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Next-Generation Pasta: Trends and Challenges in Plant-Based and Protein-Enriched Formulation

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Abstract

The high demand for healthier food is contributing to the innovation in pasta formulations, traditionally based on durum wheat semolina. In this context, recent reformulation has focused on the addition of plant-based and protein-rich ingredients, such as legumes, pseudocereals, fish protein, and dietary fiber, to enhance nutritional value and functional properties of pasta product. The reformulations cause an increase in protein, fiber content, amino acid, antioxidant capacity, glycemic control, and prebiotic activity. However, ingredient substitutions pose technological challenges, including changes in texture and high losses during the cooking process. Therefore, this study aims to optimize functional pasta product and address technological challenges by applying different processing methods such as fermentation, extrusion, and enzymatic treatments. The results showed that pasta fortification provided substantial nutritional benefits, although the impact on sensory characteristics posed a significant concern. This was because physicochemical properties of functional ingredients could alter the texture, color, and flavor of product, directly impacting consumer acceptance.

Keywords: plant-based pasta, protein enrichment, functional food, sensory evaluation, pasta reformulation

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INTRODUCTION

Pasta is one of the most widely consumed foods globally due to adaptability, durability, and compatibility with a wide variety of dishes. Typically, traditional pasta is made from durum wheat semolina, a coarse and high-gluten flour that produces a dense texture and characteristic yellow color. This formulation has remained largely consistent for decades and is part of traditional diets in many Mediterranean and European countries. However, with growing concerns about chronic disease, food sustainability, and functional nutrition, traditional pasta is facing increasing scrutiny. The development in recent years has caused a transition in consumer trends toward healthier, more nutrient-rich, and sustainable food options (Dixon et al., 2023). The rising trend of lifestyle-related diseases, including obesity, cardiovascular, and type 2 diabetes, has driven consumer to search food product with higher nutritional quality and a lower glycemic index (Mozaffarian, 2016). The sustainability movement has also driven interest in reducing reliance on traditional wheat cultivation because of high input requirements and environmental impact (Kheiralipour et al., 2024). Therefore, pasta is identified as a strategic target for reformulation due to health and sustainability concerns.

Several efforts have been carried out to reformulate pasta and fulfill modern nutritional needs as well as environmental standards using various protein-rich plant-based ingredients. Plant-based pasta refers to formulations that use ingredients from botanical sources, such as legumes (lentils and chickpeas), pseudocereals (quinoa and amaranth), vegetables, and agro-industrial by-product. These ingredients offer an improved nutritional profile and contribute functional properties, including antioxidant activity and prebiotic effects (Olamiti & Ramashia, 2024; Paucar-Menacho et al., 2023a). In comparison, protein-enriched pasta emphasizes increasing protein content using sources such as soy, egg white, whey protein, and whole grain flours, which can significantly enhance the amino acid composition and satiety index of the final product (Kamble et al., 2019; Thomas et al., 2022). However, transforming traditional pasta into functional product has challenges. These include maintaining a balance between high nutritional content and sensory qualities, which determine consumer acceptance. Previous studies have shown that adding fermented red wine dregs to hamburger meat provides health benefits, causing a darker color, more acidic flavor, and reduced cooking yield (Pereira et al., 2022). Therefore, the addition or substitution of functional components requires formulation strategies to maintain the culinary characteristics of traditional pasta.

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Due to the importance of healthier and more sustainable food innovation, this study aims to review the available literature related to the development of pasta into functional food product. The results are expected to provide an overview of the development direction, potential, and challenges associated with the development of functional pasta.

LITERATURE REVIEW

History Of Pasta and the Evolution of Nutrition

Pasta plays an important role in global culinary traditions, particularly in Mediterranean cultures where it is identified as a staple food. Historically, the production has depended primarily on durum wheat semolina due to the unique texture and functional properties, which are attributed to high gluten content. Furthermore, the dense texture, yellow color, and desirable elasticity have been the culinary attractions for centuries (Kadkol & Sissons, 2016; Mercatante et al., 2025). Traditional milling still retains most of nutrients, but with the advent of industrial milling, many important components, such as bran and germ, have been lost and replaced by more durable refined flours (Mercatante et al., 2025).

Semolina-based pasta contains high levels of carbohydrates (typically 70–76%), with moderate protein (10–14%) and low fiber (2.9%), leading to a relatively high glycemic index and insufficient micronutrients (Gumul et al., 2023). These deficiencies have caused growing efforts for reformulation using alternative ingredients that fulfill current dietary demands. Technological innovations are increasingly driving pasta reformulation, where the replacement of semolina with whole wheat flour, pseudocereals, nuts, and vegetable powders show promise in improving nutritional profile and health-promoting properties (Demir & Bilgiçli, 2021; Kumar et al., 2024). Modern processing methods such as extrusion, fermentation, and thermal drying are being adapted to incorporate functional ingredients like inulin, dietary fiber, and protein isolates (Gumul et al., 2023). Despite nutritional benefits, these changes impact texture and flavor of traditional pasta, showing the need for optimization strategies to maintain culinary identity.

Technological Properties and Processing Effects

The use of non-traditional ingredients in pasta formulation has led to significant changes in the technological properties, particularly in terms of cooking quality, water absorption, texture, firmness, and rheological behavior. Furthermore, interactions in food matrix and the degree of ingredient substitution play a significant role in determining the structural performance of product. These technological dimensions influence product's

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physicochemical profile and consumer acceptance, playing an essential role in the success of pasta reformulation.

Table 1 shows several studies that explore the influence of various ingredients and processing methods on the technological properties of enriched pasta. Based on observation, most studies indicate a trade-off between nutritional enhancement and desirable texture attributes, such as firmness and cohesiveness. Lei et al. (2021) reported that the use of alternative flours rich in fiber tended to affect the integrity of the gluten-starch network, causing high cooking loss and hardness. Ray et al. (2023) also reported that the addition of quinoa seeds could increase cooking loss and hardness. According to A. S. Desai et al. (2019a), salmon-derived protein enhanced cooking quality and texture by increasing protein retention and reducing surface stickiness.

Table 1. Processing Technologies and Effects of Enriched Pasta

Ingredients	Processing Method	Parameter	Results	References
Insoluble dietary fiber (IDF) from wheat bran	Direct mixing	Cooking loss and firmness	Slightly increases cooking loss and hardness	(Lei et al., 2021)
Soybean pulp (okora)	Semolina substitution	Cooking quality	Decreases optimum cooking time and slightly increases hardness	(Kamble et al., 2019)
Amaranth flour	Direct mixing	Cooking loss, water absorption, and firmness	Slightly increases cooking loss as well as decreases water absorption and hardness.	(Martinez et al., 2014)

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Salmon	Semolina substitution	Texture and cooking quality	Improves protein retention and decreases stickiness	(A. S. Desai et al., 2019)
Quinoa germ	Direct mixing	Cooking quality and firmness	Increases cooking loss, cooking weight, and hardness	(Ray et al., 2023)
Cassava flour	Extrusion	Texture and firmness	Texture acceptance at 10% cassava flour	(Adetola et al., 2020)
Soy protein isolate and egg white	Blending	Cooking loss and texture	Decreases cooking loss and increases hardness and tensile strength	(Rachman et al., 2019)
Red bean flour	Rice flour substitution	Texture	Improves hardness, stickiness, and consistency	(Arribas et al., 2020a)

Water absorption and elasticity are other important indicators of technological functionality. Ramos et al. (2023) showed that dough fermentation with the enzyme transglutaminase could restructure gluten-starch interactions by increasing protein binding capacity, thereby improving pasta texture and hydration. Furthermore, increased water absorption can improve pasta swelling index. The addition of protein-rich ingredients also has a positive impact on technological performance. Rachman et al. (2019) reported that the addition of 15% soy protein isolate and egg white improved the textural characteristics of banana paste. However, excessive protein levels can inhibit hydration and expansion during cooking, requiring an optimal mixing ratio.

Processing methods, such as extrusion, have been shown to mitigate some of the side effects of fiber addition. Adetola et al. (2020) showed that adding 10% cassava peel

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flour made by extrusion could replace durum flour in pasta production. The observation supported previous reports, where extrusion enhanced gelatinization and matrix cohesion, leading to increased firmness and reduced breakage. Similarly, Arribas et al. (2020a) reported improvements in the hardness, stickiness, and consistency of red bean flour-based pasta.

Enzymatic and microbial interventions are further discussed in the literature as effective strategies for improving technological outcomes. Proteolytic enzymes and lactic acid bacteria have been shown to modulate protein structure, thereby improving elasticity and cooking resistance (Ramos et al., 2023). This suggests that fermentation and enzymatic treatments can be used to correct textural deficiencies in fiber- or protein-rich reformulation. Technologically, successful pasta enrichment depends on selecting compatible ingredients and adapting processing methods to maintain or enhance textural quality. From consumer perspective, maintaining familiar texture and flavor is essential for acceptance, which supports the importance of balancing nutritional enhancement with culinary standards.

Nutritional Enhancement and Protein Enrichment

The primary driver of pasta reformulation in the modern food industry is the effort to improve nutritional quality by increasing protein content and amino acid profiles. This includes the addition of protein-rich plant and animal ingredients to diversify nutrition and solve public health problems such as metabolic syndrome, obesity, and micronutrient deficiencies. Table 2 presents a summary of several studies examining nutritional enrichment strategies and quantitative results.

Legume-based flour has become a common ingredient in pasta reformulation due to high protein content. Paucar-Menacho et al. (2023b) reported that the addition of pseudocereal flour significantly improved nutritional quality and bioactive components of flour-based pasta, potentially providing health benefits compared to traditional formulation. According to Arribas et al. (2020b), substituting 40% of flour with raw peanuts (*P. vulgaris* var. Almonga) increased total inositol phosphate by approximately 132% due to the high inositol phosphate content of red beans.

Animal proteins, such as salmon, show substantial improvements in nutritional indicators. A. S. Desai et al. (2019) reported that adding salmon (30%) could increase protein content of pasta by approximately 17%, improving the biological value and digestibility of the high fish protein. Furthermore, the addition of salmon powder can increase the energy value due to the high fat content (A. S. Desai et al., 2019b). A study

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by de Souza et al. (2020) also reported that using arrowroot (*Maranta arundinacea* L.) flour fermented with kefir grains in pasta formulation increased protein content.

Table 2. Effect of adding functional ingredients on nutritional profile of enriched pasta

Ingredients	% increase	Nutritional indicators	Benefits	References
Pseudocereals (quinoa flour, cushuro, and kwicha)	13% (quinoa); 15% (kwicha); 8-15% (cushuro)	Micronutrients	High in minerals and vitamins (GABA)	(Paucar-Menacho et al., 2023a)
Soybean pulp (okora)	10–50%	Macronutrients	Increased protein, fat, fiber, and energy	(Kamble et al., 2019)
Soybean protein isolate	10–15%	Protein content	Higher protein content than wheat-based pasta	(Rachman et al., 2019)
Salmon powder	10–30%	Protein content and amino acid composition	Increased protein (up to 17%)	(Desai et al., 2019)
Salmon powder		Protein, fat, and energy content	Higher energy content than the control	(A. S. Desai et al., 2019b)
Quinoa germ	30%	Protein content	Increased protein content from 13.55% to 20.55%	(Ray et al., 2023)
Amaranth flour	30%	Macronutrients	Increased protein and fiber	(Martinez et al., 2014)

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Pea flour	5–15%	Protein	Slightly increased protein content	(Padalino et al., 2014)

GABA, Gamma-Aminobutyric Acid

Besides improving nutrition, pasta fortification with functional ingredients can affect digestibility, glycemic response, and satiety. A. Desai et al. (2019) reported that the addition of salmon flour significantly decreased starch digestibility and slowed the release of sugar, suggesting a potential reduction in glycemic index. The results showed that the formation of a protein-starch complex led to low protein digestibility. Laleg et al. (2016) also reported that increasing protein content tended to decrease digestibility due to high protein/fiber content and denser food matrix structure, delaying enzymatic activity (Petitot et al., 2010). Therefore, the metabolic regulation is particularly beneficial for people with type 2 diabetes or insulin resistance. Satiety can be enhanced by adding higher protein content to stimulate the release of satiety hormones such as GLP-1 and PYY. This contributes to appetite regulation and supports weight management strategies (Morell & Fiszman, 2017).

The analytical methods applied across the reviewed studies consistently support the observed improvements in pasta's nutritional value. For example, proximate analysis remains a fundamental method for determining macronutrient composition, ensuring consistency across enriched pasta formulation (Paucar-Menacho et al., 2023b). In vitro digestibility tests often utilize enzymatic hydrolysis to help predict bioavailability, particularly in determining protein and starch digestibility (Laleg et al., 2016). Measurement of glycemic response using the area under the glucose curve (AUC) has validated the clinical relevance of low-glycemic index formulation (A. Desai et al., 2019; Paucar-Menacho et al., 2023b). Furthermore, high-performance liquid chromatography (HPLC) has been used for amino acid profiling, particularly useful in comparing enriched pasta with traditional formulation in terms of essential amino acid content (Laleg et al., 2016). The precision of HPLC analysis is another method that facilitates data-driven reformulation strategies and provides an evidence base for claims about improved protein quality and functional performance.

Functional and Bioactive Properties

Pasta reformulation with the addition of functional ingredients and bioactive compounds is an essential method to enhance nutritional value of this staple food. The

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integration of antioxidants, prebiotics, dietary fiber, and other bioactive compounds allows pasta to provide nutritional adequacy and physiological benefits. Table 3 presents a summary of the functional compounds used in pasta reformulation, including sources, bioactivity metrics, assessment methods, and major results from the literature.

Table 3. Biological activity of several functional components in enriched pasta

Functional components	Source	Biological activity	Determination method	References
Protein	Salmon	Antioxidant activity	ORAC	(A. S. Desai et al., 2019)
Phenols	Red beans and carob fruit	Antioxidant activity	ORAC	(Arribas et al., 2020b)
Phenolic compounds, GABA	Pseudocereal (quinoa, cushuro, and kwicha flour)	Antioxidant activity, nerve signal inhibitor	ORAC, RP-HPLC, and UV detection	(Paucar-Menacho et al., 2023b)
Phenolic compounds	Quinoa seeds	Antioxidant activity	DPPH	(Demir & Bilgiçli, 2021)
Phenolic compounds	Parota flour	Antioxidant activity	ABTS	(Moo-Huchin et al., 2025)
Phenolic compounds	Flaxseed oil and flour	Antioxidant activity	FRAP and DPPH	(Amri et al., 2024)
Tocochromanols, carotenoids	Pumpkin oil	Antioxidant activity	TEAC and ORAC	(Durante et al., 2019a)
Fiber	Pseudocereals (amaranth, buckwheat, quinoa)	Prebiotic	In vitro	(Achinna & Deshpande, 2025)
Phenolic compounds	Soybean pulp (okora)	Hypoglycemic effect, antioxidant activity	In vitro (enzymatic hydrolysis), DPPH	(Kamble et al., 2019)

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ORAC, Oxygen Radical Absorbance Capacity; RP-HPLC, reversed-phase high-performance liquid chromatography; DPPH, 1,1-difenil-2-pikrilhidrazil; ABTS, 2,2'-azino-bis (3-ethylbenzothiazoline-6-sulfonic acid); FRAP, Ferric Reducing Antioxidant Power; TEAC, Trolox Equivalent Antioxidant Capacity.

According to Table 3, various functional compounds introduced through plant and marine sources substantially improve the physiological and metabolic performance of pasta. Most studies report that pasta enriched with plant ingredients has antioxidant capacity. The addition of red bean flour and carob fruit flour resulted in antioxidant activity based on ORAC test in pasta (Arribas et al., 2020b). Furthermore, the addition of pseudocereal flour increases GABA content, which functions as an inhibitory neurotransmitter in the central nervous system with various promising bioactivities, including antihypertensive, immunomodulatory, antidiabetic, and antitumoral properties (Paucar-Menacho et al., 2023b).

Bioavailability as part of sustainability is shown by the addition of marine proteins to pasta (A. S. Desai et al., 2019). Based on previous studies, salmon-enriched pasta has shown improved protein release through in vitro digestion. Furthermore, prebiotic function was clearly shown in pseudocereal-based synbiotic pasta (Achinna & Deshpande, 2025). Through gut microbiota assays, the addition of probiotics to the pseudocereal matrix stimulated the growth of beneficial bacteria. Strategically, the integration of fermented, phenolic-rich ingredients was also found to play a crucial role in functional enhancement. Fermentation was found to enhance the antioxidant activity of wheat flour by releasing phenolic fractions into a free form (Islam et al., 2024). Kamble et al. (2019) confirmed that the addition of soybean pulp had a hypoglycemic effect, capable of lowering the glycemic index by up to 54%. Meanwhile, the addition of extracts such as α-cyclodextrins from pumpkin improved the stability of bioactive components, particularly carotenoids, in enriched pasta (Durante et al., 2019a).

Sensory Evaluation and Consumer Acceptance

New-generation pasta innovations are focused on enhancing nutritional value by adding plant-based and high-protein ingredients require adjustments to ensure the desired taste and texture. These innovations require careful adjustment as consumer acceptance remains a significant challenge, particularly when the taste or texture differs from traditional pasta. Therefore, there is a need to understand how ingredient substitutions affect taste, texture, aroma, appearance, and overall acceptability. Table 4 summarizes recent studies evaluating the sensory outcomes of enriched pasta product.

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Table 4. Acceptance of pasta enriched with several functional ingredients

Functional Ingredients	Sensory test method	Key findings	References
Amaranth flour	Multi-sample comparison test	A maximum substitution of 30% was still acceptable.	(Martinez et al., 2014)
Pumpkin oil and flour	Quantitative descriptive	Overall acceptance was still below that of the control pasta (semolina flour-based pasta).	(Durante et al., 2019b)
Fish protein hydrolyzate	Generic descriptive	The addition of 5% hydrolyzate was still acceptable.	(Laishram et al., 2025)
Pea flour	Hedonic-9 scale	The addition of 15% approached the sensory properties of the control pasta.	(Padalino et al., 2014)
Soybean pulp (okora)	Hedonic-9 scale	The addition of 10% approached the sensory properties of the control.	(Kamble et al., 2019)
Parsley leaf powder	Hedonic-9 scale	The addition of up to 7.5% resulted in higher acceptance scores than the control.	(Bouasla et al., 2022)

Based on Table 4, several studies reported success in maintaining the acceptability of enriched pasta. Product made with fish protein hydrolysate led to a darker color, and an addition of 5% was still acceptable (Laishram et al., 2025). The study also reported that the addition of fish protein hydrolysate could produce a bitter taste and undesirable fermentation aroma. Meanwhile, Durante et al. (2019a) reported that pasta enriched with pumpkin oil and flour had good acceptability scores. These results showed

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the need to balance nutritional enhancement with potential losses, particularly in sensory aspects. Another study attempted to replace semolina flour with pea flour (Padalino et al., 2014), where a 15% addition was considered to have sensory properties close to the control. The addition of guar seed flour was considered to improve the overall quality of pea flour-enriched pasta. The addition of protein from soybean pulp decreased consumer acceptance (Padalino et al., 2014). In line with previous studies, enriched pasta tends to lower overall acceptance levels, as the elastic properties provided by gluten are difficult to replicate using functional ingredients. However, the addition of parsley leaf powder by approximately 7.5% caused higher acceptance scores compared to the control. This improvement was attributed to higher taste and aroma scores due to the presence of parsley (Bouasla et al., 2022).

The effect of substitution level on sensory perception was evident across all studies. Acceptability scores generally remained high with substitution levels of 30%. Above this threshold, significant decreases in texture and flavor perception were frequently reported. Sensory changes extend beyond flavor and texture, as visual appearance, often affected by colored flours, also shapes consumer perception. This is shown by the greenish discoloration of pasta enriched with parsley powder, which decreases color scores (Bouasla et al., 2022).

CONCLUSION

In conclusion, this study shows that pasta is a widely consumed food globally, offering significant potential as a fortification medium. Various fortification strategies have been applied to enhance pasta nutritional content and functional properties by adding nutrient-rich plant-based ingredients, such as legumes, pseudocereals, and animal derivatives. These additions contribute to improved macro- and micronutrient profiles alongside digestibility. Functional compounds such as polyphenols, fiber, and prebiotics provide other benefits, including antioxidant activity and modulation of gut microbiota. However, ingredient substitution poses technological challenges, such as changes in physical and sensory properties. The problem can be addressed through the application of appropriate processing methods, such as fermentation, extrusion, and enzymatic treatment. Although fortification offers significant benefits, the impact on sensory characteristics cannot be ignored, as physicochemical properties of functional ingredients can affect the texture, color, and flavor of the final product, which influence consumer acceptance. This shows the need to balance increased nutritional value with the risk of sensory quality degradation. Based on the results, consumer acceptance remains high

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when sensory quality is maintained, particularly at ingredient substitution levels below 30%.

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