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Fortified millet noodles: Processing approaches, nutritional enhancement and health implications: A comprehensive review

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Abstract

Millet-based noodles are gaining attention as nutritionally superior alternatives to conventional wheat noodles due to their higher dietary fiber, mineral content, and presence of bioactive compounds. However, the absence of gluten and inherent processing challenges often limit their textural and sensory quality. Fortification strategies involving legumes, protein-rich ingredients, micronutrients, and functional additives have been explored to overcome these limitations and enhance nutritional value. This review synthesizes published research on the development of fortified millet noodles, focusing on millet types used, formulation and fortification strategies, processing techniques, nutritional enhancement, sensory acceptability, and potential health benefits. Evidence from existing studies indicates that fortified millet noodles exhibit improved protein quality, increased dietary fiber and mineral content, reduced glycemic response, and enhanced antioxidant activity compared to conventional noodles. Moderate levels of millet incorporation combined with appropriate processing interventions were found to be critical for achieving consumer acceptability. Despite promising outcomes, challenges remain in terms of standardization, nutrient bioavailability, and large-scale commercialization. Fortified millet noodles represent a viable functional food option with significant potential for improving dietary quality and contributing to nutritional security.

Keywords: Millets, fortification, noodles, food processing, functional foods, nutritional quality, glycemic index

Introduction

Noodles constitute one of the most widely consumed cereal-based convenience foods across the globe. Traditionally produced from refined wheat flour, conventional noodles are energy-dense but nutritionally limited, particularly in dietary fiber, micronutrients, and bioactive compounds. The increasing prevalence of lifestyle-related disorders such as diabetes, obesity, and micronutrient deficiencies has intensified the search for healthier alternatives to refined cereal products. In this context, millets have re-emerged as nutritionally rich, climate-resilient cereals with significant potential for food diversification and nutritional security. Millets such as finger millet (*Eleusine coracana*), foxtail millet (*Setaria italica*), pearl millet (*Pennisetum glaucum*), proso millet (*Panicum miliaceum*), barnyard millet (*Echinochloa frumentacea*), and kodo millet (*Paspalum scrobiculatum*) are rich sources of dietary fiber, minerals, essential amino acids, and phytochemicals. Several studies have demonstrated their role in improving glycemic control, lipid metabolism, and antioxidant status. However, incorporation of millets into noodle formulations presents technological challenges due to the absence of gluten, resulting in poor dough handling, reduced elasticity, and compromised sensory quality. Consequently, fortification and composite flour approaches have been widely investigated to improve both nutritional and functional properties of millet noodles. This review critically examines research conducted on fortified millet noodles, emphasizing processing methods, fortification strategies, nutritional outcomes, sensory attributes, and health implications.

Nutritional composition of millets relevant to noodle formulation

Millets possess superior nutritional profiles compared to refined wheat flour. Finger millet is particularly rich in calcium (300-450 mg/100 g) and iron, while pearl millet contains higher

zinc and protein content. Foxtail and proso millets contribute substantial dietary fiber and slowly digestible starch fractions. Li *et al.* (2024) ^[7] reported considerable variability in mineral and polyphenol content among millet species, highlighting their potential role in addressing micronutrient deficiencies.

The high fiber content of millets contributes to delayed gastric emptying and reduced postprandial glucose response. Moreover, the presence of phenolic compounds and antioxidants supports their classification as functional ingredients in processed foods such as noodles.

Incorporation of different millets in noodle development

Foxtail millet-based noodles

Foxtail millet has been extensively studied for noodle formulation due to its mild flavor and relatively better processing properties. Meherunnahar *et al.* (2023) ^[2] developed foxtail millet-based instant noodles and reported significant increases in protein, dietary fiber, ash, calcium, and phosphorus compared to wheat noodles. The study also demonstrated improved essential amino acid profiles and protein efficiency ratios when foxtail millet was combined with protein-rich fortificants.

Jadhav *et al.* (2025) ^[4] observed that noodles prepared with composite blends of foxtail millet and sorghum exhibited higher antioxidant activity and acceptable sensory scores at moderate substitution levels, confirming the suitability of foxtail millet for composite noodle products.

Finger millet-based noodles

Finger millet has attracted considerable attention due to its exceptionally high calcium content. Shukla and Srivastava (2011) ^[1] evaluated finger millet-incorporated noodles and reported enhanced dietary fiber, calcium, and iron content along with a significantly lower glycemic index compared to wheat noodles. These findings highlight the potential of finger millet noodles for diabetic and health-conscious populations.

Tanwar *et al.* (2023) ^[3] further demonstrated that finger millet substitution up to 30% improved nutritional and rheological properties, although higher incorporation levels negatively affected dough extensibility and cooking quality.

Proso, barnyard, and kodo millet noodles

Underutilized millets such as proso, barnyard and kodo millet have also been explored for noodle development. Bhavadharani *et al.* (2025) ^[5] reported that gluten-free noodles prepared from germinated proso and barnyard millet flours exhibited improved protein content, dietary fiber, and mineral levels with acceptable sensory characteristics. Germination was found to enhance nutrient availability and functional properties.

Composite and multi-millet noodle formulations

Composite flour approaches combining multiple millets or millets with other cereals and tubers have been widely adopted to overcome processing limitations. Studies on multi-millet noodles revealed increased protein, ash and fiber content along with reduced carbohydrate levels compared to control products. Chigbo *et al.* (2025) ^[6] demonstrated that composite noodles prepared from pearl millet and water yam flour showed improved mineral content and consumer acceptability.

Multi-millet formulations offer nutritional diversity and improve amino acid balance, making them suitable for addressing protein-energy malnutrition and micronutrient deficiencies.

Fortification strategies in millet noodles

Protein fortification

Protein fortification using legumes, oilseed meals and mushroom powders has been shown to improve the biological value of millet noodles. Meherunnahar *et al.* (2023) ^[2] reported that the addition of mushroom powder to foxtail millet noodles enhanced lysine content and overall protein quality.

Micronutrient and functional fortification

Although direct micronutrient fortification studies in millet noodles are limited, research indicates that increased millet content contributes to higher iron, calcium, zinc and antioxidant levels. Studies on phenolic-rich composite noodles reported reduced starch digestibility, suggesting improved glycemic response and functional benefits.

Processing techniques and their influence on quality

Processing methods such as extrusion cooking, steaming, germination and hydrocolloid incorporation significantly influence noodle quality. Extrusion improves starch gelatinization, reduces cooking loss and enhances textural stability. Germination enhances enzyme activity and nutrient bioavailability, while hydrocolloids such as guar gum and xanthan gum improve dough elasticity and mouthfeel in gluten-free formulations.

Nutritional and health implications

Fortified millet noodles consistently demonstrate higher dietary fiber, mineral content, protein quality, and antioxidant activity than conventional wheat noodles. Several studies reported lower glycemic indices for finger millet and composite millet noodles, supporting their role in diabetes management. Increased fiber and phenolic content may also contribute to improved gut health and reduced oxidative stress, although long-term clinical evidence remains limited.

Sensory acceptability and consumer perspective

Sensory evaluation studies indicate that millet substitution levels between 30% and 50% generally yield acceptable products. Excessive millet incorporation negatively affects texture and flavor, emphasizing the importance of formulation optimization. Consumer acceptance improves when fortification strategies address textural limitations without compromising traditional noodle characteristics.

Challenges and future research needs

Despite encouraging results, challenges such as lack of gluten structure, variability in millet quality, limited micronutrient bioavailability data, and scalability issues persist. Future research should focus on human intervention studies, standardized fortification protocols, shelf-life evaluation, and economic feasibility to support commercialization.

Conclusion

Fortified millet noodles represent a nutritionally enhanced, functional alternative to conventional noodles. Research

evidence demonstrates their potential to improve protein quality, dietary fiber, micronutrient intake, and glycemic response. With optimized processing and fortification strategies, millet noodles can play a significant role in promoting nutritional security and sustainable food systems.

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