm³) indicated a porous structure suitable for rapid hydration—critical for cookie formulation (Gaur et al., 2019).

Table 3. Physical Characteristics of Tamarind Seed Polysaccharide Powder

Property	**Value**
Yield (%)	28.5
True Density (g/cm³)	1.015

Bulk Density (g/cm³)	0.651
Angle of Repose (°)	29.5

The chemical profile (Table 4) was rich in carbohydrates (74.5%), with moderate protein (10.6%) and low fat (1.2%), which ensures nutritional enhancement without increasing lipid content. The ash (1.605%) and crude fiber (2.4%) support functional and mineral enrichment (Singh et al., 2022).

Table 4. Chemical Composition of Tamarind Seed Polysaccharide Powder

Component (%)	**Value**
Moisture	8.10
Fat	1.2
Carbohydrate	74.5
Protein	10.6
Ash	1.605
Crude Fiber	2.4

3.2.3 Mineral Composition

The mineral composition of seeds (Table 5) and the extracted powder (Table 6) confirmed the presence of calcium, phosphorus, potassium, magnesium, and trace elements like iron, manganese, and zinc. These values enhance the nutritional profile of food products and align with Singh et al. (2022).

Table 5. Micronutrient Composition of Tamarind Seeds (Prathisthan variety)

Mineral	**Value (mg/100g)**
Calcium (Ca)	145
Phosphorus (P)	170
Potassium (K)	510
Magnesium (Mg)	248

Mineral	**Value (mg/100g)**
Iron (Fe)	15.5
Manganese (Mn)	3.6
Zinc (Zn)	6.9

Table 6. Micronutrient Composition of Tamarind Seed Polysaccharide Powder

3.2.4 Functional Properties

Mineral	**Value (mg/100g)**
Calcium (Ca)	120.50
Phosphorus (P)	140.00
Potassium (K)	240.80
Magnesium (Mg)	102.60
Iron (Fe)	3.80
Manganese (Mn)	1.52
Zinc (Zn)	1.05

Extraction conditions significantly influenced yield, solubility, and swelling index (Table 7). Increasing soaking time and temperature (up to 18 h, 55°C) maximized yield (20.57%), solubility (87.6%), and swelling (3.51 mL/g), consistent with polymer hydration theory and previous tamarind gum studies.

Table 7. Effect of Soaking Time and Extraction on Functional Properties

Soaking Time (hr)	**Extraction Temp (°C)**	**Yield (%)**	**Solubility (%)**	**Swelling Index (mL/g)**
6	35	14.5	48.50	1.95
12	45	17.4	72.20	2.86
18	55	20.57	87.60	3.51
24	65	22.6	82.80	4.11

Water absorption increased proportionally with added polysaccharide powder (Table 8), reaching 168.75 mL for 37.5 g TSPP, indicating strong water-holding capacity. This aligns with Kumar & Prabhasankar (2014), affirming TSPP's potential in baked goods to enhance moisture retention and structure.

Table 8. Water Absorption Capacity of Tamarind Seed Polysaccharide Powder

Sample	**TSPP Added (g)**	**Water Absorbed (ml)**
T1	12.5	56.25
T2	25.0	112.50
T3	37.5	168.75

3.3. Utilization of Extracted Polysaccharide Powder in Cookies and Sensory Evaluation

Two sets of formulations were evaluated. Final formulations (TS1–TS3) balanced TSPP inclusion and butter reduction to enhance nutritional quality.

Table 9 and **Table 10** show that butter was progressively replaced by 20–30 g TSPP while adjusting milk volume to maintain dough consistency. Flowchart 2 details the cookie preparation process.

Table 9. Cookie Formulation – Initial Trial

Ingredient	**T0**	**T1**	**T2**	**T3**
Maida (g)	100	100	100	100
Sugar (g)	55	55	55	55
Butter (g)	50	37.5	25	12.5
TSPP (g)	–	12.5	25	37.5
Baking Soda (g)	1.5	1.5	1.5	1.5

Ingredient	T0	T1	T2	T3
Ammonium Bicarbonate (g)	1.5	1.5	1.5	1.5
Salt (g)	0.5	0.5	0.5	0.5
Milk (ml)	30	40	50	60

Table 10. Cookie Formulation – Final (TS1–TS3)

Ingredient	T0	TS1	TS2	TS3
Maida (g)	100	100	100	100
Sugar (g)	55	55	55	55
Butter (g)	50	30	25	20
TSPP (g)	–	20	25	30
Baking Soda (g)	1.5	1.5	1.5	1.5
Ammonium Bicarbonate (g)	1.5	1.5	1.5	1.5
Salt (g)	0.5	0.5	0.5	0.5
Milk (ml)	30	45	50	55

Sensory evaluation (Table 15) showed TS1 (20 g TSPP) scored highest in appearance, texture, crispiness, and taste. Overuse of TSPP (TS2, TS3) led to flavor masking and slight chewiness. Thus, TS1 achieved optimal balance between sensory acceptability and nutritional enhancement, as supported by Kumar et al. (2016) and Rajeswari et al. (2022).

3.4. Physico-Chemical and Microbial Properties of Prepared Cookies

3.4.1 Physical Properties

Trial results (Table 11) showed that increasing TSPP content led to wider cookies (diameter from 11.04 to 13.20 cm) and higher spread ratio (1.84 to 2.10). This is attributed to increased water binding and release during baking. Final formulation results (Table 12) confirmed 50–60% TSPP inclusion provided desirable spread and shape with moderate bake-loss, consistent with Sharma & Prasad (2023) and Kumari et al. (2022).

Table 11. Physical Properties of Cookies – Trial 1

Sample	TSPP (%)	Diameter (cm)	Thickness (cm)	Spread Ratio	Weight (g)	Weight Loss (%)
T0	0	11.04	6.00	1.84	35.92	6.11
T1	25	11.30	6.10	1.85	34.80	9.20
T2	50	12.60	6.20	2.03	32.58	16.13
T3	75	13.20	6.30	2.10	31.50	

Table 12. Physical Properties of Cookies – Final

Sample	TSPP (%)	Diameter (cm)	Thickness (cm)	Spread Ratio	Weight (g)	Weight Loss (%)
T0	0	11.04	6.00	1.84	35.92	6.11
TS1	40	12.00	6.15	1.95	33.20	12.80
TS2	50	12.60	6.20	2.03	32.58	16.13
TS3	60	12.80	6.25	2.05	31.90	

3.4.2 Chemical Composition

The TSPP inclusion significantly reduced fat content (from 25.8% to 11.3%) and increased protein (6.8% to 9.5%), ash (0.5% to 1.3%), and fiber (0.24% to 2.3%) in cookies (Tables 13 and 14). Moisture increased due to higher milk addition and hydrocolloid water retention. These nutritional shifts are consistent with findings of Chaudhary et al. (2023), Daramola & Osanyinlusi (2018), and Rajeswari et al. (2022), supporting the functional enrichment potential of TSPP.

Table 13. Chemical Composition of Cookies – Trial 1

Parameter (%)	T0	T1	T2	T3
Moisture	8.1	8.6	9.2	9.8
Fat	25.8	20.1	13.7	8.4
Carbohydrate	80.5	78.9	77.4	75.8
Protein	6.8	7.5	8.4	9.2
Ash	0.5	0.7	0.9	1.1
Crude Fiber	0.24	0.65	1.45	2.40

Table 14. Chemical Composition of Cookies – Final

Parameter (%)	T0	TS1	TS2	TS3
Moisture	8.1	8.9	9.4	9.9
Fat	25.8	17.2	14.5	11.3
Carbohydrate	80.5	78.4	76.9	75.1
Protein	6.8	8.1	8.7	9.5
Ash	0.5	0.9	1.1	1.3
Crude Fiber	0.24	1.2	1.8	2.3

3.5. Energy Value and Techno-Economic Feasibility

The energy content of cookies reduced significantly with TSPP inclusion (Table 16 & 17). TS1 showed a 13.9% decrease in caloric value (from 581.4 to 500.8 kcal/100 g) due to lower fat content, while protein increased. This trend aligns with Chaudhary et al. (2023) and Rathod & Annapure (2017), highlighting the use of hydrocolloids to develop lower-calorie, high-fiber bakery products.

Table 16. Energy Value of Cookies (Based on Atwater Factors)

Sample	Fat (%)	Carb (%)	Protein (%)	Energy (kcal/100g)
T0	25.8	80.5	6.8	581.4
TS1	17.2	78.4	8.1	500.8

Table 17. Theoretical Energy Value of Cookies

Sample	Energy (kcal/100g)
T0	581.4
TS1	500.8

The economic feasibility is further supported by reduced reliance on costly fat sources (butter) and improved nutritional output per unit cost, making the formulation practical for commercial scale-up.

Conclusion

The current research demonstrated that tamarind seed polysaccharide powder (TSPP), extracted through an optimized aqueous-ethanol process, possesses favorable functional and nutritional properties suitable for bakery applications. Incorporating TSPP in cookie formulations significantly improved the nutritional profile by enhancing protein, ash, and fiber content, while effectively reducing fat and caloric values. Sensory evaluation confirmed that cookies with 20% TSPP (TS1) were the most acceptable, maintaining desirable appearance, texture, and taste. Additionally, the energy value of the TSPP-enriched cookies decreased by 13.9%, offering a health-conscious alternative to traditional high-fat cookies.

The results validate the potential of TSPP as a sustainable, low-cost, and clean-label ingredient for developing functional bakery products. Utilization of tamarind seed by-products not only enhances the nutritional value of cookies but also supports waste minimization and value addition in agro-processing. The techno-economic feasibility and nutritional benefits suggest a promising avenue for commercial bakery industries aiming to meet the rising consumer demand for healthy, fiber-rich, and low-fat snacks

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