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Review Article

The Role of Millet in Gut Modulation and Irritable Bowel Syndrome (IBS) Management: A Review

Maissa Dely* and Melika Mankai

University of Carthage, Research Laboratory: Technological Innovation and Food Security (LR22-AGR01), Higher Institute of Food Industries of Tunisia (ESIAT), Tunis, Tunisia

***Corresponding Author:** Maissa Dely, University of Carthage, Research Laboratory: Technological Innovation and Food Security (LR22-AGR01), Higher Institute of Food Industries of Tunisia (ESIAT), Tunis, Tunisia.

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Abstract

Disorders of gut-brain interaction (DGBI), particularly irritable bowel syndrome (IBS), affect a significant proportion of the global population and are characterized by chronic digestive symptoms without identifiable organic lesions.

Nutrition plays a key role in their management, especially through gluten-free and low-FODMAP diets, which have shown clinical benefits in some patients. However, commonly consumed grains such as wheat and rye are often poorly tolerated in this context. Millet, an ancient grain that is naturally gluten-free and low in FODMAPs, offers potential as a well-tolerated alternative. It is rich in specific dietary fibers and has positive effects on the gut microbiota, short-chain fatty acid production, and intestinal inflammation.

This review explores the possibility of using millet as a functional ingredient in the creation of products for patients with IBS, aiming for a sustainable, well-accepted, and science-based nutritional approach.

Keywords: Millet; Gut Modulation; Irritable Bowel Syndrome

Introduction

Disorders of gut-brain interaction (DGBI), formerly known as functional gastrointestinal disorders (FGIDs), are chronic conditions whose etiology remains unclear and which affect up to 40% of the global population according to the Rome IV diagnostic criteria [1]. These conditions, which include irritable bowel syndrome (IBS) and functional dyspepsia, manifest as persistent gastrointestinal symptoms without any identifiable organic abnormalities.

IBS, in particular, is one of the most common functional gastrointestinal disorders, with an estimated global prevalence of 10% [2]. It is characterized by abdominal pain, bowel movement disorders, and bloating, which are often debilitating for patients. According to the Rome III consensus, symptoms must be present at least 3 days per month over the last 3 months, with improvement after defecation and/or a change in stool frequency or appearance [2].

Furthermore, clinical overlap between IBS and gluten-related disorders (GRD) has been demonstrated in recent years. Up to 50% of people with celiac disease (CD) continue to experience gastrointestinal symptoms consistent with IBS, despite following a gluten-free diet for a year [1]. The prevalence of non-celiac gluten sensitivity (NCGS) is estimated at around 10.6%, compared to 1% for CD [1].

These data highlight the growing importance of diet as a therapeutic lever in gastrointestinal disorders. Currently, a gluten-free diet is the only validated treatment for CD and NCGS [1]. It is also considered beneficial, to a certain extent, for patients with IBS [1]. This trend has contributed to the boom in the gluten-free market, which is estimated to be growing at an annual rate of nearly 10% [1].

Simultaneously, the role of FODMAPs (Fermentable Oligo-, Di-, Monosaccharides And Polyols) in triggering symptoms has been increasingly recognized [3]. These carbohydrate compounds, which are poorly absorbed and fermentable, can trigger symptoms in patients with IBS through osmotic mechanisms and the production of intestinal gas [4]. A low-FODMAP diet, supervised by a healthcare professional, can provide relief for around 50% of patients [5].

However, traditional grains such as wheat and rye, which are rich in fructans, pose a problem in this context. Their consumption, which is ubiquitous in Western diets, is frequently associated with an exacerbation of IBS symptoms [6].

Despite several technological approaches aimed at reducing their FODMAP content (sourdough fermentation, enzymes, germination), there is still no standardized method or universally accepted solution for the manufacture of well-tolerated cereal products [7].

Millet has characteristics particularly suited to the nutritional needs of patients with gut-brain interaction disorders, especially IBS. Naturally gluten-free and low in FODMAPs, it is an attractive alternative to traditional grains, which are often poorly tolerated in this context [8].

Its high content of specific dietary fibers—including arabinoxylans, beta-glucans, and other non-starch polysaccharides—gives it beneficial functional properties: positive modulation of the gut microbiota, stimulation of short-chain fatty acid (SCFA) production, reduction of intestinal inflammation, and improved transit. These properties make millet not only an ingredient compatible with gluten-free and low-FODMAP diets, but also a strategic nutritional lever for improving patients' quality of life [8]. Despite this potential, it remains under-explored in the formulation of products adapted to gut-brain interaction disorders [8].

The objective of this review is to evaluate the potential of millet as a functional ingredient, both for the formulation of gluten-free products and for its integration into a low-FODMAP diet, in order to offer a sustainable and well-tolerated nutritional alternative for patients with IBS.

Nutrition, gut, brain: A triangle of influence in digestive health

The gut-brain axis is a bidirectional pathway connecting the gastrointestinal system to the central nervous system via neural, hormonal, and immunological signals. The gastrointestinal system is home to a vast community of microbes unique to each individual in the small and large intestines [9].

Two key physiological barriers are the blood-brain barrier and the intestinal barrier, both of which are dynamic structures. In a healthy person, these barriers are functional [9]. In healthy individuals, these barriers maintain their integrity. Intestinal microbes and their metabolites play a significant role in regulating and maintaining this barrier function.

The bidirectional dialogue between the brain, gut, microbiota, and immune system regulates essential intestinal functions such as motility, permeability, mucin secretion, immunity (cytokines), and microbial composition [9].

In irritable bowel syndrome (IBS), this balance is disrupted. In particular, visceral hypersensitivity, dysmotility, alterations in the microbiota, central sensitization, and underlying chronic stress are observed [9]. The gut microbiota, composed of billions of microorganisms, plays an essential role in maintaining the host's physiology, particularly through the fermentation of undigested carbohydrates and the development of the immune system [9].

The intestinal mucosa consists of an epithelium covered with mucus, where secreted IgA prevents the adhesion of pathogens, supported by enzymes such as proteases [9]. The vagus nerve, a major component of the gut-brain axis, modulates the integrity of the intestinal barrier, secretory and immune functions, and digestive motility [9]. Its activation is influenced by intestinal microbes, their metabolites (such as short-chain fatty acids), and various neurotransmitters such as serotonin, GABA, and dopamine [9].

This neuro-immuno-microbial dialogue, via the vagus nerve, impacts intestinal microbial diversity and contributes to the overall balance of the digestive ecosystem [9]. Diet is the most effective way to modify the gut microbiota [9]. A less diverse diet lacking in essential nutrients will reduce the availability of substrates necessary for microbial growth, leading to intestinal dysbiosis, i.e., a decrease in beneficial species and a proliferation of pathogenic species [9]. While it is challenging to pinpoint specific dietary components that negatively affect the gut microbiome, both short- and long-term dietary changes influence the gut microbiota and its interactions with the host's autonomic nervous system [9].

Chronic consumption of carbohydrates, proteins, and animal fats is associated with an increase in Prevotella spp [9]. The Western diet, rich in processed, fried, fatty, and sugary foods, is known to induce a reduction in microbial diversity.

Dietary modifications such as the FODMAP diet and the traditional dietary advice (TDA) diet have improved symptoms and led to changes in microbial composition [9]. High consumption of saturated fatty acids (SFAs), common in Western diets rich in processed, fried, fatty, and sugary foods, is associated with a reduction in the total bacterial community and changes in microbial composition. Specifically, this includes a decrease in beneficial bacteria like Lactobacillus and an increase in Firmicutes, which may contribute to increased intestinal permeability [9]. Despite this, some studies report an increase in microbial diversity, although this paradox requires further investigation [9].

In contrast, Mediterranean and plant-based diets promote greater microbial diversity and support beneficial microbes, contributing to improved gut health [9]. Given the strong influence of diet on microbiota composition and digestive health, specific dietary approaches such as the low-FODMAP diet represent promising strategies to improve quality of life for patients with IBS [9].

Since diet influences the composition and balance of the microbiota as well as digestive health, it is reasonable to consider specific dietary approaches, such as a low-FODMAP diet, as a solution that could improve the quality of life of patients suffering from irritable bowel syndrome.

Low FODMAP diet

The therapeutic approach to the different subtypes of IBS must be tailored to the specific symptoms presented. In the case of diarrhea-predominant IBS (IBS-D), the main objective is to reduce excessive bowel movements. Conversely, in the case of constipation-predominant IBS (IBS-C), the focus is on promoting regular bowel movements [9].

The consumption of FODMAPs, short-chain fermentable carbohydrates including galacto-oligosaccharides (GOS), fructo-oligosaccharides (FOS), lactose, excess fructose, and sorbitol, is known to cause or aggravate gastrointestinal symptoms in people with irritable bowel syndrome (IBS) [9].

These carbohydrates are poorly absorbed in the small intestine and fermented by the colonic microbiota, leading to increased gas production and intestinal distension, which can cause bloating, abdominal pain, diarrhea, or constipation [9].

In response to these mechanisms, the low-FODMAP diet was developed and has established itself as an effective dietary approach to alleviating IBS symptoms. This diet involves limiting the consumption of these fermentable carbohydrates in order to reduce intestinal fermentation and excess gas, thereby improving digestive comfort and quality of life for patients [9].

However, this dietary approach is associated with a significant reduction in luminal bifidobacteria after four weeks [9]. This decrease is primarily due to the limited intake of fructans (including FOS) and GOS, which serve as key substrates for beneficial bacterial fermentation in the gut [9]. Despite this reduction in bifidobacteria, many patients experience a noticeable improvement in gastrointestinal symptoms.

However, this diet must be followed under professional supervision to avoid nutritional deficiencies and to gradually reintroduce FODMAPs to identify individual tolerance thresholds [9].

Millet stands out for its composition, which makes it particularly easy to digest, making it a food well suited to people with digestive disorders.

As a result, it is an excellent option for diets aimed at limiting digestive disorders, such as the low FODMAP diet. In addition to its nutritional and environmental qualities, millet is therefore an ideal food for those seeking to better manage their digestive symptoms.

Millet as a strategic nutritional ally in gut health management

During the 1990s, Prime Minister HD Deve Gowda publicly stated that ragi mudde (made from millet balls served with sambar) was his favorite dish in Karnataka [10].

This statement sparked a nationwide trend, prompting many restaurants to add the dish to their menus under the name “Prime Minister’s Delight.” Similar stories can be found around the world, where millet has been a staple food for centuries [10]. But it is not only its traditional roots that deserve our attention: above all, it is its remarkable contribution to human health that has placed it at the heart of contemporary nutritional strategies [10].

Millet is highly digestible, making it an excellent choice for people suffering from digestive disorders or food intolerances [10].

Their non-acidifying and non-allergenic nature, combined with the absence of gluten, makes them particularly well tolerated by people with celiac disease or gluten sensitivity [10]. This remarkable digestive tolerance, combined with a high fiber, mineral, and antioxidant content, makes it an ideal food for diets aimed at relieving intestinal discomfort.

In addition, their ease of preparation and culinary versatility allow them to be incorporated into a wide variety of traditional and modern dishes: breads, porridges, snacks, baby foods, fast foods, nutritional powders, and even millet wine [10]. Widely consumed in various regions of India such as Odisha, Madhya Pradesh, Rajasthan, Jharkhand, Karnataka and Uttarakhand [10].

Millet has long been a staple of the local diet [10]. Today, it is also attracting considerable interest for its potential as a functional food, particularly due to its phytochemical compounds, which have beneficial effects on digestive and metabolic health [10].

Millets as Functional Foods : Nutritional Properties and Supplement Potential

Millet stands out from other cereals due to its high content of dietary fiber, antioxidants, and protein. It is also rich in essential amino acids—except for lysine and threonine—and contains significant amounts of sulfur-containing amino acids such as cysteine and methionine. Its nutritional composition includes 60–70% starch ; 7–11% protein ; 2–7% crude fiber, 1,5–5% fat ; and various flavonoids [10].

Despite their many nutritional and environmental benefits, millets are still underutilized and rarely found in contemporary diets.

In addition, millets are gluten-free and rich in essential vitamins and nutrients such as iron, calcium, potassium, zinc, and magnesium, essential fatty acids, and amino acids [11] reported that foxtail millet is an excellent source of protein with a value of 14% ; and that brown millet was rich in fiber and zinc ; with 16,08% and 66,10 mg, respectively.

Kodo millet exhibited an impressive iron content of 206,5 mg, while a high calcium level was observed in pearl millet (3811,98 mg). Moreover, millets contain more lipids than sorghum, rice, and maize [10].

[8] reported that pearl millet and foxtail millet are rich in micronutrients such as calcium (10-348 mg/100 g) ; iron (2,2-17,7 mg/100 g) ; zinc (0,4-2,8 mg/100 g) ; and phosphorus (189-293 mg/100 g) ; as well as vitamins such as thiamine (0,15-0,60 mg/100 g) ; niacin (0,89-4,6 mg/100 g) and riboflavin (0,9-0,28 mg/100 g). Millet contains essential amino acids that ensure its contribution to human nutritional security when consumed [10].

In fact, consuming millet helps prevent metabolic disorders and correct lifestyle-related disorders. As it is administered in food form, it is easy to consume and has greater bioavailability [8]. Dietary trials with millet supplementation have shown encouraging results in terms of health and performance.

Trials on dietary supplementation with millet have been promising, showing improvements in health and performance, including anemia [8]. Regular supplementation with a healthy blend of several varieties of millet (kodo millet, foxtail millet, finger millet, and wheat with added legumes) in primary school children in India had a positive effect on increasing anthropometric indices [8].

[12] observed a significant increase in the weight of preschool children after supplementation with amylase-rich malted millet mixtures over a period of 4 months. A randomized clinical trial program based on a dietary approach using pearl millet ladoo (an Indian dessert) showed a significant increase in mean hemoglobin (Hb) levels in adolescent girls [8]. Dietary supplementation of school-going adolescent girls with millet porridge improved hemoglobin levels [8].

Millet: A Dietary Ally in the Prevention of Lifestyle-Associated Disorders

Malnutrition remains a global scourge, affecting 22.3% of children under the age of 5 with stunted growth according to the WHO, while noncommunicable diseases (NCDs) continue to wreak havoc, causing nearly 41 million deaths annually, or 74% of all deaths worldwide [8]. Among these NCDs, cardiovascular diseases are the leading cause of death with 17,9 million deaths, followed by cancer (9,3 million) and diabetes (2 million) [8].

At the same time, obesity now affects 16% of adults, and its prevalence has more than doubled over the last 30 years, exacerbating these diseases [8].

In this context, millets appear to be key nutritional allies, thanks to their unique composition and proven beneficial effects. Their low digestible starch content (around 3%), combined with a high level of phenolic compounds capable of inhibiting the enzymes α-amylase and α-glucosidase, gives millet significant hypoglycemic properties [8].

Experimental studies show that β-glucan extracted from *Eleusine coracana* effectively inhibits these enzymes, reducing carbohydrate digestion and lowering postprandial blood sugar levels. In diabetic animal models, millet-based diets reduce blood glucose levels, lower oxidative stress, limit lipid peroxidation, and improve glucose tolerance [8].

In humans, regular consumption of millet has been shown to significantly lower fasting blood sugar and HbA1c levels, which are key indicators of glycemic control. In terms of cardiovascular health, millet is rich in phytosterols and pinacosanols, which act to lower LDL cholesterol, the main risk factor for atherosclerosis [8].

For example, millet bran oil reduced lipid accumulation and adipose hypertrophy in animal studies, while improving the gut microbiota with a beneficial increase in *Akkermansia* and *Prevotellaceae* bacteria [8].

The dietary fiber and protein in millet also help lower blood pressure by inhibiting angiotensin-converting enzyme (ACE), with significant reductions in systolic and diastolic blood pressure observed in hypertensive patients who consume millet [8].

Furthermore, as cancer is a major cause of death, millet stands out for its strong antioxidant properties, which help prevent the growth of cancer cells. For example, kodo millet extracts can inhibit the proliferation of colorectal cancer cells by up to 100%, while foxtail millet extracts block the growth of breast and liver cancer cells [8].

In addition, certain compounds in foxtail millet bran promote apoptosis in colorectal cancer cells and prevent their migration. Black sorghum, rich in powerful antioxidant compounds, also shows antiproliferative activity comparable to that of quercetin. Thus, millets have significant potential in the prevention and control of cancer [8].

Finally, millets play a key role in regulating thyroid function thanks to their high manganese content, an element essential for hormonal homeostasis. Their resistant starch and tannins modify digestion by forming complexes with starch, thereby reducing calorie absorption, which promotes weight management and combats obesity, an aggravating factor in NCDs [8].

As a result, millets are a multifunctional food solution that can prevent and mitigate major diseases such as diabetes, cardiovascular disease, hypertension, thyroid dysfunction, and obesity, while also being an accessible and sustainable traditional food.

Beyond their metabolic effects, millets also play an essential role in intestinal health, a key axis of immune and metabolic regulation, thus reinforcing their value in the prevention and management of lifestyle-related diseases.

Contribution of millet to gut microbiota health

Incorporating millet into the diet significantly improves gut health and overall nutrition thanks to its high dietary fiber content, which accounts for approximately 15 to 20% of its composition [13].

These fibers consist mainly of non-starch polysaccharides, particularly arabinoxylan and β-glucan, which are known for their beneficial effects on the digestive system. Insoluble fibers, such as cellulose and hemicellulose, increase stool volume by up to 30%, promoting regular bowel movements and preventing constipation [14].

At the same time, soluble fibers, such as beta-glucans, arabinoxylans, and pectins, have gelling properties that increase the viscosity of intestinal contents, thereby reducing the absorption of macronutrients [8]. This mechanism leads to an average reduction of 15-20% in postprandial blood sugar spikes and a 10-15% decrease in blood LDL cholesterol, thereby helping to prevent metabolic diseases [8].

These soluble fibers are fermented in the colon by gut microbiota bacteria, such as Bacteroides and Bifidobacterium, producing short-chain fatty acids (SCFAs) such as acetate, propionate, and butyrate [15].

These SCFAs play a fundamental role in intestinal and metabolic health: they reduce intestinal permeability, which decreases the passage of toxins to the liver and bloodstream, thereby reducing systemic inflammation [8]. Butyrate, in particular, stimulates the repair of the intestinal mucosa by increasing epithelial cell migration by 25 to 40% and creates an anaerobic environment that limits the proliferation of pathogens such as *E. coli* and *Salmonella* [8].

In addition, the insoluble fiber in millet increases the water retention capacity of stool, improving intestinal transit with an average reduction in transit time of 12 to 24 hours, which promotes the elimination of toxins [8].

Resistant starch, which accounts for a significant proportion of the carbohydrates in millet, acts as a prebiotic, increasing the population of beneficial bacteria such as *Bifidobacterium*, *Lactobacillus*, and *Akkermansia* by 30 to 50% [8]. These changes in the gut microbiota are associated with a significant improvement in metabolic markers, with a 10 to 25% reduction in insulin resistance and a decrease in systemic inflammatory factors [8].

However, processing millet, particularly hulling, results in a significant loss of fiber. For example, hulling more than 30% of the grains can reduce the fiber content by 40–50%, thereby diminishing the beneficial effects on gut health (80). Milling also affects the insoluble fiber content, which is lower in milled flours compared to whole grains [16]. In contrast, sprouting increases fiber content, with increases of up to 20 to 35% depending on the sprouting time [17].

The effects of millet consumption on the microbiota have been demonstrated in several animal studies. For example, a millet-based dietary supplement restored intestinal microbial diversity in pigs suffering from acute malnutrition, reducing the presence of pathogenic bacteria by up to 40% [8]. In addition, millet fermentation increases the abundance of beneficial bacteria such as Pediococcus and reduces that of pathogenic bacteria, contributing to optimal microbial balance [8].

Increased production of SCFAs by the microbiota fermenting millet fibers is associated with a significant reduction in the risk of obesity and type 2 diabetes, with decreases of 15 to 30% in fat mass and glycated hemoglobin indicators [8].

Finally, millet has a significant gastroprotective effect. The polyphenols present in the inner shell of foxtail millet bran have demonstrated notable anti-inflammatory activity in cellular and animal models, reducing inflammatory markers by more than 30% [8].

This millet also reduces gastric ulcers by lowering plasma and mucosal levels of thiobarbituric acid reactive substances (TBARS) by nearly 40%, while increasing antioxidant and digestive enzyme activities by 20 to 35% [8].

These combined effects strengthen the protection of the gastric mucosa and contribute to better overall digestive health. The polyphenols present in millet, which are poorly absorbed in the small intestine, mainly reach the colon, where they undergo biotransformation by the intestinal microbiota [18].

This process is fundamental because colonic bacteria metabolize these polyphenols into bioactive metabolites, including phenolic acids such as protocatechuic acid, as well as short-chain fatty acids (SCFAs) such as butyrate, acetate, and propionate, which account for approximately 90% of the total SCFAs produced in the intestine [18].

These metabolites play a crucial role in strengthening the intestinal barrier, modulating the immune response, and neutralizing free radicals, thereby reducing local oxidative stress [18].

At the same time, regular consumption of millet promotes the proliferation of beneficial bacteria such as Bifidobacterium and Lactobacillus, known for their probiotic effects, while inhibiting the growth of pathogenic bacteria, thus contributing to a balanced and healthy intestinal ecology [18]. This symbiotic interaction between polyphenols and microbiota not only improves the bioavailability of antioxidant compounds, but also activates key cellular pathways such as Nrf2 and NF-κB [18].

Activation of Nrf2 leads to the transcription of genes encoding major antioxidant enzymes such as heme oxygenase-1 (HO-1), NAD(P)H quinone oxidoreductase 1 (NQO1), and glutathione S-transferase (GST), which effectively protect cells from damage induced by reactive oxygen species (ROS) [18].

In addition, the polyphenols in millet inhibit the activation of NF-κB, thereby limiting the production of pro-inflammatory cytokines such as TNF-α and IL-6, reducing chronic inflammation associated with metabolic and cardiovascular diseases [18].

In short, thanks to their high content of fermentable fiber and polyphenols, millets play a key role in intestinal health by modulating the composition and activity of the microbiota, promoting the production of antioxidant and anti-inflammatory metabolites, and activating protective cellular mechanisms [18]. These combined effects are particularly relevant in the context of irritable bowel syndrome (IBS), where dysbiosis and intestinal inflammation contribute to the onset of symptoms. Thus, consuming millet could help reduce oxidative stress and local inflammation, limiting the intensity and frequency of clinical manifestations. This combined mechanism also contributes to the prevention of chronic diseases linked to oxidative stress and inflammation, such as diabetes, cardiovascular disease, and certain cancers.

Conclusion

Millet grains, rich in protein, fiber, vitamins, minerals, and bioactive compounds, offer significant nutritional and therapeutic potential. Their anti-inflammatory, prebiotic, and antioxidant properties promote beneficial modulation of the gut microbiota, thereby improving digestive health.

These effects are particularly relevant for individuals with persistent gastrointestinal disorders, such as irritable bowel syndrome (IBS), where microbiota balance and inflammation control are crucial.

However, while data from preclinical research indicate that millet may alleviate IBS symptoms by influencing intestinal fermentation and short-chain fatty acid production, rigorous clinical research is needed to validate these benefits in humans.

A better understanding of the interaction between millet fiber, the microbiota, and irritable bowel syndrome could pave the way for the development of new tailored nutritional approaches to facilitate the management of this complex disorder.

Thus, millet appears not only as a valuable source of nutrients, but also as a promising functional food capable of supporting gut health and improving the quality of life for patients with IBS and other digestive disorders.

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