

Millets and Gut Health: A Review of the Role of Dietary Fibre, Polyphenols and Resistant Starch

Arundhati Rai^{1*}, Manjusha Rai²

¹Assistant Professor, Home Science, Pt. D.D.U. Govt. P.G. College, Palahipatti, Varanasi, UP, India

²Assistant Professor, Home Science, Km. Mayawati Govt. Girls P.G. College, Badalpur, Gautam Buddha Nagar, UP, India

Corresponding Author Email ID: manjusharai2012@gmail.com

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Abstract

Millets are nutrient-dense, climate-resilient cereals that contain dietary fibre, resistant starch, polyphenols, minerals and other bioactive compounds. Increasing evidence suggests that these components may influence gut microbiota composition, microbial metabolites and intestinal health. This review summarizes current evidence on the relationship between millet consumption and gut health, with particular emphasis on dietary fibre, resistant starch and polyphenols. Millet fibres can serve as substrates for beneficial gut microorganisms and may promote the production of short-chain fatty acids (SCFAs), while resistant starch is fermented more slowly and can support saccharolytic bacteria. Millet polyphenols may also interact with gut microbes, and microbial transformation can alter their bioavailability and biological activity. Processing methods such as soaking, germination, fermentation, cooking, milling and dehulling can modify fibre, starch and polyphenol profiles and consequently influence their physiological effects. Fermented millet foods may provide additional opportunities for delivering bioactive compounds and beneficial microorganisms. Evidence from in vitro studies, animal experiments and emerging human studies indicates potential benefits for glycaemic regulation, inflammation, oxidative stress and metabolic health. However, human clinical evidence specifically linking millet consumption with changes in gut microbiota and long-term health outcomes remains limited. Overall, millets represent promising functional grains for supporting gut health, although more well-designed human intervention studies are needed to establish dose-response relationships and identify the effects of individual millet varieties and processing methods.

Keywords: Millets, Gut health, Resistant starch, Polyphenols, Gut microbiota.

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Introduction

Millets are small-seeded cereal grains traditionally cultivated in many parts of Asia and Africa. In recent years, they have attracted renewed scientific and public interest because of their nutritional value, environmental resilience and potential contribution to healthier dietary patterns. Millets provide carbohydrates, protein, dietary fibre, minerals and phytochemicals, with composition varying among species and cultivars.^[1,2] Their ability to grow under relatively dry and marginal conditions has also increased their relevance to food and nutrition security.

Beyond their basic nutrient content, millets contain components that may influence physiological processes after consumption. Dietary fibre, resistant starch and polyphenols are particularly important because they can interact with the gastrointestinal tract and gut microbiota. Dietary fibre can be fermented by intestinal microorganisms, producing metabolites such as acetate, propionate and butyrate. Resistant starch similarly escapes digestion in the small intestine and becomes available for microbial fermentation in the colon.^[3,4] Polyphenols may affect microbial growth and may themselves be transformed

by intestinal microorganisms into smaller metabolites with different biological properties.^[5,6]

The gut microbiota is increasingly recognized as an important component of human health. Its metabolites and interactions with the intestinal barrier and immune system can influence glucose metabolism, inflammation and other physiological processes. Dietary patterns are among the major factors shaping the gut microbiome, and fibre-rich foods can support microbial diversity and beneficial metabolic activity.^[7] In this context, millet-based diets may have potential as part of dietary strategies that support a healthier gut environment.

This review examines the relationship between millets and gut health, focusing on dietary fibre, resistant starch and polyphenols, their interactions with gut microbiota and metabolites, the influence of processing, and emerging evidence on metabolic and intestinal health.

Millets as Functional Foods

Millets can be considered potential functional foods because they provide nutrients together with bioactive components that may have physiological benefits. Major millet species include pearl millet, finger millet, foxtail millet, little millet,

kodo millet, proso millet and barnyard millet. Their nutritional composition differs according to species, genotype, growing conditions and processing methods.^[8,9]

Millet is generally good source of dietary fibre and contain phenolic compounds, including phenolic acids and flavonoids. Finger millet, for example, has received considerable attention because of its dietary fibre and polyphenol content.^[10] Millet starch characteristics also vary, influencing digestibility and postprandial glucose responses. These features make millets relevant not only as cereal substitutes but also as ingredients for developing functional and culturally appropriate foods.

Nutritional Components Relevant to Gut Health

Dietary Fibre

Dietary fibre includes carbohydrate polymers that resist digestion in the small intestine and reach the large intestine, where many components can be fermented by gut microorganisms. Fibre can influence stool characteristics, intestinal transit, microbial composition and production of SCFAs. Reviews of dietary fibre and gut microbiota show that fermentable fibres can promote beneficial microbial functions and contribute to host physiology.^[7]

Millets contain soluble and insoluble fibre, including cellulose, hemicellulose and other non-starch polysaccharides. The quantity and physicochemical properties of fibre differ among millet species and processing conditions. Recent in vitro evidence indicates that foxtail millet bran dietary fibres can support beneficial gut microbes and microbial metabolites while suppressing some pathobionts.^[11] Such findings support the possibility that millet fibre may act as a substrate for favourable microbial fermentation.

Resistant Starch

Resistant starch is a fraction of starch that escapes digestion in the small intestine and reaches the colon. It can be fermented by gut microorganisms and may increase the production of SCFAs. Resistant starch has also been associated with changes in microbial composition and functional pathways in meta-analytic evidence.^[4] Different millet varieties and processing conditions can alter starch structure and digestibility. Cooking, cooling and other processing treatments can modify the proportion of resistant starch. Resistant starch can support bacteria capable of utilizing complex carbohydrates, including beneficial members of the genus *Bifidobacterium*.^[12] Thus, the starch fraction of millets may contribute to their potential effects on gut microbial metabolism.

Polyphenols

Millets contain diverse polyphenolic compounds, including phenolic acids and flavonoids. These compounds possess antioxidant properties and may influence cellular signalling. Importantly, polyphenols can interact bidirectionally with the gut microbiota: they may influence microbial populations, while microorganisms can transform polyphenols into

metabolites that may be more readily absorbed.^[5] Finger millet polyphenols have been studied for their antioxidant and other health-related properties [10]. Recent experimental work suggests that millet polyphenol-rich extracts can influence human faecal bacteria and intestinal epithelial responses.^[6] However, the physiological significance of these findings requires confirmation through well-controlled human studies.

Millet Dietary Fibre and Gut Microbiota

The gut microbiota responds strongly to the quantity and type of dietary carbohydrates reaching the colon. Fermentable fibre provides substrates for microorganisms and can increase the production of SCFAs. Millet fibre may therefore influence gut microbial ecology through both direct substrate availability and changes in the intestinal environment.

In vitro fermentation studies provide useful evidence. Sori et al.^[13] reported changes in gut microbiota and metabolomic profiles following fermentation of kodo and little millet by human gut microbiota. Similarly, Li et al.^[11] found that foxtail millet bran dietary fibres fostered beneficial microbes and metabolites in vitro. These studies suggest that millet fibre can be microbiologically active, although in vitro findings cannot be assumed to reproduce effects in humans.

Polyphenol–Gut Microbiota Interaction

Polyphenols can affect the gut microbiota through antimicrobial, substrate-related and signalling mechanisms. At the same time, microbial enzymes can break down complex polyphenols into smaller metabolites. This interaction may influence the biological availability and activity of millet-derived phenolic compounds. Experimental studies indicate that millet polyphenols may affect microbial communities and inflammatory or antioxidant pathways. Balkrishna et al.^[5] discussed potential mechanisms involving Nrf2 and NF- κ B signalling and gut microbiota, while Maurya et al.^[6] observed effects of millet polyphenol-rich extracts on human faecal bacteria and intestinal epithelial models. These findings are promising but remain largely experimental.

Millets and Short-Chain Fatty Acids

SCFAs, particularly acetate, propionate and butyrate, are major products of microbial fermentation of dietary carbohydrates. They participate in energy metabolism, immune regulation and maintenance of intestinal homeostasis.^[3] Dietary fibre and resistant starch are important substrates for SCFA production. Millet consumption may therefore contribute to SCFA formation by providing fermentable carbohydrates. Evidence from resistant-starch research supports the ability of resistant starch to alter gut microbial functions and fermentation patterns.^[4] In vitro millet fermentation studies also demonstrate changes in microbial metabolites.^[13] More human studies are needed to determine whether habitual millet intake produces clinically meaningful increases in SCFAs.

Millet and Intestinal Barrier Integrity

The intestinal barrier regulates the movement of nutrients while limiting the passage of potentially harmful substances. Its integrity depends on epithelial cells, mucus, immune components and intercellular tight junctions. Dietary factors and microbial metabolites can influence this barrier. Millet polyphenol-rich extracts have shown effects on intestinal epithelial cell models exposed to inflammatory stress, suggesting potential protective mechanisms.^[6] The production of SCFAs from millet fibre and resistant starch may also be relevant because microbial metabolites can influence epithelial physiology.^[3] Nevertheless, direct clinical evidence that millet consumption improves intestinal barrier function in humans remains insufficient.

Millet, Inflammation and Oxidative Stress

Oxidative stress and chronic low-grade inflammation are involved in the development of several metabolic disorders. Millet polyphenols and other phytochemicals have antioxidant properties that may help modulate oxidative pathways. Experimental studies have also linked millet bioactive compounds with signalling pathways involved in inflammation and antioxidant defence.^[5] The gut microbiota may contribute to these effects because microbial metabolites can influence immune and metabolic signalling. The interaction between millet components, gut microbes and host tissues is therefore likely to be multifactorial. Current evidence supports biological plausibility, but the magnitude of these effects in humans is not yet well established.

Millet and Metabolic Health

Gut microbial metabolism is connected with host energy balance and metabolic health. Millet-based dietary interventions have been investigated for possible effects on glucose and lipid metabolism. A systematic review by Naik et al.^[14] examined the effects of millet consumption on metabolic homeostasis in adults, while Anitha et al.^[15] reported evidence from a systematic review and meta-analysis concerning fasting and postprandial blood glucose. Animal research also suggests that millet fibre may influence metabolic outcomes. Yang et al.^[16] reported that soluble dietary fibre from fermented and unfermented millet bran reduced high-fat-diet-induced obesity-related outcomes in mice. Such findings support further investigation but should not be directly extrapolated to human clinical outcomes.

Millet and Glycaemic Regulation

Millet may support glycaemic regulation because of their fibre content, starch structure and polyphenols. Compared with highly refined cereal products, some millet-based foods may produce lower postprandial glycaemic responses, although the response depends strongly on variety, particle size, cooking method and food formulation. Anitha et al.^[15] found evidence of beneficial effects of regular millet consumption on fasting and postprandial blood glucose

in a systematic review and meta-analysis. Singh et al.^[17] also discussed the potential contribution of millet dietary bioactives and gut microbiota to anti-diabetic mechanisms. However, differences among individual studies highlight the need to consider the specific millet, dose, preparation and overall dietary context.

Role of Processing in Modifying Functional Properties

Soaking

Soaking can alter hydration, enzyme activity and some antinutritional factors. It may also influence starch digestibility and phenolic availability. The nutritional effects depend on the soaking conditions and subsequent cooking or processing steps.^[18,19]

Germination

Germination activates endogenous enzymes and can modify starch, protein and phenolic compounds. It may increase the availability of certain bioactive compounds while changing digestibility. These changes make germinated millet useful for developing functional food products, although the final effects depend on germination conditions.^[18]

Fermentation

Fermentation can modify carbohydrates, reduce some antinutritional factors and transform phenolic compounds. Balli et al.^[20] examined the effects of fermentation on millet phenolic content and demonstrated that fermentation-related changes are not necessarily uniform across all phenolic compounds. Fermentation can therefore alter the functional profile of millet foods in complex ways.

Cooking

Cooking changes starch structure and may influence digestibility and resistant starch formation. Thermal processing can either increase or decrease the availability of specific compounds depending on the treatment.^[21] A recent review of thermal and non-thermal processing emphasized the importance of processing conditions in determining millet starch properties and digestibility.^[22]

Milling and Dehulling

Milling and dehulling can substantially change fibre and polyphenol content because many bioactive compounds are concentrated in outer grain layers. Excessive removal of bran may reduce dietary fibre and associated phytochemicals. Therefore, processing should balance palatability and technological properties with retention of nutritionally important components.^[19]

Fermented Millet Foods and Gut Health

Fermented millet foods are traditional in many regions and may offer combined benefits from millet nutrients and fermentation-derived changes. Fermentation can influence microbial substrates, phenolic compounds and digestibility. It may also reduce selected antinutritional

factors and improve sensory characteristics. The gut-health relevance of fermented millet foods is supported by experimental evidence, including studies of millet fermentation and microbial metabolism.^[13] However, the microorganisms present in fermented foods vary with raw material, starter culture, processing conditions and storage. Human intervention studies are needed to establish whether regular intake of specific fermented millet foods produces measurable changes in gut microbiota or health outcomes.

Traditional Indian Millet Foods

Millet has long been incorporated into traditional Indian diets in forms such as rotis, porridges, fermented batters, porridges and other region-specific preparations. These foods represent culturally familiar ways of increasing millet consumption. Their health effects depend not only on the grain but also on preparation, accompanying foods and portion size.

Traditional processing methods such as fermentation, soaking and cooking can modify starch digestibility, fibre characteristics and polyphenol availability. Consequently, studying whole dietary patterns and real food preparations may provide more useful information than evaluating isolated millet components alone.

Antinutritional Factors and Their Relevance

Millet contains phytates, tannins and other compounds that may reduce the bioavailability of certain minerals or influence digestion. These compounds are not universally harmful; some also have antioxidant and other biological activities. Their effects depend on dose and dietary context.

Processing methods including soaking, germination, fermentation and cooking can reduce or modify several antinutritional factors [18,19]. Understanding these changes is important when developing millet-based functional foods, particularly for populations with high dependence on cereal-based diets.

Emerging Evidence on Millets and Gut Health

Research on millet–gut interactions is expanding from compositional studies toward direct microbiome and intervention research. Huey et al.^[23] reported findings from a randomized trial of an iron- and zinc-biofortified pearl millet complementary feeding intervention in young children, including assessment of gut microbiota. Rajalakshmi et al.^[24] also reported evidence from a millet-based dietary intervention examining gut microbiota, inflammatory signalling, glycaemic control and healthy ageing.

These studies illustrate an important transition from theoretical mechanisms and in vitro fermentation toward human evidence. Nevertheless, differences in millet varieties, intervention doses, participant characteristics and dietary backgrounds make direct comparison difficult. Future studies should use standardized dietary interventions, detailed microbiome methods and clinically relevant outcomes.

Conclusion

Millet contains dietary fibre, resistant starch and polyphenols that can interact with the gut microbiota and intestinal environment. Available evidence suggests that millet-derived carbohydrates can provide substrates for microbial fermentation and SCFA production, while polyphenols may influence microbial communities and host signalling pathways. Processing methods further modify these functional components and may affect the physiological properties of millet foods.

Evidence from in vitro studies, animal experiments and emerging human interventions supports the potential role of millet in gut and metabolic health. However, the human evidence base remains smaller than the mechanistic literature. Future research should prioritize well-designed clinical trials comparing specific millet varieties and processing methods, with standardized assessment of dietary intake, gut microbiota, microbial metabolites and relevant health outcomes. Millet therefore represents a promising component of diverse, fibre-rich dietary patterns, while continued research is needed to define their specific contribution to gut health.

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