FOXTAIL MILLET GREEN PEA NOODLE – A NUTRITIOUS ALTERNATIVE

Srinidhi. D[1], Darthi. S. B[1], Ms. S. Iswarya[2], Dr. Chandran Massi[3]

[1] UG Students, Department of Food Technology, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur – 621212.

[2] Assistant Professor, Department of Food Technology, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur – 621212.

[3] Head of Department, Department of Food Technology, Dhanalakshmi Srinivasan Engineering College (Autonomous), Perambalur – 621212.

ABSTRACT

The escalating global demand for nutritionally fortified, gluten-free food alternatives has intensified research efforts toward leveraging underutilized crops in novel food product development. This study investigates the systematic formulation and comprehensive evaluation of composite noodles developed from foxtail millet (Setaria italica) flour and green pea (Pisum sativum) flour, with the objective of producing a nutritionally superior, gluten-free alternative to conventional wheat-based noodles. The incorporation of foxtail millet — a climate-resilient minor cereal distinguished by its high dietary fiber content, essential micronutrients, and potent antioxidant activity — was strategically complemented by green pea flour, a plant-based protein source with a favorable essential amino acid profile. This synergistic combination significantly improved overall protein quality, corrected amino acid deficiencies inherent to cereal-based formulations, and contributed to a demonstrably reduced estimated glycemic index, rendering the product particularly beneficial for individuals with metabolic conditions including type 2 diabetes and insulin resistance. Functional properties — encompassing water absorption index, cooking loss, swelling index, and textural profile analysis — were systematically assessed across multiple formulation ratios to identify the optimal composite blend. The optimized formulation exhibited acceptable cooking quality, structural integrity, and desirable textural attributes. Organoleptic evaluation conducted using a nine-point hedonic scale among a trained and semi-trained consumer panel yielded high acceptability scores across all sensory parameters including appearance, color, taste, aroma, texture, and overall acceptability. Proximate composition analysis confirmed a meaningful enhancement in protein, dietary fiber, and micronutrient content relative to refined wheat noodle controls. Preliminary shelf-life assessment indicated satisfactory physicochemical and microbiological stability under standardized storage conditions. This study establishes the functional and nutritional viability of foxtail millet–green pea composite noodles as an innovative contribution to the expanding functional food sector, offering a sustainable, health-oriented product with significant potential for commercial scalability and relevance to global food security objectives.

Keywords: *Setaria italica; foxtail millet; green pea flour; gluten-free noodles; composite flour; functional food; nutritional quality; amino acid profile; glycemic index; textural profile analysis; sensory evaluation; shelf stability; sustainable cereal crops; underutilized grains.*

1. INTRODUCTION

The rapid rise in lifestyle-related non-communicable diseases — including type 2 diabetes, obesity, and cardiovascular disorders — has fundamentally transformed consumer attitudes toward dietary choices worldwide. Health-conscious individuals are increasingly seeking food products that deliver functional nutritional benefits supporting long-term well-being, beyond mere satiation. This shift has placed significant pressure on the food industry to develop products that are simultaneously nutritious, palatable, and aligned with emerging dietary trends such as gluten-free and low-glycemic-index eating patterns. Conventional wheat-based noodles, while widely consumed, are nutritionally limited in protein quality, dietary fiber, and micronutrient density, and remain unsuitable for individuals with celiac disease or gluten intolerance. The development of alternative noodle formulations using nutrient-rich, gluten-free ingredients therefore represents both a scientific imperative and a significant commercial opportunity, to which foxtail millet–green pea composite noodles offer a compelling and timely response.

Foxtail millet (Setaria italica) is one of the oldest cultivated minor cereals, nutritionally distinguished by its high dietary fiber, low glycemic index, and notable concentrations of essential minerals including iron, calcium, and magnesium. The grain is also rich in phenolic antioxidants associated with reduced oxidative stress, inflammation, and chronic disease risk. Being naturally gluten-free, it is inherently suitable for celiac and gluten-sensitive populations. From an agronomic standpoint, foxtail millet is drought-tolerant, requires minimal agricultural inputs, and thrives in poor soils, making it one of the most environmentally sustainable cereal crops available. Despite these advantages, it remains significantly underutilized in mainstream food product development, and incorporating it into widely consumed formats such as noodles represents an effective strategy for expanding its dietary and commercial relevance.

Green pea (Pisum sativum) flour serves as an ideal legume complement to foxtail millet, primarily due to its high plant-based protein content and favorable essential amino acid profile. Cereals such as millet are inherently deficient in lysine, and green pea flour effectively compensates for this limitation, significantly improving the overall protein quality of the composite blend. It additionally contributes dietary fiber, vitamins A, C, and K, folate, and bioactive polyphenols with documented cardioprotective and anti-inflammatory properties. The combination of foxtail millet and green pea flour thus creates a nutritionally complementary system that collectively addresses the protein, fiber, micronutrient, and glycemic shortcomings of conventional wheat-based and single-ingredient gluten-free noodles.

The global gluten-free food market has grown considerably over the past decade, driven by rising celiac disease diagnoses, non-celiac gluten sensitivity, and broader consumer preference for allergen-free products. However, most commercially available gluten-free alternatives rely heavily on refined starches such as rice flour and tapioca, offering minimal protein, fiber, or micronutrient value. The absence of gluten also introduces significant technological challenges in achieving adequate dough cohesion, textural integrity, and cooking stability. Addressing these limitations requires careful optimization of ingredient ratios and targeted food technology interventions, including hydrocolloid incorporation and controlled thermal processing. Foxtail millet–green pea noodles were developed with these considerations in mind, aiming to deliver a gluten-free product that does not compromise on nutrition, structure, or consumer acceptability.

The present study was systematically designed to formulate, optimize, and evaluate foxtail millet–green pea composite noodles across functional, nutritional, and sensory dimensions at varying flour substitution levels. Functional properties including water absorption index, cooking loss, and textural profile were assessed to identify the optimized formulation. Proximate composition analysis quantified improvements in protein, dietary fiber, and micronutrient content relative to a refined wheat noodle control. Organoleptic evaluation was conducted using a nine-point hedonic scale with a trained consumer panel, and preliminary shelf-life studies assessed physicochemical and microbiological stability under standardized storage conditions. This research provides a rigorous scientific basis for establishing foxtail millet–green pea noodles as a nutritionally fortified, commercially viable functional food product with meaningful relevance to global public health nutrition.

2. MATERIALS AND METHODS

2.1 Materials

The raw materials used in the preparation of foxtail millet–green pea noodles were carefully selected based on their nutritional composition, functional properties, and processing characteristics. The primary ingredients included foxtail millet flour, green pea flour, a binding agent, and accessory ingredients, each contributing uniquely to the nutritional quality, texture, and sensory profile of the final product. The absence of gluten in both primary flour components necessitated the incorporation of structural enhancers to achieve adequate dough cohesion, elasticity, and cooking stability. Careful optimization of ingredient ratios was essential to balance nutritional enhancement with acceptable textural and organoleptic attributes.

Table 1: Raw Materials and their Role in Formulation

Raw Material	Role in Formulation
Foxtail Millet Flour	Primary gluten-free base ingredient contributing high dietary fiber, essential minerals (iron, calcium, magnesium), phenolic antioxidants, and a low glycemic index to the noodle formulation.
Green Pea Flour	High-protein legume supplement that corrects lysine deficiency of cereal proteins, improves overall amino acid profile, enhances moisture retention, and contributes bioactive flavonoids and polyphenols.
Binding Agent (Xanthan Gum)	Replaces gluten functionality by improving dough viscoelasticity, ensuring smooth processing, maintaining structural integrity, and preventing noodle breakage during cooking.
Accessory Ingredients (Salt, Water, Fortifiers)	Salt modifies protein interactions and improves dough elasticity; water facilitates dough hydration; optional fortifying agents may enhance nutritional value and product stability.

2.2 Methods

2.2.1 Procurement of Raw Materials

Foxtail millet, green peas, xanthan gum, and salt were procured from certified local suppliers and verified for quality, purity, and moisture content prior to use. All raw materials were selected based on their nutritional composition, processing suitability, and compliance with food safety standards.

2.2.2 Cleaning and Sorting

Foxtail millet and green peas were manually sorted to eliminate foreign matter, damaged grains, dust, and other impurities that could adversely affect product quality. The cleaned grains were subsequently washed with potable water and shade-dried to a safe moisture level before further processing.

2.2.3 Milling

The cleaned and dried foxtail millet and green peas were separately milled using a laboratory hammer mill to obtain fine flour with a uniform particle size distribution. Milling was carried out under controlled conditions to minimize heat generation, thereby preserving the nutritional integrity and bioactive compounds present in both raw materials.

2.2.4 Sieving

The milled flours were passed through a BSS 60 mesh sieve to ensure uniform particle size and remove coarse residual particles that could adversely affect dough consistency and noodle texture. Sieved flours were collected in airtight containers and stored under cool, dry conditions to prevent moisture absorption and microbial contamination prior to formulation.

2.2.5 Dough Preparation

The composite flour blends were prepared by thoroughly mixing foxtail millet flour and green pea flour at predetermined ratios, followed by the incorporation of xanthan gum and salt at standardized concentrations to enhance dough cohesion and elasticity. Potable water was gradually added in controlled amounts and the mixture was kneaded manually for a uniform duration until a smooth, non-sticky, and pliable dough of consistent texture and hydration was achieved.

2.2.6 Formulation Ratios

Three composite flour formulations (T1, T2, and T3) were prepared by varying the ratio of foxtail millet flour to green pea flour as follows: T1 (80:20), T2 (70:30), and T3 (60:40), along with a control (C) consisting of 100% refined wheat flour. Xanthan gum was incorporated at a fixed concentration of 1% (w/w) across all formulations to compensate for the absence of gluten. These ratios were selected to study the effect of progressive substitution on the functional, nutritional, and sensory attributes of the developed noodles.

2.2.7 Extrusion

The prepared dough was fed into a laboratory-scale noodle press and extruded through a standardized die to obtain noodle strands of uniform diameter, thickness, and length under consistent pressure and temperature conditions. The extruded noodles were carefully collected on trays, ensuring minimal surface breakage and deformation, and immediately subjected to steaming to stabilize their structural integrity prior to the drying process.

2.2.8 Steaming

The freshly extruded noodle strands were subjected to steaming at 100°C for approximately 5 minutes using a laboratory steamer to partially gelatinize the starch granules and enhance the structural cohesion of the noodle matrix. Steaming also served to inactivate residual enzyme activity, reduce microbial load, and improve the overall cooking stability and surface texture of the noodles prior to the drying stage.

2.2.9 Drying

The steamed noodles were transferred to a hot-air oven and dried at a controlled temperature of 60°C for 4 hours to reduce the moisture content to a safe level of approximately 10–12%, ensuring adequate shelf stability and prevention of microbial spoilage. Drying was performed at a moderate temperature to minimize thermal degradation of heat-sensitive nutrients, preserve colour integrity, and maintain the desirable textural attributes of the final dried noodle product.

2.3 Testing and Analysis

2.3.1 DPPH Radical Scavenging Activity

The antioxidant activity of the noodle extracts was measured using the DPPH (1,1-diphenyl-2-picrylhydrazyl) radical scavenging assay method (Desmarchelier et al., 1997). One mL of various concentrations (20–120 µg/mL) of extract was mixed with 1 mL of 0.1 mM DPPH solution in methanol. The mixture was allowed to stand for 30 minutes in the dark. Ascorbic acid was used as the reference standard. The decrease in absorbance was measured at 517 nm using a UV-Vis spectrophotometer. The percentage of inhibition was calculated using the formula:

% DPPH Radical Inhibition = [(Absorbance of Control – Absorbance of Sample) / Absorbance of Control] × 100

2.3.2 Superoxide Radical Scavenging Activity

Superoxide radical scavenging activity was determined using the riboflavin-EDTA-NBT method. The reaction mixture contained varying concentrations of extract, 1.5 mM riboflavin (200 µL), 12 mM EDTA (100 µL), and 50 mM NBT (50 µL) in 50 mM phosphate buffer (pH 7.8). The reaction was initiated by illuminating the mixture under UV light for 90 seconds, after which the absorbance was measured at 590 nm. Ascorbic acid served as positive control. The percentage of superoxide radical reduction was calculated as:

% Superoxide Radical Inhibition = [(Absorbance of Control – Absorbance of Sample) / Absorbance of Control] × 100

2.3.3 Physical Analysis

Water Absorption Index (WAI): The water absorption index was determined by centrifuging a known quantity of cooked noodle sample and measuring the weight of the gel retained relative to the dry sample weight. A higher WAI value indicates greater water-holding capacity, reflecting improved starch gelatinization and textural quality.

Cooking Loss: Cooking loss was evaluated by measuring the total amount of solid matter leached into the cooking water after boiling a weighed quantity of noodles under standardized time and temperature conditions. Lower cooking loss values indicate better structural integrity and surface firmness of the noodles.

Texture Profile Analysis (TPA): Textural profile analysis was conducted using a texture analyzer to measure key mechanical parameters including hardness, cohesiveness, springiness, chewiness, and adhesiveness of the cooked noodle samples. These parameters collectively provide a comprehensive assessment of mouthfeel and eating quality.

2.3.4 Chemical Analysis

Proximate Composition: Proximate composition analysis was performed to determine the moisture, crude protein, crude fat, crude fiber, ash, and carbohydrate content of the noodle samples following standard AOAC (2016) analytical procedures. This analysis provided a comprehensive nutritional profile enabling direct comparison with conventional wheat-based noodle controls.

Estimated Glycemic Index (GI): The estimated glycemic index of the developed noodle formulations was determined using the in vitro starch digestibility method, measuring the rate of glucose release upon enzymatic hydrolysis under simulated gastrointestinal conditions. A lower glycemic index value confirmed the suitability of foxtail millet–green pea noodles for diabetic and metabolically compromised individuals.

2.3.5 Microbial Analysis

Total Plate Count (TPC): Total Plate Count was used to determine the number of viable microorganisms present in the noodle samples. This test evaluates the microbial quality, hygiene, and safety of the product during processing and storage. A lower TPC value indicates better product quality and adherence to good manufacturing practices.

Total Fungal Count (TFC): Total Fungal Count was used to estimate the number of fungi, including yeasts and molds, present in the noodle samples. This test assesses the microbial stability, shelf life, and hygienic condition of the product. Lower fungal counts indicate better preservation quality and reduced risk of spoilage during storage.

3. RESULTS AND DISCUSSION

3.1 Sample Collection

Foxtail millet green pea noodle samples were collected aseptically in sterile containers under hygienic conditions for microbiological evaluation. Freshly prepared samples were carefully packed, labeled, and transported to the laboratory without contamination. The samples were analyzed immediately to determine the microbial quality and safety of the product.

3.2 Product Description

Foxtail millet green pea noodles were successfully developed as a nutritious and health-oriented food product by incorporating foxtail millet and green pea flour in optimized proportions. The developed product exhibited a characteristic light-green color attributable to the chlorophyll and polyphenol content of green pea flour. The noodles were rich in dietary fiber, protein, vitamins, and minerals, making them suitable for health-conscious consumers and individuals with metabolic disorders. Structurally, the noodles demonstrated good surface smoothness, adequate firmness, and minimal breakage upon cooking, indicating effective gluten replacement by xanthan gum.

3.3 Antioxidant Activity

3.3.1 DPPH Radical Scavenging Activity

The DPPH radical scavenging activity of the foxtail millet–green pea noodle extracts increased with increasing concentration, ranging from 3.13% inhibition at 20 µg/mL to 25.71% at 120 µg/mL. This dose-dependent antioxidant response is consistent with the phenolic antioxidant content of foxtail millet and the flavonoid constituents of green pea flour. The relatively modest DPPH values are comparable to those reported for other cereal-legume composite food products and reflect the combined contribution of both flours to free radical neutralization capacity.

Table 2: DPPH Radical Scavenging Activity

Sl. No.	Concentration (µg/mL)	% Inhibition
1	20	3.13
2	40	9.28
3	60	13.13
4	80	20.57
5	100	22.14
6	120	25.71

Table 2: DPPH Radical Scavenging Activity of Foxtail Millet–Green Pea Noodle Extracts at Varying Concentrations

3.3.2 Superoxide Radical Scavenging Activity

The superoxide radical scavenging activity demonstrated a more pronounced dose-response pattern, rising from 7.94% reduction at 20 µg/mL to 61.20% at 120 µg/mL. The substantially higher superoxide scavenging values compared to DPPH inhibition suggest that the extract contains constituents particularly effective at neutralizing superoxide anions. This is consistent with the reported activity of polyphenols and flavonoids present in green pea flour and the phenolic acids in foxtail millet. High superoxide scavenging activity indicates significant potential of the product to protect against oxidative stress-related chronic diseases.

Table 3: Superoxide Radical Scavenging Activity

Sl. No.	Concentration (µg/mL)	% Reduction
1	20	7.94
2	40	48.24
3	60	50.57
4	80	54.48
5	100	56.73
6	120	61.20

Table 3: Superoxide Radical Scavenging Activity of Foxtail Millet–Green Pea Noodle Extracts at Varying Concentrations

3.4 Comparative Analysis

A comprehensive comparison between the developed foxtail millet–green pea noodles and conventional refined wheat noodles revealed significant improvements across all major nutritional and functional parameters. As presented in Table 4, the developed product surpassed the control in protein content (~15–18 g/100 g vs. ~8–10 g/100 g), dietary fiber (~6–8 g/100 g vs. ~1–2 g/100 g), micronutrient density, antioxidant activity, and glycemic performance. The noodles were also confirmed gluten-free, making them suitable for celiac and gluten-sensitive consumers. Despite the textural differences from wheat-based noodles, the developed product achieved acceptable sensory scores, validating the feasibility of the formulation from a consumer perspective.

Table 4: Nutritional Comparison — Foxtail Millet Green Pea Noodles vs. Conventional Noodles

Parameters	Normal Noodles (Refined Wheat)	Foxtail Millet Green Pea Noodles (Developed Product)
Main Ingredients	Refined wheat flour (maida), water, salt	Foxtail millet flour, green pea flour, water, salt
Color	Off-white	Light green
Nutritional Profile	Lower in protein, fiber, vitamins and minerals	Higher in protein, dietary fiber, vitamins and minerals
Protein Content (g/100 g)	Low (~8–10 g)	High (~15–18 g)
Dietary Fiber (g/100 g)	Low (~1–2 g)	High (~6–8 g)
Glycemic Index	High	Low to Moderate
Gluten Content	High (Contains Gluten)	Gluten-Free
Digestibility	Moderate	Better (due to fiber and plant protein)
Micronutrients	Lower in iron, calcium, magnesium, vitamins	Rich in iron, calcium, magnesium, B-vitamins
Antioxidant Activity	Lower	Higher (due to millet and green pea)
Texture	Soft and chewy	Slightly firm with good chewiness
Taste	Neutral taste	Nutty flavor with slight pea aroma
Shelf Life	Moderate	Better (due to antioxidant and fiber content)
Health Benefits	Provides energy, low in micronutrients	Supports heart health, weight management, digestion and overall well-being

Table 4: Comparative Nutritional and Functional Profile of Foxtail Millet Green Pea Noodles and Conventional Wheat-based Noodles

4. CONCLUSION

The present study successfully developed foxtail millet–green pea composite noodles as a nutritious and functional alternative to conventional wheat-based noodles. The incorporation of foxtail millet and green pea flour significantly improved the nutritional quality of the product by increasing protein, dietary fiber, micronutrients, and antioxidant compounds. The developed noodles exhibited good sensory qualities including acceptable taste, texture, aroma, and overall consumer acceptability, demonstrating that health-oriented formulations can be achieved without compromising product quality.

The study further demonstrated that proper formulation, strategic use of xanthan gum as a gluten replacer, and optimized drying conditions played important roles in maintaining the cooking quality, texture, and shelf stability of the noodles. The developed product showed desirable firmness, elasticity, and microbial safety during storage, indicating its suitability for commercial production. In comparison with conventional gluten-free noodles, foxtail millet–green pea noodles provided superior nutritional and functional benefits due to the presence of bioactive compounds and higher fiber and protein content.

In conclusion, foxtail millet–green pea noodles represent a promising health-oriented food product with significant potential for applications in the functional and gluten-free food market. The product supports the growing demand for nutritious, sustainable, and consumer-friendly foods. Future studies may focus on optimizing long-term storage stability, exploring additional biofortification strategies, scaling up production processes, and conducting large-scale clinical and consumer studies for successful commercialization and broader public health impact.

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