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The role of fiber in gut health and chronic diseases: a comprehensive review

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REVIEW PAPER

Abstract

The gut microbiota is vital for human health but contributes to various conditions ranging from inflammation to obesity if there is dysbiosis. Diets lacking in fiber contribute to gut health issues. Fiber acts as a prebiotic by feeding gut bacteria while encouraging microbial diversity. Decreased barrier functioning, resulting from low levels of fiber, has been linked to various gastrointestinal disorders. Through butyrate production, diets rich in fiber reduce the risk of chronic diseases, such as heart disease and type 2 diabetes. This review focuses on the role of dietary fiber in gut health and chronic diseases linked to the gut. Further, customized nutrition plans are followed as a way to upsurge fiber uptake to the extent based on lifestyle, genetics, and the composition of each person's gut microbiome. Increasing fiber intake rendering to one's requirements enhanced the benefits of improving gut health, reducing inflammation, and the prevention and treatment of chronic diseases, such as cancer, diabetes, and cardiovascular diseases.

Keywords: gut microbiome; gut–brain axis; dietary habits; fiber-rich diet

Introduction

Background on gut health

The human gut puts up a complex ecosystem consisting of billions of bacteria, viruses, fungi, and archaea, affecting the immune system, metabolism, and digestion processes (Amato *et al.*, 2021). The gut microbiota is affected by genetic, nutritional, environmental, and lifestyle features that determine the overall health and disease susceptibility of an individual (Chang *et al.*, 2021). The gut microbiota has a strong impact on physiological functions by forming a symbiotic association with the host. In this regard, it aids energy metabolism by breaking down dietary fibers and producing short-chain fatty acids (SCFAs) that provide energy for intestinal epithelial cells and also regulate immunological responses (Delannoy-Bruno *et al.*, 2022). Moreover, through the stimulation of mucins and antimicrobial peptide synthesis, the microbiome manages the reliability of intestinal barrier and averts the colonization of pathogens (Schut *et al.*, 2021). Studies disclose that diseases, such as inflammatory bowel disease, obesity, diabetes, and neurodegenerative disorders, have been related to dysbiosis, or a disruption in gut microbiota (Fu *et al.*, 2022a). The gut microbiota instigates colonization at birth and is dynamic over time. A range of aspects influence the community's development, such as early nutrition, nursing, antibiotic use, and delivery methods (Beller *et al.*, 2022). Species of *Bifidobacterium* and *Lactobacillus*, which endorse immune system maturation and digestion, are predominant in the gut microbiome during infancy. Diversity upsurges with age and matures in adulthood (Cobo-López *et al.*, 2022). However, during the lifespan, the composition of microbiomes remains dynamic and has a variable impact from dietary habits and environmental exposures to medical considerations (Goyal *et al.*, 2015). The novel investigation now focuses on the role of gut microbiota in chronic diseases. For instance, alteration in microbial composition relates to lipid metabolism and altered levels of insulin sensitivity that result in metabolic diseases (Lee *et al.*, 2024). The immunological dysregulation induced through gut dysbiosis is further linked with inflammatory diseases, such as Crohn's disease and ulcerative colitis (Fachi *et al.*, 2024). Microbial metabolites affect mental health as well as cognitive purpose through the gut–brain axis, an axis of bidirectional statement between the gut and the central nervous system (CNS; Oyarzun *et al.*, 2022). The conservation of physiological balance and overall wellness is contingent on gut microbiota. Its configuration and purpose can be understood to help avert and accomplish disease. For better gut health and deterrence of chronic diseases, upcoming studies must emphasize on custom-made microbiome-centered treatments, which comprise probiotics, prebiotics, and dietary variations (Delannoy-Bruno *et al.*, 2022).

Role of diet in gut health

The human gut microbiota influences immunological reactions, neurological procedures, and metabolic actions, all of which are vital for the overall health (Amato *et al.*, 2021). Diet is probably one of the significant factors influencing the diversity, functioning, and robustness of gut microbes (Delannoy-Bruno *et al.*, 2022). The current paper is centered on the investigation of the relationship between diet and gut health as influenced by macronutrients, micronutrients, dietary fiber, and specific food components. The gut microbial populaces are resolute by the specific functioning of macronutrients, such as proteins, lipids, and carbohydrates. The chief source of energy for gut microorganisms is dietary carbohydrates, mainly polysaccharides, which endorse the growth of beneficial bacteria (Beller *et al.*, 2023). On the contrary, dysbiosis, characterized by reduced diversity and increased richness in taxa that promote inflammation, is related to a high fat diet (Lee *et al.*, 2024). Protein ingestion is also said to impact gut health, while on average, plant-based proteins can better sustain the diversity of microorganisms as opposed to animal-based proteins (Geng *et al.*, 2021). Dietary fiber has been recognized to be essential for the maintenance of gut health, because it promotes the production of SCFAs and good bacterial populaces (Delannoy-Bruno *et al.*, 2022). According to Chang *et al.* (2021), such SCFAs, such as butyrate, propionate, and acetate, are significant for immunomodulation, metabolic regulation, and gut barrier integrity*et al.*. Diets rich in fiber have been revealed to avert metabolic diseases and decrease inflammation by altering gut microbiota conformation (Cobo-López *et al.*, 2022).

Vitamins, minerals, and other micronutrients play an important role in keeping the steadiness of gut microbes. Microbial metabolism and immunological functioning are regulated by vitamins D and B (Fu *et al.*, 2022a). According to Fachi *et al.* (2024), minerals, such as iron and zinc, also affect the functioning of intestinal barrier and bacterial development, which, in turn, affect inflammation and infection. Some of the powerful dietary components altering gut microbiome include probiotics, polyphenols, and artificial sweeteners. Plant-based diets rich in polyphenols decrease gut-related inflammation, causing increased diversity (Osborn *et al.*, 2022). Probiotics and prebiotics contribute toward increasing healthy counts of microbes by contributing to the overall digestive health as well as to more desirable metabolic output (Manrique *et al.*, 2016).

Artificial sweeteners also are associated with variations in gut flora, and may lead to metabolic dysregulation as detected by Trevelline and Kohl (2022). Apart from digestion, there is a connection between gut flora, food, and health. Oyarzun *et al.* (2022) stated that dietary patterns affect the gut–brain axis, where metabolites produced by the microbiota impact mood regulation and neurological functioning. Additionally, nutrition-induced changes in the microbiota affect metabolic diseases, such as type 2 diabetes and obesity (Rowan *et al.*, 2017). According to Gao *et al.* (2018), dietary variables and chronic pressure act synergistically to change the gut microbiota conformation, which effects inflammation and immunological reactions. Long-term dietary habits influence microbial variety, metabolic functions, and the overall health, thus establishing nutrition as an essential determinant of gut microbiota. The diet rich in nutrients and fiber supports a good gut flora, while excessive consumption of fat, sugar, and artificial additives can lead to dysbiosis and metabolic diseases. Understanding these dietary influences can help guide personalized nutritional therapies for enhancing gut fitness and systemic well-being.

Focus on fiber

Dietary fiber, tranquil, mostly of multifaceted carbohydrates, is the indigestible part of plant-based diets. It plays a significant role in both general metabolic functions and gut health (Martel *et al.*, 2022). Two main forms of fiber exist: soluble and insoluble fiber. Soluble fiber liquefies in water to produce a gel-like material that binds to fatty molecules in the digestive tract, giving long-lasting satiety and potential compensation for managing weight and metabolic health (Suresh *et al.*, 2024). Moreover, dietary fiber is one of the main regulators of gut microbiota composition that influences fermentative activity which is beneficial for SCFA and diversity of microorganisms (Loo *et al.*, 2020; Martel *et al.*, 2022). It is more and more acknowledged that the interaction between gut microbiota and dietary fiber intake assists in the deterrence of chronic diseases, such as obesity, diabetes, and cardiovascular diseases (CVDs) (Donovan, 2017; Gomaa, 2020; Zeng *et al.*, 2018). Insoluble fiber absorbs water in the gut, adding mass to stool, and although both types of fiber are good for the gut, they work in different ways. Here soluble fiber, common in foods, such as oats, beans and apples, comes in handy (Bishehsari *et al.*, 2018); it works hard at feeding friendly bacteria living (and working) inside the gut microbiome, which then produces SCFAs for the energy needed by the cells of colon lining (Carlson *et al.*, 2018). Insoluble fiber, which is present in whole grains, nuts and vegetables, helps to avoid constipation and reduces the risk of colorectal cancer by speeding up food passage through the digestive tract, thereby limiting the period for which any harmful substances are in contact with internal walls (Calatayud *et al.*, 2021).

A fiber-rich diet is linked with a reduced risk of numerous chronic illnesses, such as heart disease, type 2 diabetes, and definite types of cancers. Dietary fiber is more than just a gut therapist (Wang *et al.*, 2021). These benefits are believed to be related to the gut microbiota-modulating effects of fiber. For example, regarding the etiology and pathophysiology of obesity-related diseases, other than hypertension, SCFA production by fiber-fermenting bacteria downregulates inflammatory cascades (Bishehsari *et al.*, 2018), improves insulin sensitivity during development and instantaneous biological time, and regulates appetite while reducing body weight (Tremblay *et al.*, 2020). It may also bind bile acids in the gut and help excrete them with faeces, lowering cholesterol levels, which are linked to heart diseases (Bishehsari *et al.*, 2018).

Objective of the review

This review aims to deliver readers with a widespread understanding of how fiber-rich diet supports intestinal health and averts chronic diseases. The review deliberates the mechanisms through which fiber affects the gut bacteria composition, absorption of SCFAs, and the overall health of gut tissues. The review also highlights how the consumption of fiber helps in sustaining a balanced microbiota, boosts immunity, and is vital for preventing illnesses related to the gut. Such an approach of weighing both its advantages and possibly drawbacks, which may comprise causing gastrointestinal (GI) distress, the study considers numerous types of dietary fibers, their source, and possibly the effects thereof on different populations. A great deal could be made regarding diets that include much of fiber. High levels of fiber, when tailored definitely for an individual, help in a reduced risk of chronic diseases and eventually pave the way toward good health and well-being.

Understanding Gut Health

Microbiome composition: overview of gut microbiota and its role in health

Human gut microbiota is an extremely complex ecosystem, comprising trillions of bacteria, fungi, viruses, and archaea that are mainly present in the large intestine (Donovan, 2017; Rinninella *et al.*, 2019). These microorganisms, whose composition varies with environmental factors, age, and nutrition, play a critical role in immunological regulation, digestion, and metabolic health (Prasad and Bondy, 2019; Vinelli *et al.*, 2022). Dietary fibre types, especially soluble fibers, expressively participate in gut microbiota by encouraging the synthesis of advantageous SCFAs (Guan *et al.*, 2021; McRorie and McKeown, 2017 *et al.*). Recently, several chronic diseases have been associated with altered composition of microbiota, emphasizing the importance of fiber-rich diets to maintain gut health (Dong *et al.*, 2019; Matt *et al.*, 2018).

This microbial community contributes to various physiological functions, including digestion, nutrient absorption, immune modulation, and mental health (Cui *et al.*, 2019). The modulation of composition of gut microbiota is a multifaceted process regulated by different factors, such as diet and genetic age or environmental exposure that represent lifestyle discriminant; among its modulators, the most relevant ones are related to what we eat. For example, fiber-rich diets stimulate the growth of beneficial bacteria, such as *Bifidobacterium* and *Lactobacillus,* which are involved in maintaining gut barrier function and producing SCFAs, having a number of human health benefits (Chen *et al.*, 2019). Figure 1 illustrates the composition of gut microbiome and how dietary fiber impacts it.

The diversity and equilibrium of gut microbiota are the key factors to health. A healthy microbiome can confer

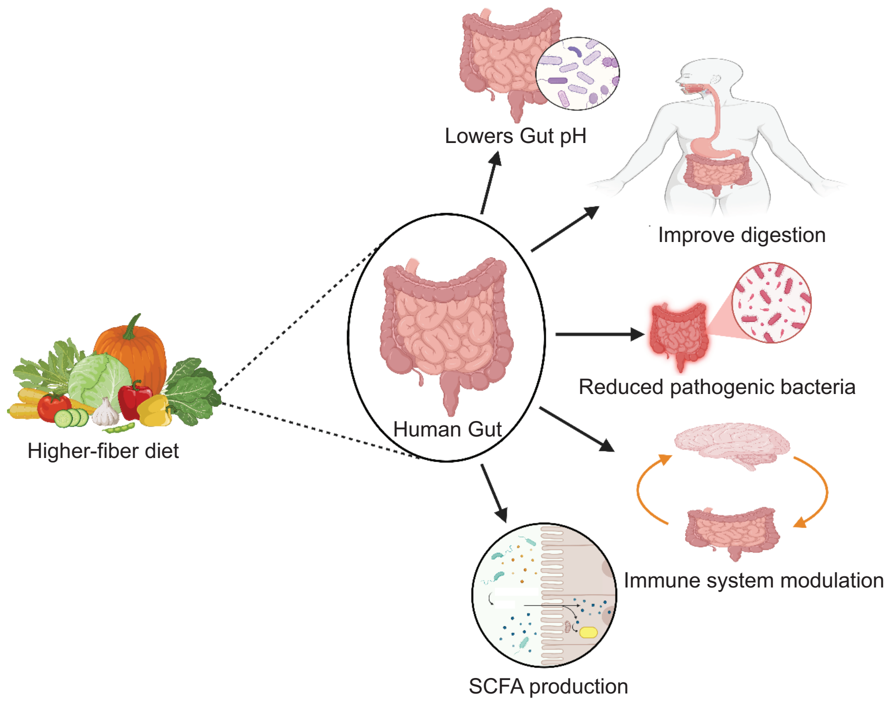

Figure 1. Impact of dietary fiber on gut microbiome.

multiple benefits, and a loss of diversity in the bacterial community dysbiosis is tightly associated with various diseases, such as inflammatory bowel disease (Chakrabarti *et al.*, 2022), obesity, metabolic syndrome, etc. The common causes of dysbiosis are antibiotic therapies, infection, or a high-fat and low-fiber diet. Dysbiosis or disproportion of gut microbiota may promote the expansion of disease by facilitating the overgrowth of pathogenic bacteria, enhancing intestinal permeability, and endorsing chronic inflammation (Rinninella *et al.*, 2019). Since dietary fibers play a key role in regulating the composition and activity of gut microbiota, the preservation of microbial diversity through diet and lifestyle is important for the overall health (Donovan, 2017; Vinelli *et al.*, 2022). Both soluble and insoluble fibers enhance the development of SCFAs and aid in the advancement of a good bacterium, which has a key interaction with better immune and metabolic functions (Guan *et al.*, 2021; Prasad and Bondy, 2019). Regular intake of fiber from fruits, vegetables, and whole grain helps decrease inflammation and upholds gut homeostasis (Cui *et al.*, 2019; Joye, 2020).

Gut barrier function: explanation of gut lining and its role in immune function

The gut or intestinal barrier is an intricate system that contributes centrally to balance homeostasis and defend the body against harmful compounds. This barrier consists of a monolayer of intestinal epithelial cells linked by protein claudins and occludins that prevent pathogens, toxins, and undigested food particles from translocating into the bloodstream (Dai and Chau, 2017). This barrier provides a critical defense against systemic inflammation and immune tolerance. The gut microbiota plays many crucial roles in the proper functioning of intestinal lining, and one such role is that it helps to maintain the integrity of this barrier. SCFAs, particularly butyrate, are an energy source for colonocytes and one of the key signaling molecules that helps to maintain the integrity of gut barrier (Debnath *et al.*, 2019). An intact and effective gut barrier protects the immune system from harmful substances (such as bacterial endotoxin), which would otherwise enter the general circulation, contributing to chronic inflammation that drives many diseases (Chen *et al.*, 2019). The integrity of gut barrier is heavily influenced by dietary patterns. Diets rich in fiber strengthen GI barrier as they improve the production of SCFAs and promote eubiotic gut microbiota (Guan *et al.*, 2021; Vinelli *et al.*, 2022). The amendment of gut microbiota through fiber consumption largely inspires gut homeostasis and the overall health circumstances (Cui *et al.*, 2019; Donovan, 2017).

Guts–brain axis: discussion on the connection between gut health and mental health

The gut–brain axis is a bidirectional network that links CNS with peripheral functioning of the enteric nervous system (ENS) (Bailén *et al.*, 2020). Motor activities in the gut involve a complex interaction that employs neural innervation and hormonal and immunological signals, with an important impact on the microbiota present at this level (Chakrabarti *et al.*, 2022). New studies even hint that the gut microbiota can control something as complex and diverse in expression as brain function, leading to anxiety, depression, or stress-related ailments (Calatayud *et al.*, 2021). There are a few ways in which the gut–brain axis works. First, the most important way microorganisms in the gut influence brain functioning is by producing neurotransmitters and neuroactive compounds (Hills *et al.*, 2019). Some gut bacteria strains, such as *Clostridium sporogenes*, have been shown to produce neurotransmitters, such as gamma-aminobutyric acid (GABA), serotonin, and dopamine, key molecules that control mood, anxiety, and cognition (Chakrabarti *et al.*, 2022). Moreover, gut microbiota can modulate systemic levels of inflammatory cytokines that also affect brain function and behavior. Gut dysbiosis can drive this increased production of cytokines, which have subsequently been implicated in mood disorders and cognitive decline (Debnath *et al.*, 2019). It becomes apparent that the health of these gut critters or their balance and the overall integrity of the wall is a key for mental functioning. Increased intestinal permeability can result in an abnormal lipopolysaccharide (LPS) and other endotoxins passage across the gut barrier responsible for inducing neuroinflammation, which has been linked to depression and mental pathologies (Chakrabarti *et al.*, 2022). Accessory SCFAs generated by fiber fermenting gut bacteria also have neuroprotective benefits, further underscoring the critical roles of dietary fiber in maintaining wellness at both ends (Cui *et al.*, 2019).

The gut microbiota associated with major mental health disorders has been proposed as a potential causative factor of these conditions, and diet has been indicated to influence prevention, alleviation or treatment (Dinan and Cryan, 2017). The composition of gut microbiota, its diversity, and the integrity of both GI barrier and the part directed to communicate with the brain, that is, the ENS, are the associated factors together contributing toward perturbing or controlling health over time (Shah *et al.*, 2020).

Dietary Fiber: Types and Sources

Types of dietary fiber: soluble vs. insoluble fiber and their distinct roles

One of the most important nutrients for any diet is fiber, which has two varieties: dietary soluble and insoluble fiber. Each type of fiber has a unique function in supporting health, especially gut health.

Soluble fiber

Soluble fiber dissolves in water to form a gel-like material and assists in controlling blood sugar and cholesterol levels (McRorie and McKeown, 2017). This type of fiber can easily be fermented by gut bacteria, and these bacteria break it down into SCFAs, such as butyrate, acetate, and propionate, that are important for health of the gut (Guan *et al.*, 2021). SCFAs are a source of energy for colonocytes, decrease inflammation, and strengthen the gut barrier, thereby endorsing the overall GI homeostasis (Prasad and Bondy, 2019; Vinelli *et al.*, 2022). When soluble fibre is fermented, it encourages *Bifidobacteria* and *Lactobacilli* to proliferate to promote more diversity of gut microflora, which leads to a preventional dysbiosis (Donovan, 2017; Holscher, 2017). Oatmeal, pulses, oranges, carrots, and barley are the staple diet containing more dietary soluble fiber because it benefits gut, lowers cardiac ailments, and controls blood sugar levels in diabetics (Jones, 2014; Rinninella *et al.*, 2019). Besides, by absorbing water, deferring digestion, and boosting fullness, soluble fiber aids in weight control (Thompson *et al.*, 2017). Such mechanisms comprise binding with bile acids in the colon and thus plummeting its availability for cholesterol metabolism (Khan *et al.*, 2018). Given the plethora of health benefits, it is not surprising that dietary advice has progressively placed a premium on foods rich in soluble fiber for ornamental gut microbiota composition, metabolic health management, and longer-term well-being (Cui *et al.*, 2019; He *et al.*, 2022). Natural sources, their benefits, and impacts of soluble fiber are mentioned in Table 1.

Insoluble fiber

Insoluble fiber does not dissolve in water, contrary to soluble fiber. It also prevents constipation by bulking up stool, thereby enhancing ease of food passing through the gut (McRorie and McKeown, 2017). Insoluble fiber is mainly non-fermentable; thus, it doesn't contribute to SCFAs in the synthesis of gut microbiota. On the other hand, its structural features are vital for maintaining digestive integrity and preventing intestinal diseases, such as piles and diverticulosis (Donovan, 2017). Insoluble fiber is found in wheat bran, nuts, seeds, and fruit and vegetable peels. These foods encourage GI motility, accelerate the colonic transit time, and enhance fecal size (Esteban *et al.*, 2017; Rinninella *et al.*, 2019). Studies have shown that insoluble fiber reduces the development of chronic diseases in the gut by enhancing gut regularity and avoiding constipation (Vinelli *et al.*, 2022).

In addition, mechanical possessions of insoluble fiber are connected to ornamental gut homeostasis through

Table 1. Soluble fibers and their impact on gut health.

Soluble fiber type	Natural sources	Benefits	Impact on gut health	References
Inulin	Chicory root, garlic, onion	Prebiotic effects	Promotes beneficial bacteria growth	Hiel *et al.*, 2019
Pectin	Apples, citrus fruits	Reduces cholesterol	Enhances production of short-chain fatty acids (SCFAs)	Bishehsari *et al.*, 2018
Beta-glucans	Oats, barley	Lowers LDL cholesterol	Stimulates immune function	Hills *et al.*, 2019
Psyllium	Psyllium husks	Relieves constipation	Improves gut motility	Jha *et al.*, 2019; Jovanovski *et al.*, 2021
Guar gum	Legumes, guar beans	Controls blood sugar	Modifies gut microbiota composition	Carlson *et al.*, 2018; Yasukawa *et al.*, 2019
Arabinoxylans	Whole grains, bran	Antioxidant properties	Enhances microbiota diversity	Makki *et al.*, 2018
Fructooligosaccharides	Bananas, asparagus	Improves calcium absorption	Promotes bifidobacteria	Tanes *et al.*, 2021
Resistant starch	Green bananas, potatoes	Supports weight management	Increases SCFA production	Koh *et al.*, 2016; Ojo *et al.*, 2020
Cellulose	Vegetables, grains	Adds bulk to stool	Supports gut integrity	Peredo-Lovillo *et al.*, 2020
Algal polysaccharides	Seaweed	Anti-inflammatory effects	Encourages beneficial microbiota	Mayrhofer, 2019; Spencer *et al.*, 2021
Xylooligosaccharides	Corn, bamboo shoots	Improves gut metabolism	Stimulates lactobacilli	Fuller *et al.*, 2016
Lactulose	Dairy products	Treats hepatic encephalopathy	Supports bifidobacteria growth	Holscher, 2017
Chitosan	Shellfish, fungi	Antibacterial properties	Regulates intestinal flora	Calatayud *et al.*, 2021
Agar	Seaweed	Promotes satiety	Supports SCFA production	Mayrhofer, 2019
Hemicellulose	Whole grains	Reduces inflammation	Balances gut pH levels	Tangestani *et al.*, 2020
Mucilage	Flaxseed, okra	Soothes GI tract	Protects gut lining	Nie *et al.*, 2021
Polyphenol-associated	Tea, cocoa	Antioxidant activity	Modifies gut microbiome	Loo *et al.*, 2020
Alginates	Seaweed	Reduces appetite	Enhances gut viscosity	Vinelli *et al.*, 2022
Soluble Corn Fiber	Corn	Increases calcium absorption	Supports gut microbiome	Jakeman *et al.*, 2016; Tan *et al.*, 2020; Whisner *et al.*, 2016
Soluble dextrin fiber	Potato starch	Supports weight control	Improves gut dysbiosis	Czarnowski *et al.*, 2024; Emilien *et al.*, 2020
Blueberry soluble fiber	Blueberries	Reduces gestational diabetes risk	Enhances gut health	Basu *et al.*, 2021
Fenugreek soluble fiber	Fenugreek	Enhances physical endurance	Modifies gut microbiome	Herrick *et al.*, 2020
Mixed soluble fibers	Various sources	Improves renal anemia	Alters gut microbiota composition	Li *et al.*, 2022
Hydrolyzed guar gum	Guar beans	Improves fecal characteristics	Modifies gut microbiota	Yasukawa *et al.*, 2019
High-soluble fiber spaghetti	Wheat-based pasta	Modifies glycemic response	Supports gut metabolism	Papakonstantinou *et al.*, 2022
Novel dietary fiber	Various plant sources	Enhances satiety, lowers glucose levels	Alters gut microbiome	Wu *et al.*, 2023

modulation of the structure of microbiota and reinforcement of intestinal barrier integrity (Baky *et al.*, 2024; Prasad and Bondy, 2019). Because dietary insoluble fiber may help to dilute possible carcinogens and speed their elimination from the intestines, its deficiency is associated with augmented risks for cancer development of the colon and rectum (Ran *et al.*, 2021). In addition, through its roles in aiding weight control and reducing the potential for complications because of obesity, insoluble fiber positively affects metabolic health (Dong *et al.*, 2019; He *et al.*, 2022). A diet containing adequate insoluble fiber is necessary for the overall GI health. Its significance in supporting intestinal rhythm, diversity of microbiome, and reducing the incidence of chronic diseases is reflected in the latest dietary guidelines (Cui *et al.*, 2019; Hussain *et al.*, 2020; Lamothe *et al.,* 2021). Future investigations into the complex interplay between insoluble fiber, gut microbiota, and metabolic health should be conducted to maximize its functional benefits in human nutrition (Han *et al.*, 2023; Meldrum and Yakubov, 2024). Insoluble fiber types and their impact on gut health are shown in Table 2.

Natural Sources of Fiber

Many foods come from plants or plant-based items, such as whole grains, legumes, and fruits, which make the gut happy when consumed in larger amounts (Rezende *et al.*, 2021). Good sources of dietary fiber are fruits, vegetables, whole grains (brown rice or whole wheat pasta, legumes, beans, and peas), nuts, and seeds. This way, one gets diverse fiber types and other nutrients from each group in a compounded manner that generally encourages good health. Figure 2 shows soluble and insoluble fiber types in various foods (Afzaal *et al.*, 2022; Benítez-Páez *et al.*, 2016; Carlson *et al.*, 2018; Dinan and Cryan, 2017; Holscher, 2017; Joye, 2020; Koh *et al.*, 2016; Kumar *et al.*, 2020; Rezende *et al.*, 2021).

Fruits and vegetables

Fruits and vegetables are filled with both soluble and insoluble fiber. Fruits that are high in soluble fiber, such as berries, oranges, pears, and apples, decrease cholesterol and keep blood sugars under control (Hussain *et al.*, 2020). Fruit skins (not bananas, but that of apples and pears) are the best source of insoluble fiber that aids digestion and does not cause constipation (Cui *et al.*, 2019). Broccoli, brussel sprouts, and carrots contain a healthy dose of fiber, providing combination of soluble fiber that acts as prebiotics to keep good bacteria in the gut strong. Leafy greens have less fiber than root vegetables listed, but they should still be included as part of an overall fiber-rich diet because leafy greens are a rich source of other essential nutrients, such as vitamins A, C, and K (Dinan and Cryan, 2017).

Whole Grains

Whole grains, such as amaranth grain, contain tremendously smooth insoluble fiber, another outstanding source of dietary fiber. Brown rice can avert many gut disorders and endorses a healthy intestine because of a high fiber reserve (Joye, 2020). Whole grains, including oats, contain soluble fiber, which is especially effective at helping reduce LDL cholesterol and improve heart health. In whole grains, more insoluble fiber can be found in the bran section, making it a very effective tool for adding bulk to stool and regularizing bowel movements (Jha *et al.*, 2019).

Legumes

Many types of beans, as well as lentils, chickpeas (garbanzo beans), and peas, are the legumes especially high in fiber. A balanced combination of soluble and insoluble fiber, these nutrients result in a healthy digestive track, with controlled blood sugar level, that keeps a person feeling full (Jha *et al.*, 2019). If anyone wants to increase the intake of fiber in diet, legumes are the best option because they are rich in fiber and are highly beneficial, particularly for vegetarians and vegans. Legumes are also a rich source of potassium, magnesium, iron, and protein (Korczak and Slavin, 2020).

Nuts and seeds

Seeds and nuts, including almonds, flaxseeds, chia seeds, and walnuts, are rich in dietary fiber. Soluble and insoluble fiber types, together with healthy fats, proteins, and numerous vitamins and minerals, are abundantly found in these foods (Benítez-Páez *et al.*, 2016). Flaxseeds and chia seeds are the top picks for soluble fiber, which can

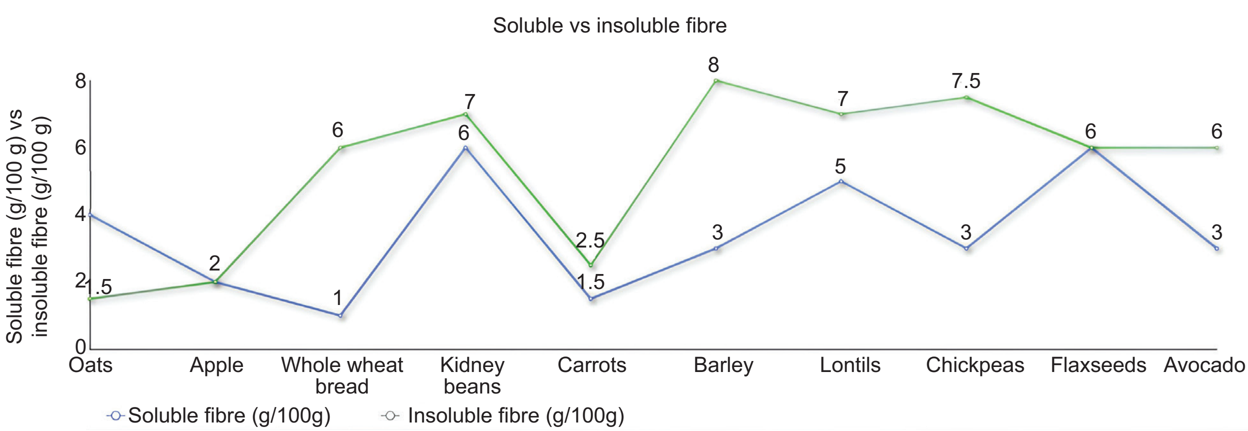

Figure 2. Soluble versus insoluble fiber.

Table 2. Insoluble fiber types and impact on gut health.

Insoluble fiber type	Natural sources	Benefits	Impact on gut health	References
Cellulose	Whole grains, fruits, and vegetables	Supports bowel regularity	Promotes stool bulk and enhances peristalsis	Kudou *et al.*, 2022; Turner and Lupton, 2021
Hemicellulose	Cereal grains, nuts, and legumes	Increases water-holding capacity	Facilitates softer stools and improved transit time	Hiel *et al.*, 2019; Moreira *et al.*, 2024
Lignin	Flaxseeds, carrots, and wheat bran	Antioxidant properties	Protects gut lining and aids microbiota diversity	Cantero *et al.*, 2017; Holscher, 2017
Resistant starch	Unripe bananas and cooked/cooled potatoes	Enhances satiety	Produces short-chain fatty acids (SCFAs) upon fermentation	Jha *et al.*, 2019; Liu *et al.*, 2020; Miao *et al.*, 2024
Chitin	Shellfish and mushrooms	Binds toxins in the gut	Contributes to detoxification and gut health	Morrison *et al.*, 2020
Raffinose	Beans and Brussels sprouts	Prebiotic effects	Promotes growth of beneficial bacteria	Makki *et al.*, 2018
Arabinoxylans	Wheat and corn bran	Enhances stool consistency	Reduces inflammatory markers	Iversen *et al.*, 2022; Merenkova *et al.*, 2020
Polyphenolic fibers	Berries and tea leaves	Combats oxidative stress	Modulates gut microbiota composition	Arikawa *et al.*, 2017; Loo *et al.*, 2020
Pectic substances	Apples and citrus peels	Supports bile acid metabolism	Improves microbiota integrity	Mayrhofer, 2019
Xylan	Corn husk and barley	Improves digestibility	Aids mucosal barrier strengthening	Martin-Gallausiaux *et al.*, 2021
Glucan	Oats and barley	Lowers cholesterol	Enhances SCFA production	Korcz *et al.*, 2018
Mannans	Guar gum and locust bean gum	Enhances stool bulk	Influences gut bacteria diversity	Nie *et al.*, 2021
Galactans	Lentils and chickpeas	Prebiotic activity	Increases bifidobacteria	Hiel *et al.*, 2019
Fructooligosaccharides	Onions and garlic	Reduces pathogen adherence	Supports gut barrier functions	Tang *et al.*, 2017
Psyllium	Psyllium husk	Soothes GI distress	Enhances stool bulk and SCFA production	Kudou *et al.*, 2022; Shah *et al.*, 2020
Beta-glucans	Oats and barley	Immunomodulation	Improves gut epithelial health	Holingue *et al.*, 2020
Inulin	Chicory root and asparagus	Prebiotic effects	Enhances bifidobacteria and SCFA production	Hiel *et al.*, 2019
Resistant dextrins	Corn fiber and wheat fiber	Improves glycemic control	Promotes SCFA production	Mao *et al.*, 2021
Mucilages	Cactus and aloe vera	Soothes intestinal lining	Reduces GI inflammation	Malipatlolla *et al.*, 2021; Remes-Troche *et al.*, 2021
Tannins	Tea and coffee	Antioxidant properties	Modulates microbiota to reduce inflammation	Koh *et al.*, 2016; van Trijp *et al.*, 202
Konjac glucomannan	Konjac root	Improves stool bulk and lipid metabolism	Alters gut microbiota in obese individuals	Li *et al.*, 2022

help reduce cholesterol and grow good gut bacteria (Korcz *et al.*, 2018). Furthermore, the fiber in nuts and seeds decreases blood sugar levels and assist in averting type 2 diabetes (He *et al.*, 2022).

Recommended fiber intake: overview of dietary guidelines for fiber consumption

No specific daily recommended intake (DRI) of fiber is established because referrals may differ with age, gender, and health status. Typically, adults have a DRI of fiber set at 25–38 g/day (Fu-Shin *et al.*, 2022). According to the National Academy of Medicine, an individual should take at least 25 g/day of fiber. Males aged <50 years should consume up to 38 g/day of fiber (Xie *et al.*, 2021). For individuals aged ≥50 years, a slightly reduced intake of fiber is recommended. The requirement for males after this age increases to about 30 g/day, and for females, the requirement is 21g/day, which is explained by a drop in calorie intake with age (Li *et al.*, 2020; Liu *et al.*, 2020). The studies have found that the mean intake of fiber in most industrialized nations is still manifold lower, although dietary guidelines call for its adequate intake (Baky *et al.*, 2024). For instance, the average consumption of dietary fiber is only around 15 g/day in the United States. In contrast to what is usually suggested, this intake is remarkably small (Cui *et al.*, 2019). 'Fiber gap,' is associated with increased risk for chronic diseases, including coronary heart disease, type 2 diabetes, and numerous forms of cancers (He *et al.*, 2022; Korczak and Slavin, 2020). A key reason for the gap in fiber intake is the lack of dietary fiber in fruits, vegetables, and whole grains, which are crucial for gut health and overall metabolic balance (Joye, 2020).

Studies have shown that the structure and activities of gut microbiota are beneficially altered by insoluble dietary fiber, which is for the most part, not subject to degradation in the digestive system (Baky *et al.*, 2024; Wang *et al.*, 2021). The insoluble fiber maintains homeostasis of the gut and reduces inflammation through the modulation of gut motility and through being a fermentable substrate to the Probiotics (Hussain *et al.*, 2020; Katsirma *et al.*, 2021). With relationship to its impact on gut microbiota, the preventive role of fiber against chronic diseases is well established. Studies showed that insoluble dietary fiber, especially in cereals and plant foods, enhances metabolic health, increases the production of SCFAs, and alters gut microbial diversity (Han *et al.*, 2023; Wang *et al.*, 2019). Dietary fiber influences the body's immune response and decreases the prevalence of metabolic illnesses by acting upon intestinal mucus layers and biochemical pathways (Capuano, 2017; Meldrum and Yakubov, 2024). Reducing the fiber gap, therefore, requires a multilevel approach, including the development of new products rich in fibers, public health campaigns, and education about the benefits of fiber-enriched food. This variance may be addressed by cumulative ingesting of fruits, vegetables, whole grains, and underutilized plant-based fiber sources, with the possibility of advancing public health consequences (Barrett *et al.*, 2020; Stephen *et al.*, 2017). In addition, personalized nutrition plans that individualize fiber intake recommendations based on person's specific gut microbiota composition are likely to be more beneficial for health (De Roos and Brennan, 2017; Jinnette *et al.*, 2021). This is demonstrated by the huge health risk that the existing fiber gap presents in affluent countries.

Studies have revealed that insoluble dietary fiber plays a key role in the deterrence of chronic diseases and the general promotion of health (Dreher, 2018; Tosh and Bordenave, 2020). The development of gut and metabolic health of the population would be certified by rectifying this nutritional gap through diet variation and public health policies. Therefore, increasing the consumption of fiber-rich foods is essential to bridge fiber gap, considering the overall public health. The best form of dietary fiber comes from whole, plant-based foods, and there is no shortage of healthy options that can be included in a well-rounded diet (Miller, 2020). Figure 3 shows data comparing the recommended daily fiber intake with the average intake in different regions (Afzaal *et al.*, 2022; Benítez-Páez *et al.*, 2016; Carlson *et al.*, 2018; Dinan and Cryan, 2017; Gill *et al.*, 2021; Holscher, 2017; Hussain *et al.*, 2020; Katsirma *et al.*, 2021; Kumar *et al.*, 2020; Venter *et al.*, 2022).

Role of fiber in gut health

Fiber is vital for a healthy microbiome because it helps to determine the abundance and types of ends in the colon, promotes normal bowel movements crucial to prevent autointoxication by removing waste products quickly from the body at least once daily, and supports gut lining integrity (Loo *et al.*, 2020). Arguably, the most important factor in gut health is a diverse diet rich in fiber, which can help to maintain balance between various species of beneficial bacteria and pathogens that form part of person's normal flora (Fuller *et al.*, 2016). In the presence of fiber in the diet, it is fermented by gut bacteria to form SCFAs. They offer several health benefits: immune-boosting, anti-inflammatory, and a possible anticancer effect for colon cancer (Koh *et al.*, 2016). Dietary fiber binds with water, which is essential to support health of the digestive system, because this provides stool a greater volume and improves the speed with which it moves through the digestive system. Apart from the treatment of constipation, this procedure decreases the prevalence of GI disorders by aiding the removal of old impacted waste (Baky *et al.*, 2024). Fiber intake is also important for gut homeostasis because it manifests that the balance of microbiota is maintained and averts diseases, such as diverticulosis and irritable bowel syndrome (IBS; Cui *et al.*, 2019; Hussain *et al.*, 2020). While soluble fiber is vital in the regulation of cholesterol and for the production of SCFAs, which are beneficial for gut health, insoluble dietary fiber, which is found in whole grains, fruits, and vegetables, assists immensely with bowel regularity (Joye, 2020; Korczak and Slavin, 2020). Fiber plays an important role in the regulation of gut microbiota, influencing metabolic health, and averting chronic conditions, such as obesity and CVDs, as demonstrated by recent studies (Tosh and Bordenave, 2020; Wang *et al.*, 2021). The optimal intake of dietary fiber, from both natural and added sources, including whole fruits, vegetables, legumes, and nuts, is necessary to sustain long-term health and reduce the risk of diseases, considering the widespread 'fiber gap' that is impacting various populations (Ioniță-Mîndrican *et al.*, 2022; Stephen *et al.*, 2017).

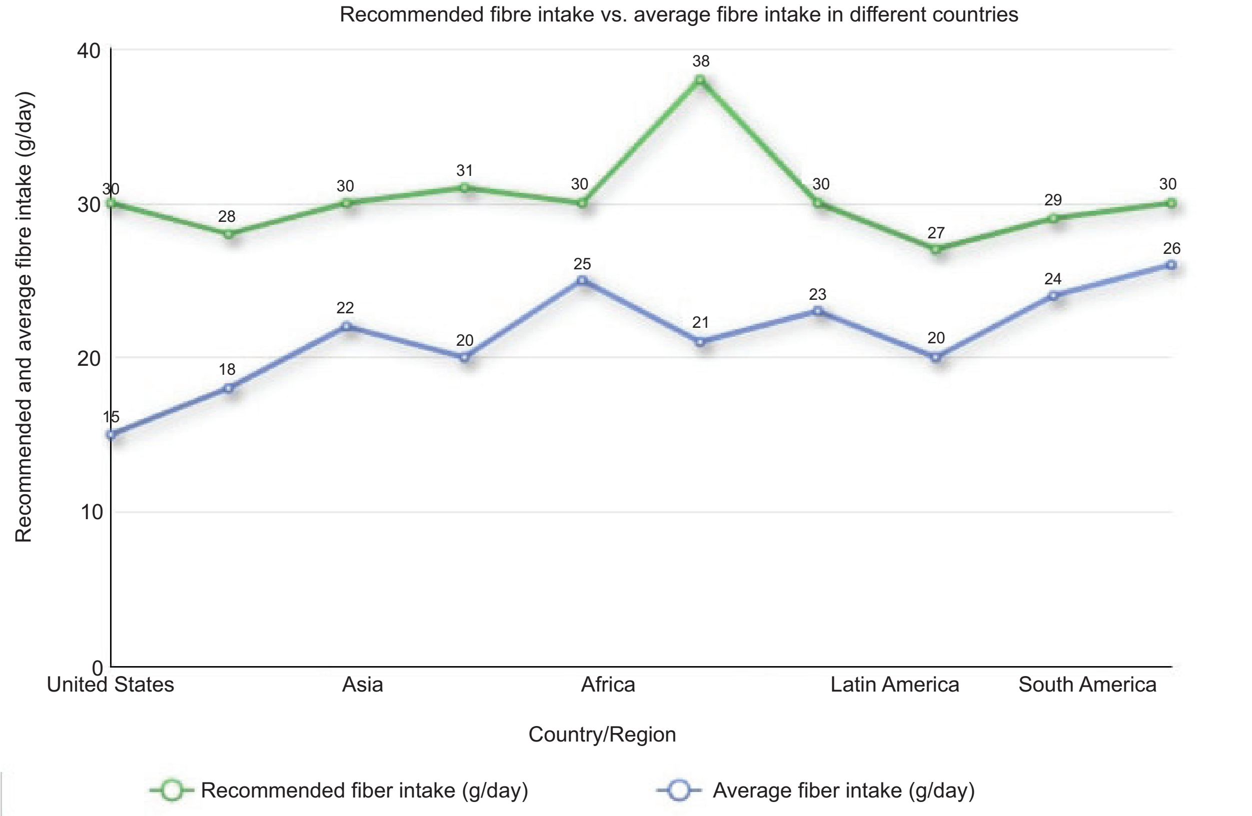

Figure 3. Recommended fiber intake versus average intake in different countries.

Mechanisms by which fiber influences gut health

Dietary fiber is an essential component of gut health and acts through multiple pathways. The breakdown of fiber by bacteria in the colon leads to production of SCFA, prebiotic effects on the composition and functioning of gut microbiota, effects motility, and stimulates to improve gut barrier. The more one knows about these mechanisms, the better one can understand how a fiber-rich diet benefits the digestive health and helps to prevent GI disorders. Figure 4 shows how dietary fiber influences gut health.

Fermentation and short-chain fatty acids

Gut bacteria require dietary fiber for performing fermentative process to produce SCFAs, such as butyrate, propionate, and acetate. Delannoy-Bruno *et al.* (2022) stated that some fiber polysaccharides impact the synthesis of SCFA and the composition of gut microbiota to impact proteome profiles within plasma and thereby the health conditions. As their study suggests, dietary interventions may specifically enhance SCFA production to support immunological reaction and the reliability of gut barricade. Similarly, Fachi *et al.* (2024) highlighted the relationship between SCFA production and the defense of microbiota in contradiction to enteric infections. According to their study, changes in interleukin 22 (IL-22) signaling influence microbial metabolism, thereby enhancing the anti-inflammatory properties of SCFAs and strengthening host apologetic system. These consequences demonstrate the importance of fiber-mediated SCFA synthesis in ensuring both GI and immunological homeostasis.

The most important mechanism by which dietary fiber affects gut health is fermentation, particularly that of the SCFAs produced when certain bacterial species ferment fibers (Portincasa *et al.*, 2022). SCFAs are produced during fermentation when bacteria break down fiber into components that include acetate (precursor energy and a signaling molecule), propionate (which influences the liver) and butyrate; SCFA plays a major role in gut health and metabolism (Lee and Kim, 2021). Figure 5 shows the fermentation and production of SCFAs.

Butyrate

Butyrate serves as a major source of energy for colonocytes (i.e., the cells lining the bowels). SCFAs, such as butyrate, support the preservation of gut barrier integrity, helping to enhance mucus production and promoting

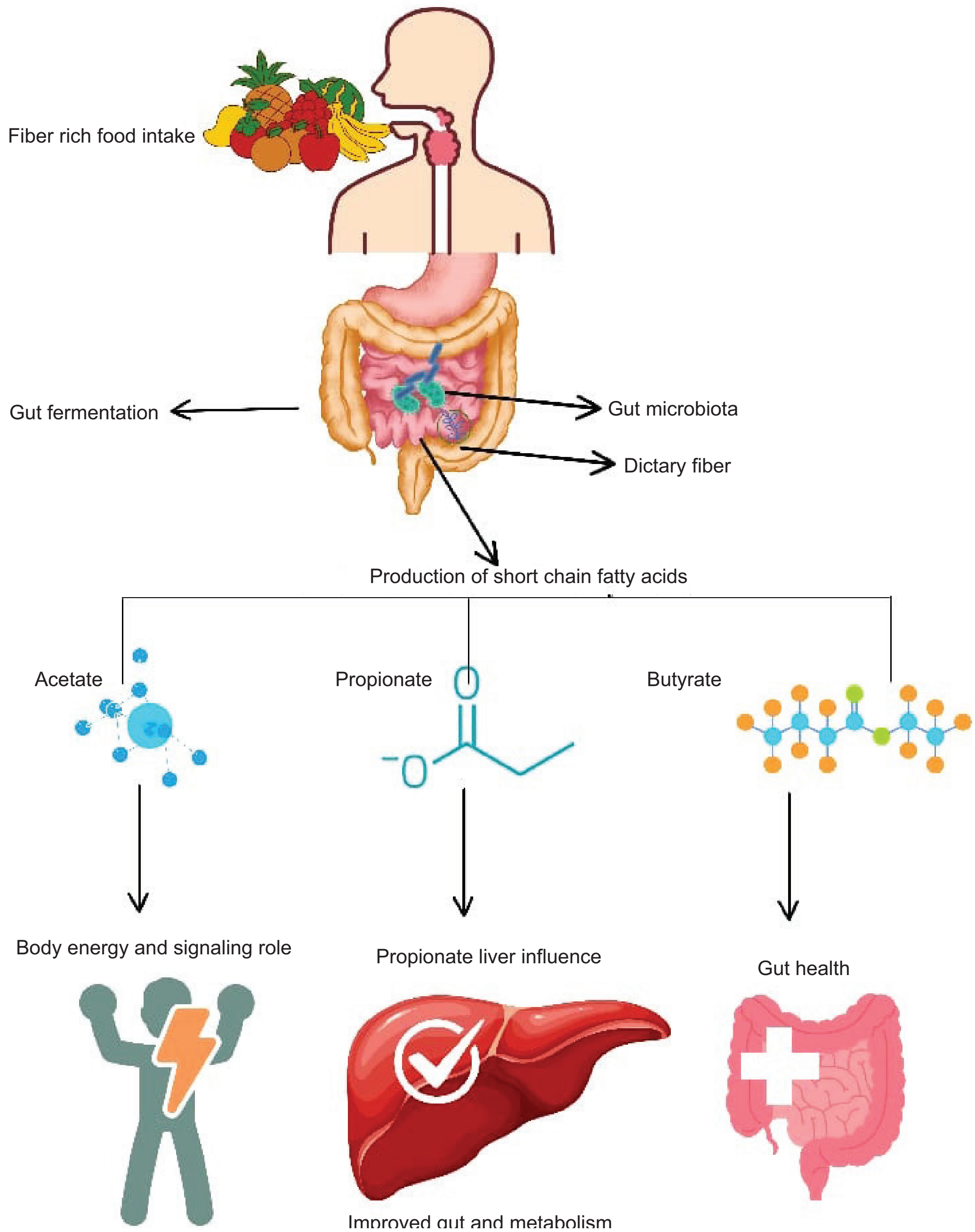

Figure 4. Influence of dietary fiber on gut health.

tight junctions between cells that inhibit harmful pathogens from moving through microscopic openings into the blood (Salamone *et al.*, 2021). Furthermore, butyrate is anti-inflammatory, reduces the risk of chronic inflammation, and IBD and decreases probability of colorectal cancer (Martin-Gallausiaux *et al.*, 2021).

Acetate and propionate

Acetate and propionate play a second important role in gut health, acting as signaling molecules that can change many metabolic processes (Koh *et al.*, 2016). The most abundant SCFA, that is acetate, is also responsible for regulating appetite and energy homeostasis (Carlson *et al.*, 2018). More importantly, it may penetrate the blood brain barrier and act on the hypothalamus to reduce appetite, potentially affecting weight control (La Torre *et al.*, 2021). Propionate is mainly absorbed in the liver and enters gluconeogenesis (Martin-Gallausiaux *et al.*, 2021) and participates in glucose regulation. The acidic pH of the colon also suppresses pathogenic

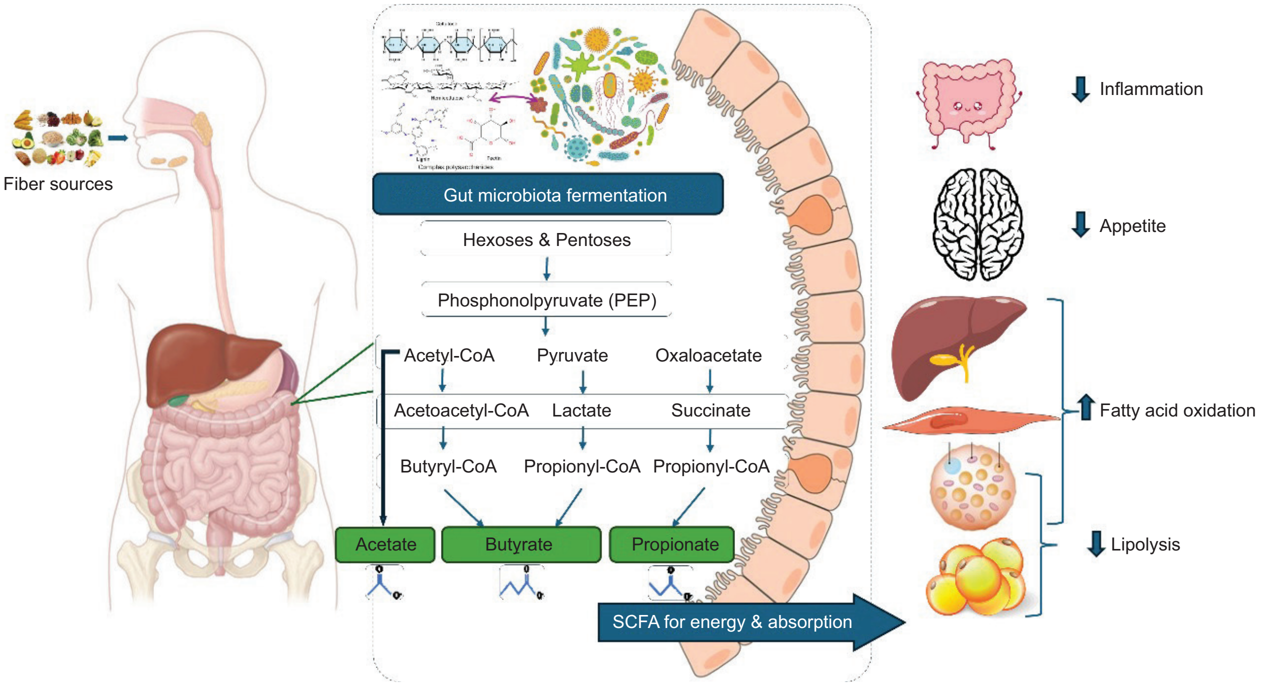

Figure 5. Fermentation and production of short-chain fatty acids.

bacteria and increases the concentration of more beneficial bacterial species (Fuller *et al.*, 2016), which is a gain for gut health: SCFAs and their organic processing in the gut are associated with better immune functioning due to their capacity to affect immune cells and suppress pro-inflammatory cytokines production (Martin-Gallausiaux *et al.*, 2021). Figure 6 shows sample data on the production of SCFAs at different levels of fiber intake (Calatayud *et al.*, 2021; Camerotto *et al.*, 2019; Carlson *et al.*, 2018; Koh *et al.*, 2016; Makki *et al.*, 2018).

Prebiotic effects

Dietary fibers, especially fermentable fibers, are prebiotic compounds that encourage the growth and activity of beneficial gut bacteria. Prebiotics (e.g., inulin, fructo-oligosaccharides [FOS], and galacto-polysacharides) help to feed good gut bugs, such as *Bifidobacteria* or *Lactobacilli*, which have been associated with various health benefits (Lee and Kim, 2021). They keep the gut healthy by preventing pathogens from adhering to host cells and causing infection by competing for resources and adhesion sites on intestinal epithelium (Seradj *et al.*, 2018). Prebiotic fibers provide a more populated and healthier area while avoiding soil disruption. Selectively stimulating beneficial bacteria by prebiotic fiber helps to maintain microbial diversity, which is essential for gut resiliency and stability. It also increases the production of SCFAs when prebiotic fibers are consumed, further supporting the later effects (Mörkl *et al.*, 2020). Consumption of prebiotic substrate is suggested to confer health benefits through their association with the well-being of probiotics. Prebiotics feed beneficial bacteria (probiotics), perpetuating a symbiotic gastrointestinal tract (GIT) ecosystem (Peredo-Lovillo *et al.*, 2020).

Impact on gut motility

Gut motility, or how quickly and efficiently one poops, is a separate issue but also a very important aspect of digestive health influenced by fiber (Kranz *et al.*, 2017). Dietary fiber is important for preserving GI health because it preseves gut motility and prevents a number of digestive glitches. Insoluble fiber does not dissolve in water, which makes stool more voluminous and upsurges its passage through the digestive system. This increases the bulk stimulating stretch receptors within the colon to initiate peristalsis, wave-like muscular contractions that move food down the digestive tract, according to McRorie Jr. and McKeown (2017) and Baky *et al.* (2024).

Soluble fiber reduces the risk of constipation and conditions, such as diverticulosis, in which small sacs in the walls of the colon are inflamed and infected, by stimulating the movement of bulky stool (Baky *et al.*, 2024; Dreher, 2018). Fiber assists is in the prevention

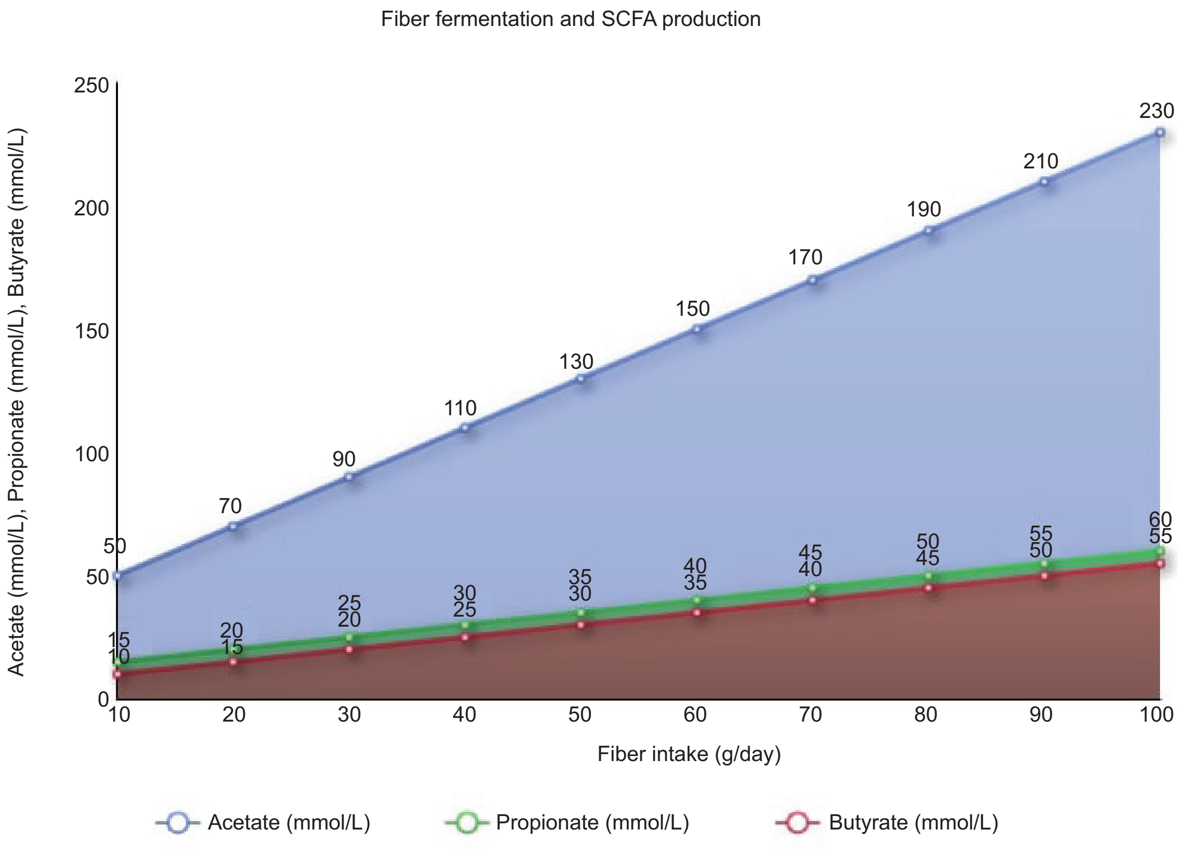

Figure 6. Fiber fermentation and production of short-chain fatty acids.

of diarrhea but also in the treatment of constipation. Soluble fiber slows digestion, which manifests that loose stool becomes firmer and evades coming out in a liquid form; insoluble fiber makes the size of stool bigger (McRorie and McKeown, 2017). Soluble fiber also delivers a gel inside the stomach. It shows the multimodal role of fiber in gut health by firming stools in the case of diarrhea and ornamental stool production in constipated patients (He *et al.*, 2022).

Insoluble fiber makes bowel motions easier and faster by keeping water in stool (Wang *et al.*, 2021). Colon health is preserved, and the risk of diverticulosis is reduced by frequent bowel movements (Dreher, 2018). Thus, in a more direct way, by encouraging sound bowel functioning and eliminating digestive disorders, ingesting high amounts of both soluble and insoluble fiber improves gut health in general. Moreover, indirect interactions with microbiome are shown to support gut homeostasis through fiber-rich diet available from whole fruits, vegetables, and grains (Cui *et al.*, 2019; He *et al.*, 2022). Such interaction of fiber with microbiome is essential for top-notch digestion and the overall health. Furthermore, its role in gut motility may also have repercussions for preventing other GI issues, such as IBS. Alternating periods of constipation and diarrhea are hallmark symptoms associated with IBS (Makki *et al.*, 2018). Still, dietary fiber, especially soluble fiber, such as psyllium, has been demonstrated to lessen these ailments by normalizing bowel functioning in humans.

Fiber and gut barrier integrity

The intestinal lining of the GIT provides an important barrier between the gut lumen and systemic circulation, thus preventing the translocation of toxic substances that, after being absorbed through inflammatory processes, contribute significantly toward the prevention of different diseases (Chen *et al.*, 2024). Gut barrier is a layer of precisely connected epithelial cells, topped by protective mucus. One of the keys to keep this barrier healthy is the dietary fiber (Carlson *et al.*, 2018). Butyrate is one of the most critical SCFAs formed from fiber, and is catabolized by gut bacteria. Butyrate enhances goblet cell production of mucus that protects gut lining from damage and infections (Meldrum and Yakubov, 2024). Intestinal permeability also decreases because of an increase in tight junction protein expression due to butyrate, thus hindering the influx of toxic substances (He *et al.*, 2022).

Further, secretory immunoglobulin A (IgA), which helps to neutralize pathogens and inhibit them from breaking through the intestinal barrier, is produced in larger amounts when a fiber-rich diet is taken (Wang *et al.*, 2021). These processes show the importance of fiber for functioning of the immune system and intestinal homeostasis (Baky *et al.*, 2024; McRorie and McKeown, 2017).

Fiber also acts in the gut immune system by affecting dendritic cell and macrophage action that detect pathogens (Mayrhofer, 2019; Fu *et al.*, 2022b). Some more indirect fiber-related effects on the gut barrier are due to changes within human microbiome, and it helps to maintain balance and microbial diversity. A diverse and balanced microbiota is less likely to contain pathogenic bacteria, which breaches gut barrier and causes inflammation (Liang *et al.*, 2018). In the end, the effects of dietary fiber on gut health are multifaceted. Gut bacteria help to ferment fiber and create SCFAs, contribute to the integrity of gut barrier, modulation of immune functioning and healthy microbiota (Basith *et al.*, 2022). The gut uses it as food for beneficial bacteria and has a role in the efficient functioning of bowel motility, thus preventing GI diseases. Owing to their support in gut barrier function, fiber-rich diet protects against chronic inflammation and associated diseases, thus demonstrating the necessity of adequate dietary fiber intake for the overall digestive health. Figure 7 presents sample data on gut permeability markers at different levels of fiber intake (Bishehsari *et al.*, 2018; Cui *et al.*, 2019; Basu *et al.*, 2021; He *et al.*, 2022).

Health Benefits of a Fiber-Rich Diet on Gut Health

Addition of dietary fiber to a diet provides positive health effects, especially for the intestines. The benefits of fiber go way beyond keeping a person regular in bathroom; it helps to prevent several digestive disorders and aids with weight management, among other things, such as reducing risk for chronic diseases, such as heart disease and diabetes. Figure 8 shows the importance of fiber intake by humans.

Prevention of gut-related disorders

Dietary fiber is critical in preventing and managing a variety of GI disorders, including IBS, Crohn's disease, and ulcerative colitis (Malipatlolla *et al.*, 2021). Dietary fiber also supports gut health by promoting colonic regularity and increasing stool bulkiness, resulting in improved transit time, which is a key to prevent constipation and associated ailments (Wang *et al.*, 2019). One of the important mechanisms by which fiber prevents gut-related disorders is inducing a fermentation process carried out by gut microbes. Consequently, SCFAs, such as acetate, propionate and butyrate, which exert anti-inflammatory effects (Wang *et al.*, 2019) while preserving gut barrier integrity, are produced in this process. These SCFAs are luminal energy substrates for colonocytes and exert anti-inflammatory effects on colonic mucosa, playing a pivotal role in suppressing inflammation, as

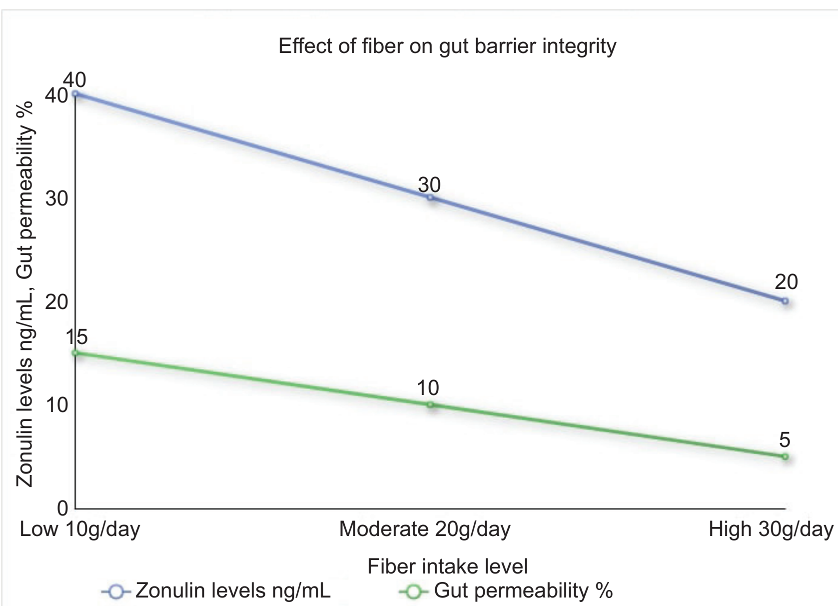

Figure 7. Effect of fiber intake on gut barrier integrity.

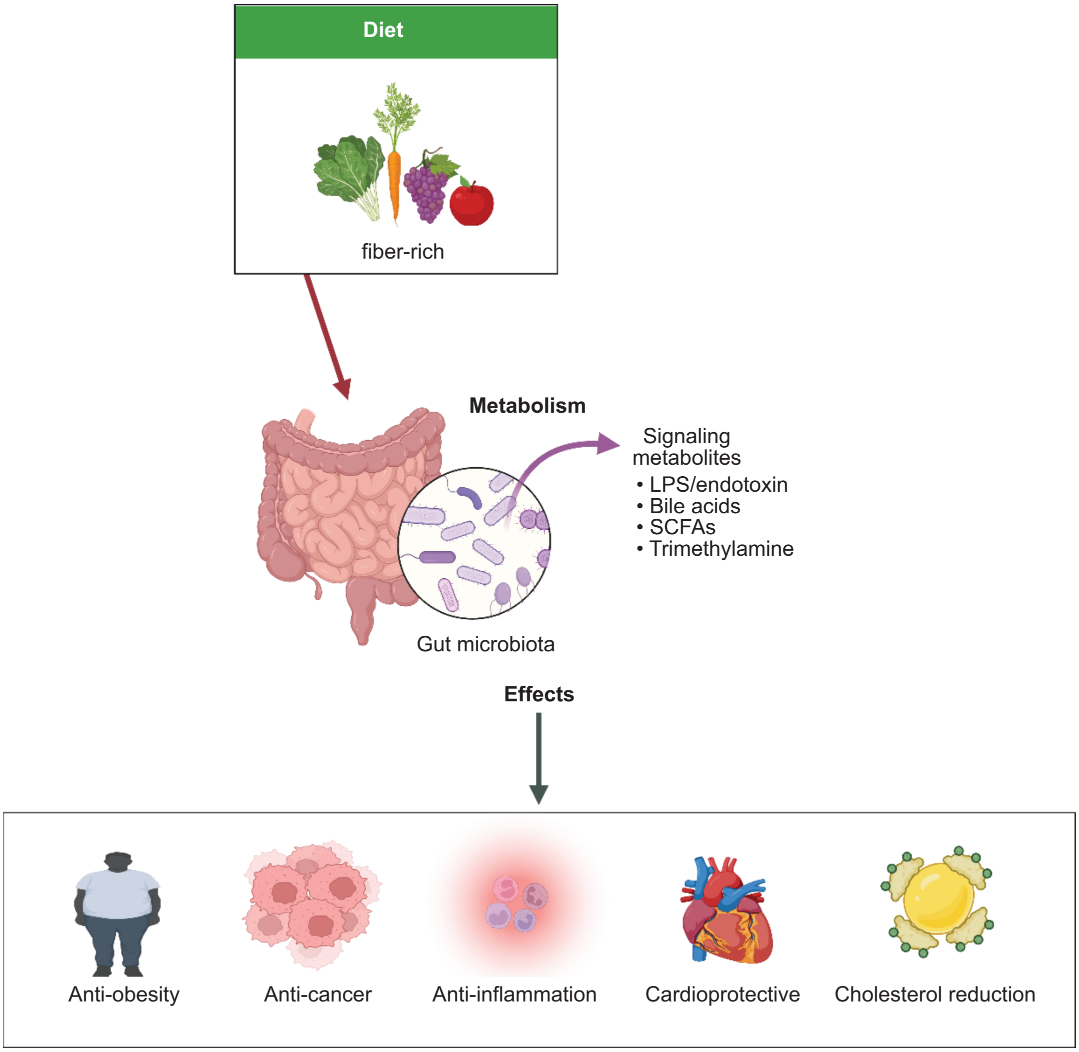

Figure 8. Why is fiber good?

observed in Crohn's disease or ulcerative colitis (Vinelli *et al.*, 2022). Fiber also prevents the disruption of intestinal microbiota balance, as dysbiosis is associated with different chronic GI diseases (Wang *et al.*, 2015).

Role in weight management

Dietary fiber has remained a valuable tool in weight management with properties such as its role in satiety, modification of gut microbiota, and reduced energy intake. According to Jovanovski *et al.* (2021), viscous fiber types, such as psyllium, produce a gel-like substance within the digestive tract that slows down stomach emptying and prolongs satiety. Meta-analyses of randomized controlled trials (RCTs) showed that the inclusion of these fibers in calorie-restricted diets significantly decreases waist circumference and body mass index (BMI). It not only changes the gut microbiota composition by increasing the abundance of bacteroidetes but also lowers the content of firmicutes, a ratio correlated to a more enhanced effect on weight management results (Delzenne *et al.*, 2020).

Long-term consumption of fibers produces systemic benefits as evidenced in case studies from the MyNewGut Consortium revealing that, in addition to their efficacy for weight-related measures, long-term consumption of fiber reduces the metabolic dysregulations attributed to obesity. The gut flora plays a crucial role in the impact of dietary fiber on weight management and metabolic health. Based on the contribution of fiber to microbial diversity and SCFA production, Waddell and Orfila (2023) studied the molecular mechanisms that link fiber intake with the prevention of obesity. These SCFAs influence energy homeostasis through the regulation of hunger hormones, such as ghrelin and leptin. Case studies through manipulation of gut microbiota exhibited significant reduction in obesity markers, such as those involving mice fed with soybean insoluble fibers (Wang *et al.*, 2021). Lee *et al.* (2024) studied the role of palmitic acid hydroxy stearic acids (PAHSAs) in diet fed to obese mice and established that their beneficial metabolic properties were reliant on gut flora. The microbiota is crucial for the regulation of metabolic reactions to dietary interferences, as the study demonstrated that PAHSAs increased insulin sensitivity and reduced inflammation, but these relations were not detected in chow-fed mice (Lee *et al.*, 2024). Moreover, dietary fibers were able to overwhelm several of the manifestations of metabolic syndrome, including reduced visceral adiposity and improved insulin sensitivity, based on clinical involvements such as the RESOLVE research (Tremblay *et al.*, 2020). All these consequences accentuate the position of dietary fiber as a foundational element for gut health and weight control. Because fiber is so filling and can help to keep full for longer period, it also plays an important role in controlling body weight (Camerotto *et al.*, 2019).

In contrast, soluble fiber types, such as those in oats, legumes, and some fruits that form a gel-like substance in the digestive tract, reduce the overall processing speed while promoting satiety (Turner and Lupton, 2021). Furthermore, the gut bacteria fermentation of fiber produces SCFAs that significantly affect energy homeostasis and appetite regulation. Acetate and propionate are two major SCFAs that are able to act as signaling molecules in gut hormones and neural pathways, which modulate energy balance (and control satiety), leading to decreased food intake, implicating a key role in weight management (Vinelli *et al.*, 2022; Wang *et al.*, 2019). Regular fiber consumption is associated with a healthy body mass index (BMI) and lower rates of obesity. (Tangestani *et al.*, 2020).

Impact on chronic diseases

It is widely known that dietary fiber, gut health, and prevention of chronic diseases are interrelated. Fiber consumption is associated with a decreased risk of developing diseases such as diabetes, heart disease, and colon cancer. Dietary fiber influences gut microbiota, which governs the course of chronic diseases. A substrate for gut microbiota, dietary fiber endorses the production of beneficial bacteria and SCFAs, both of which contribute to the reliability of gut barriers and the overall health (Feng *et al.*, 2020; Lin *et al.*, 2024). The intake of fiber modifies microbial connections, which are related to improved metabolic health and abridged inflammation. This helps to avert diseases, such as diabetes, obesity, and neurodegeneration (Laranjeiro *et al.*, 2019; Provensi *et al.*, 2019). Furthermore, it has been recognized that diet variations that adapt microbiome affect immunological responses, cognitive functioning, and pathogen resistance (Chen *et al.*, 2022; Querdasi *et al.*, 2023). This affects the prevention of chronic diseases; gut bacteria have structural functions and functional roles on host health (Mark Welch *et al.*, 2017; Rashidi *et al.*, 2021). Diet choices to exploit healthy consequences for longer periods may also be derived by considering these microbial paths.

Diabetes

Dietary fiber is one of the major contributors to prevent and manage type 2 diabetes. A fiber-rich diet can facilitate glycemic control by delaying glucose absorption rate, resulting in more stable blood sugar concentrations (Kaye *et al.*, 2020; Reynolds *et al.*, 2022). This is important, especially for people who have or are at risk of developing type 2 diabetes (Tangestani *et al.*, 2020). In addition, SCFAs generated through fiber fermentation enhance insulin sensitivity and decrease systemic inflammation, providing additional support for managing diabetes (Tang *et al.*, 2017; Turner and Lupton, 2021).

Through its interface with gut microbiota, dietary fiber significantly impacts the controlling and deterrence of diabetes through the regulation of metabolic pathways and inflammatory responses (Salamone *et al.*, 2021). Gut bacteria ferment fiber, producing SCFAs, such as butyrate, propionate, and acetate, which regulate glucose levels and enhance sensitivity to insulin (Fu *et al.*, 2022a; Salamone *et al.*, 2021). By favorably altering the composition of gut microbes, resistant starch, a type of dietary fiber, regulates blood sugar and reduces obesity risk (Liu *et al.*, 2020). According to case studies and an experimental study, inulin is a fermentable fiber, which enhances type 1 diabetes by elevating IL-22 and synthesis of SCFAs, thus reducing intestinal permeability and inflammation (Zou *et al.*, 2021).

A meta-analysis of soluble fiber supplementation established that soluble fiber supplementation significantly improves glycemic control and lowers hemoglobin A1C (HbA1C) in patients with type 2 diabetes. This suggests that fiber could be used as an adjuvant therapy (Xie *et al.*, 2021). In addition, systematic studies showed that through the promotion of beneficial bacterial species, such as *Bifidobacterium* and *Akkermansia muciniphila* in the gut microbiome, dietary fiber decreases insulin resistance and enhances glycemic control (Makki *et al.*, 2018; Mao *et al.*, 2021). For instance, controlled research established that patients on fiber-rich diets had better postprandial glucose control than those on low fiber diets (Ojo *et al.*, 2020).

Specific beneficial effects on gut microbiota with antidiabetic action are supported by bioactive dietary fiber types that increase SCFA generation and reduce oxidative stress and chronic inflammation (Nie *et al.*, 2021). The therapeutic efficacy of fiber is highlighted in a case report involving the dietary habits of patients with type 2 diabetes who received a diet rich in fermentable fiber, resulting in improvement in their lipid profiles and fasting blood sugar levels (Chi, 2023). In addition, since dietary fiber assists in enhancing metabolic parameters and diminishing systemic inflammation, it reduces the neuropathic effects of diabetes, including diabetic neuropathy (Fu *et al.*, 2022b; Hopek and Siniak, 2020).

According to Gao *et al.* (2018), long-term stress deranges the gut microbiota composition, raises intestinal permeability, and induces inflammation. These effects lead to metabolic diseases, such as diabetes. Their studies were able to prove that gut dysbiosis induced by stress triggers immune responses, along with exacerbating insulin resistance and impairing glycemic management. Thus, Gao *et al.* (2018) concluded that gut microbiota can significantly connect to metabolic well-being and psychological stress (*et al.*). A deeper understanding of the critical role that fiber plays in managing diabetes is underscored by the involvement of fiber in regulating gut microbiota and metabolic health (Adeshirlarijaney and Gewirtz, 2020; Schlesinger, 2022).

Cardiovascular disease

Soluble fiber is shown to reduce serum cholesterol levels by binding to bile acids in the gut and promoting their excretion (Davey *et al.*, 2024). Fiber also helps to maintain a healthy gut microbiota, which indirectly supports cardiovascular health, as disruptions in the population of microorganisms residing in the intestines (dysbiosis) are associated with an elevated risk for heart disease (Tang *et al.*, 2017). Dietary fiber meaningfully subsidizes to cardiovascular health by dropping the risk of CVD by lowering systemic inflammation, boosting gut microbial diversity, and improving lipid profiles (Reynolds *et al.*, 2022). Diets elevated in fiber are shown to reduce cholesterol and blood pressure, thus reducing vital risk factors for CVD (Trautwein and McKay, 2020).

According to Kaye *et al.* (2020), prebiotic fibers facilitate the fermentation of gut microbes in SCFAs, directly affecting metabolic pathways and lowering systemic inflammation. SCFAs such as butyrate modulate inflammation markers and endothelial functionality to regulate vascular function as well as prevent atherosclerosis and ischemic heart disease (Ruscica *et al.*, 2021). Long-term benefits of dietary fiber intake were noted by the NutriNet-Santé cohort trial, which revealed a relationship between rich fiber intake and decreased risks of CVD and mortality (Partula *et al.*, 2020).

On a similar note, Tosh and Bordenave, (2020) highlighted the cardiovascular benefits of soluble fibers extracted from barley and oats by reducing cholesterol and improving glycemic responses (Tosh and Birdenave, 2020). Global evaluations emphasize the need for fiber-rich dietary interventions to address this avoidable risk factor, because the burden of ischemic heart disease increases due to inadequate intake of dietary fiber (Wei *et al.*, 2024). In addition, fiber supplementation decreases inflammation and low-density lipoprotein (LDL) cholesterol in dyslipidemic individuals, thereby proving its ability to avoid CVD (Trautwein and McKay, 2020). Fiber influences gut microbiota composition by promoting beneficial bacteria that enhance the production of SCFA and reduce inflammation (Zhang and Gérard, 2022).

Low fiber intake has been linked to poor gut metabolite-sensing receptor signaling, which is related to increased CVD and hypertension risk (Kaye *et al.*, 2020). Whole grain is able to improve gut microbial diversity and lower oxidative stress, thus having good effects on heart health (Garutti *et al.*, 2022). Consistent with these results, positive effects are found to be associated with cardiovascular outcomes from plant-based, fiber-rich diets in patients suffering with familial hypercholesterolemia (Barkas *et al.*, 2020). In a nutshell, gut microbiota and dietary fiber play a crucial role in cardiovascular health. Because of substantiation from case studies and cohort research on the significance of fiber in plummeting the risk of CVD, it is an integral part of preventive healthcare strategies (Partula *et al.*, 2020; Reynolds *et al.*, 2022).

Cancer

Consuming a fiber-rich diet, especially one high in insoluble fibers, is related to lower rates of bowel cancer (Merenkova *et al.*, 2020). Soluble fiber produces bulkier stool, faster to transit through the colon, thus lessening the exposure time of potential carcinogens to intestinal linings (Tangestani *et al.*, 2020). Moreover, butyrate, one of the SCFAs produced from plant fiber fermentation, has anti-carcinogenic effects. It increases apoptotic body formation (programmed cell death) in colon cancer cells and slows the growth and proliferation of those who proliferate (Vinelli *et al.*, 2022). The impact of dietary fiber on cancer is through the alteration of gut microbiota, enhancement of immunological responses, and changes in metabolic pathways (Partula *et al.*, 2020). Butyrate has anti-inflammatory and anti-carcinogenic effects as it inhibits histone deacetylase activity and promotes death of cancer cells (Mirzaei *et al.*, 2021; Sun *et al.*, 2024). Butyrate demonstrates potential therapeutic target by its well-established role in preventing colorectal cancer (Shen *et al.*, 2020).

The National Institutes of Health and American Association of Retired Persons (NIH-AARP) Diet and Health Study discovered that high dietary fiber intake was inversely associated with colon cancer incidence, indicating the protective role of whole grains and fibers in cancer prevention (Hullings *et al.*, 2020). Dietary patterns characterized by high consumption of plant-based foods and high fiber intake decrease cancer risk and mortality, and this could be due to increased SCFA production and gut microbial diversity (Molina-Montes *et al.*, 2020). Probiotics and fiber-rich diets enhance immune checkpoint therapy outcomes according to melanoma immunotherapy research, pointing to the role of fiber in modulating immune responses to cancer (Spencer *et al.*, 2021). In addition, survival in pancreatic cancer has been linked to immune cell population and alignment of stroma fibers, emphasizing complex interactions between gut microbiota, tumor microenvironment, and dietary factors (Bolm *et al.*, 2020).

Dietary fiber alters gut microbiota, which impacts immune response and systemic inflammation, helping to prevent different cancers (Tao *et al.*, 2020). A Mediterranean diet rich in fiber significantly alters gut microbiota and metabolism, hence potentially lowering the risk of cancer (Ismael *et al.*, 2021). Stromal fiber alignment in cancer microenvironments is shown to affect cellular migration and energy use, providing insights into the mechanisms driving cancer progression (Zanotelli *et al.*, 2024). Low fiber intake in Western diet increases the menace of cancer because of dysbiosis. It leads to chronic inflammation, which emphasizes the need for dietary treatments to restore microbial balance (Clemente-Suárez *et al.*, 2023).

Studies on neuronal biomarkers and nerve density also indicate how dietary factors influence brain pathways related to the development of cancer (Ali *et al.*, 2022). In conclusion, the fact that case studies and experimental consequences indicate the association between dietary fiber and gut microbiota provides a bright prospect for cancer prevention as well as treatment (Clinton *et al.*, 2020). Clinical guidelines may offer an inexpensive way to alleviate the risk of cancer or enhance results if fiber-rich diets are a part of life. Figure 9 shows data on the relative risk of chronic diseases at various fiber intake levels (Fu *et al.*, 2022a; Li *et al.*, 2020; Liu *et al.*, 2020; Mao *et al.*, 2021; Ojo *et al.*, 2020; Xie *et al.*, 2021).

In short, the benefits of a high-fiber diet are much more than just healthy pooping (Ortega-Santos and Whisner *et al.*, 2019). Dietary fiber plays a key role in maintaining GI health, which is crucial to prevent digestive system diseases as well as to control and manage body weight that help to reduce chronic degenerative conditions, such as diabetes, CVD, and colorectal cancer (Baidoun *et al.*, 2021). The myriad benefits of fiber truly speak about its role in gut health and hence overall wellness, re-emphasizing the necessity for incorporating dietary fiber in everyday meals (Turner and Lupton, 2021; Vinelli *et al.*, 2022). Table 3 explains the role of fiber in managing gut-related disorders.

Challenges and Considerations in Fiber Intake

There are many issues and caveats to consumption for the best dietary experience—from individual variability in

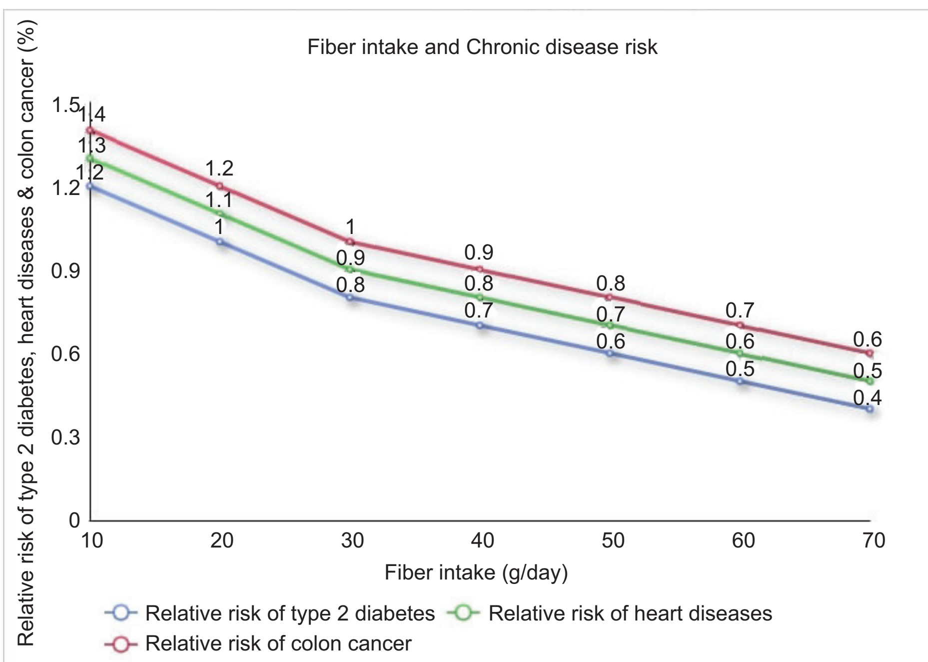

Figure 9. Fiber intake and risk of chronic diseases.

Table 3. Role of fiber in managing gut-related disorders.

Disorder	Role of fiber	References
Obesity	Modulates gut microbiota to improve metabolic functioning and regulate appetite	Guan *et al.*, 2021; Iversen *et al.*, 2022; Li *et al.*, 2022; Makki *et al.*, 2018; Perler *et al.*, 2023; Venter *et al.*, 2022
Metabolic syndrome	Enhances insulin sensitivity by promoting the production of short-chain fatty acids (SCFAs)	Koh *et al.*, 2016; Ojo *et al.*, 2020; Ye *et al.*, 2022; Eriksen *et al.*, 2020
Constipation	Increases stool bulk and improves bowel movement regularity	Gill *et al.*, 2021; Han *et al.*, 2023; Klinder *et al.*, 2016
Irritable bowel syndrome (IBS)	Alters fermentation patterns in the gut, reducing symptoms of bloating and discomfort	Armstrong *et al.*, 2021; Gill *et al.*, 2021; Klinder *et al.*, 2016; Korczak and Slavin, 2020
Inflammatory bowel disease (IBD)	Maintains gut epithelial integrity and modulates immune responses to reduce inflammation	Armstrong *et al.*, 2021; Bishehsari *et al.*, 2018; Partula *et al.*, 2020; Perler *et al.*, 2023
Colon cancer	Promotes SCFA production, especially butyrate, which suppresses tumor growth and promotes apoptosis in cancerous cells	Benítez-Páez *et al.*, 2016; Guan *et al.*, 2021; Martin-Gallausiaux *et al.*, 2021; Venter *et al.*, 2022; So *et al.*, 2021b
Gut dysbiosis	Supports beneficial bacterial growth, such as bifidobacterium and lactobacillus species, by acting as a prebiotic	Adams *et al.*, 2018; Hiel *et al.*, 2019; Kumar *et al.*, 2020; Li *et al.*, 2022; Tanes *et al.*, 2021
Small intestinal bacterial overgrowth (SIBO)	Modifies gut transit times, reducing the risk of bacterial overgrowth	Fuller *et al.*, 2016; Gill *et al.*, 2021; Nolte Fong *et al.*, 2022
Diverticulitis	Reduces intraluminal pressure in the colon, preventing diverticula formation	Gill *et al.*, 2021; Partula *et al.*, 2020
Type 2 diabetes mellitus	Slows glucose absorption and improves glycemic control by reducing postprandial blood sugar spikes	Jovanovski *et al.*, 2020; Ojo *et al.*, 2020; Perler *et al.*, 2023
Cardiovascular diseases (CVDs)	Lowers cholesterol levels by binding bile acids and promoting their excretion	Guan *et al.*, 2021; He *et al.*, 2022; Korcz *et al.*, 2018; Liu *et al.*, 2020; Partula *et al.*, 2020
Gastroesophageal reflux disease (GERD)	Enhances gastric emptying, reducing acid reflux	Debnath *et al.*, 2019; Eriksen *et al.*, 2020; Venter *et al.*, 2022
Celiac disease	Provides alternative sources of gluten-free dietary fibers to support gut health	Esteban *et al.*, 2017; He *et al.*, 2022; Makki *et al.*, 2018; So *et al.*, 2021a
Allergic gut disorders	Modulates immune responses by influencing gut-associated lymphoid tissue (GALT)	Budden *et al.*, 2024; Venter *et al.*, 2022
Chronic diarrhea	Absorbs excess water in the gut, solidifying stool consistency	Adams *et al.*, 2018; Gill *et al.*, 2021; Klinder *et al.*, 2016
Mental health (gut–brain axis)	Positively influences the gut–brain axis by promoting the production of neuroactive metabolites, such as serotonin precursors	Chakrabarti *et al.*, 2022; Dinan and Cryan, 2017; Kumar *et al.*, 2020; Perler *et al.*, 2023; Sowah *et al.*, 2022
Liver disorders	Reduces systemic inflammation and endotoxemia by improving gut barrier function	Hiel *et al.*, 2019; Makki *et al.*, 2018; van Trijp *et al.*, 2021; Ye *et al.*, 2022
Fatty liver disease	Promotes bile acid metabolism and lipid clearance, reducing hepatic fat accumulation	Benítez-Páez *et al.*, 2016; Bishehsari *et al.*, 2018; Cantero *et al.*, 2017; He *et al.*, 2022
Stress and anxiety	Reduces cortisol levels by promoting SCFA production and gut microbiota diversity	Lee and Kim, 2021; Sowah *et al.*, 2022; Tanes *et al.*, 2021; Venter *et al.*, 2022; Singh *et al.,* 2022
Radiation enteritis	Protects intestinal mucosa from radiation-induced injury by promoting epithelial repair	Malipatlolla *et al.*, 2021; Martin-Gallausiaux *et al.*, 2021; Morrison *et al.*, 2020
Pancreatic health	Improves enzyme activity and supports pancreatic health by maintaining a balanced microbiota	Adams *et al.*, 2018; Carlson *et al.*, 2018; Han *et al.*, 2023
Post-antibiotic recovery	Accelerates microbiota recovery after antibiotic treatment, restoring gut equilibrium	Hiel *et al.*, 2019; Partula *et al.*, 2020; Tanes *et al.*, 2021; Ye *et al.*, 2022
Chronic respiratory diseases	Complex carbohydrates mediate protection against conditions such as chronic obstructive pulmonary disease (COPD) through gut microbiota modulation	Budden *et al.*, 2024
Ovarian cancer recovery	High-fiber diet improves survival outcomes in ovarian cancer patients	Thomson *et al.*, 2023

(*continues*)

Table 3. Continued.

Disorder	Role of fiber	References
Colorectal cancer risk reduction	Increased fiber intake correlates with lower colorectal cancer risk	Doroudi *et al.*, 2017; So *et al.*, 2021b
Hunger and satiety control	Dietary fiber influences satiety and hunger regulation, reducing calorie intake	Shearrer *et al.*, 2016
Hormonal balance	Fiber impacts hormonal metabolism, influencing estrogen and insulin levels	Miles *et al.*, 2017

response to fiber, potentially unpleasant adverse effects, such as bloating or gas, and a universal struggle to hit the recommended daily intake of diet.

Individual Variability

The pattern between the effects of dietary fiber can be serious and depend on individual backgrounds, such as gut microbiota configuration, genetic characteristics, and whole diet. The capacity of fermentation and metabolism changes to produce SCFAs (and other metabolites) in response to dietary fibers, likely reflecting differences between the gut microbiome communities (Ye *et al.*, 2022; Zhang, 2022). As an example, some people may have a gut microbiota composition that is very efficient in fermenting fiber, producing more SCFAs. In contrast, others may produce less, as they host different microbial communities. Such variability may play a role in the realization of some of fiber's benefits, including improved gut health and reduced inflammation (Ye *et al.*, 2022; Zhang *et al.*, 2022). In addition, fiber may affect blood glucose levels and have different effects on cholesterol metabolism or digestive health, depending on genetic variation (Duque *et al.*, 2021). These discrepancies highlight the need for individualized nutritional approaches that consider not only fiber recommendations but also host genetics and microbiome profiles (Zhang, 2022; Zeng *et al.*, 2018).

Potential negative effects

Although fiber has many benefits, increasing its intake can cause problems, especially if its intake is increased in quick successions. Typically, it can lead to bloating or gas and abdominal discomfort because of the fermentation of nutrients in the colon (Kirthi *et al.*, 2021). This particularly happens if there is a rapid increase in dietary fiber and insufficient adaptation time for gut microbiota to adjust (Ye *et al.*, 2022). To counteract these, one should slowly introduce fiber in the diet, allowing a transition time for the gut. Be sure to drink lots of water, because insufficient fluids lead to constipation, as fiber absorbs water and fluids. Furthermore, mixing different fiber types (soluble vs insoluble) could be beneficial, because they may exert opposite effects on digestion and fermentation (Ye *et al.*, 2022).

Challenges in meeting fiber requirements

Most people think that some quantity of dietary fiber is good for maintaining intestinal microbiota hence they don't consume sufficient fiber. Low fiber intake is a common issue in Western diets and individual intake is usually below the threshold recommendation of 25–30 g/day (Stephen *et al.*, 2017; Zeng *et al.*, 2014). A key reason is that the diets tend to skew toward processed and refined foods, which are generally low in fiber (Kumar *et al.*, 2020). In addition, modern diets have been tailored for convenience, always devoid of whole grains, fruits, vegetables, and legumes, which are rich source of dietary fiber (Wiertsema *et al.*, 2021). A combination of individual efforts and public health policies is needed to confront these barriers. Raising the awareness of fiber supplementation, enhancing the availability of fiber-rich foods, and pushing food companies to enrich products with added fibers are important strategies for bridging this gap.

Furthermore, inclusion of fiber-rich foods at least in two meals per day (such as vegetables with lunch and dinner), substituting refined grains with whole grains, and intake of fruit and nuts during snacks are the means by which one can gradually increase dietary fiber to achieve a threshold of 25–30 g/day (Stephen *et al.*, 2017; Zeng *et al.*, 2014). Although the advantages of a high-fiber diet are clear, one must also consider challenges, such as inter-individual differences in response, adverse effects, and difficulties in meeting recommended levels of dietary fiber (Dimidi *et al.*, 2017). Customized dietary guidance, offering slow modifications in diet, and implementation of public health tactics have great potential to optimize benefits from the consumption of dietary fibers for improving gut health (Ye *et al.*, 2022; Zhang, 2022). Table 4 illustrates the challenges and solutions for meeting fiber intake.

Table 4. Challenges and solutions for meeting fiber intake.

Challenge	Description	Potential solutions	References
Low dietary fiber awareness	Many individuals are unaware of the benefits of fiber, leading to low consumption rates	Educating the public through health campaigns and dietary guidelines can increase fiber awareness. Fiber-rich food labeling may also promote awareness	Gill *et al.*, 2021; Venter *et al.*, 2022
Limited access to fiber-rich foods	In some regions, there is a limited access to fresh fruits, vegetables, and whole grains, reducing fiber intake	Increasing the availability of affordable, fiber-rich foods through local farming, community gardens, and subsidies	Kumar *et al.*, 2020
Low consumption of whole grains	Many diets are focused on refined grains, which are low in fiber, compared to whole grains	Public health campaigns that promote whole grains over refined grains and the incorporation of whole grains into processed food products	He *et al.*, 2022; Perler *et al.*, 2023
Overconsumption of processed foods	Highly processed foods, often low in fiber, dominate modern diets, leading to inadequate fiber intake	Reducing processed food consumption by substituting with fiber-rich foods such as legumes and vegetables	Benítez-Páez *et al.*, 2016; Morrison *et al.*, 2020
Inadequate meal planning	Many individuals do not plan meals that include fiber-rich foods, resulting in low intake	Meal planning education, apps for tracking fiber intake, and cooking workshops can help people include fiber-rich foods in their meals	Guan *et al.*, 2021; Tanes *et al.*, 2021
Fad diets and fiber exclusion	Certain fad diets, such as low-carb or ketogenic diets, often limit fiber intake by excluding fiber-rich plant foods	Encouraging diet balance and educating individuals on the importance of fiber as part of a healthy eating plan	Kumar *et al.*, 2020
Fiber tolerance issues	Some people may experience bloating, gas, or discomfort when increasing fiber intake too quickly	Gradual introduction of fiber into the diet and ensuring adequate water intake to prevent gastrointestinal discomfort	He *et al.*, 2022; Morrison *et al.*, 2020
Lack of fiber in processed foods	Many processed foods, including snacks and ready meals, lack sufficient fiber content	Reformulating processed foods to include more fiber and encouraging consumers to choose high-fiber products	Venter *et al.*, 2022
Cultural dietary preferences	Some cultural or traditional diets may not emphasize fiber-rich foods, contributing to lower intake	Incorporating fiber-rich foods into traditional diets while maintaining cultural preferences	He *et al.*, 2022; Ye *et al.*, 2022
Age-related factors	As individuals age, changes in digestive health and metabolism can decrease the ability to tolerate high-fiber foods	Adapting fiber intake to the individual's tolerance and gradually increasing fiber to support digestion	Armstrong *et al.*, 2021; Ye *et al.*, 2022
Medical conditions	Certain health conditions, such as irritable bowel syndrome (IBS) or inflammatory bowel disease (IBD), may limit fiber intake due to intolerance	Personalized dietary plans to include fiber sources that are easier to digest, and using supplements when necessary	Armstrong *et al.*, 2021; Gill *et al.*, 2021
Misconceptions about fiber	Many people mistakenly believe that all fiber types are the same, overlooking the specific benefits of different types of fiber	Providing education on soluble versus insoluble fiber types and their distinct health benefits	Kumar *et al.*, 2020; Morrison *et al.*, 2020
Low fiber content in animal products	Animal products typically do not contain fiber, making it challenging for individuals with animal-based diets to meet their fiber needs	Encouraging plant-based meals or the addition of fiber-rich side dishes to animal-based meals	Jha and Mishra, 2021; Ye *et al.*, 2022
Fiber interactions with medications	Some medications, such as laxatives or antibiotics, may interfere with the digestion or absorption of fiber	Consulting healthcare providers about proper medication and dietary fiber management	He *et al.*, 2022; Ojo *et al.*, 2020
Food preferences and picky eating	Picky eating habits, particularly in children, can make it difficult to incorporate fiber-rich foods into their diets	Introducing fiber-rich foods in a fun and appealing manner to encourage consumption among children	Armstrong *et al.*, 2021; Jha and Mishra, 2021
Fiber loss during cooking	The fiber content of some foods can be reduced during cooking, especially in vegetables and grains	Encouraging cooking methods that preserve fiber, such as steaming or microwaving, instead of boiling	He *et al.*, 2022; Kumar *et al.*, 2020

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Table 4. Continued.

Challenge	Description	Potential solutions	References
Lack of knowledge about fiber sources	Many individuals do not know which foods are good sources of fiber beyond fruits and vegetables	Providing information on lesser-known fiber-rich foods, such as legumes, seeds, and whole grains	Perler *et al.*, 2023; Tanes *et al.*, 2021
Cost of fiber-rich foods	Whole grains, fruits, and vegetables can be expensive, especially in the areas with limited access to fresh produce, making it hard for some to afford fiber-rich foods	Providing subsidies or programs that reduce the cost of fiber-rich foods for lower-income populations	Kumar *et al.*, 2020; Tanes *et al.*, 2021
Challenges about fiber supplementation	While fiber supplements can help increase fiber intake, they may not be as beneficial as whole food sources and can cause digestive issues if overused	Promoting whole foods as the preferred source of fiber, with supplementation used as a last resort	Ojo *et al.*, 2020; Perler *et al.*, 2023

Research Requirements in Fiber and Gut Health

Dietary fiber and its effects on gut health are one of the most discussed topics in this field, but in this modern area, it still requires the resolution of many key issues surrounding how the bodies take up consumed fibers (Miranda-Galvis *et al.*, 2021). Since the evolution of this field, there are several specific areas where future investigations could have particularly larger impacts. This encompasses new research areas, the prospect of an individualized gut microbiome-based approach to nutrition, and broad population-level dietary strategies for increasing fiber consumption (Schimmel *et al.*, 2022). Research is underway to explore recent progress in understanding the complex connection between dietary fiber and the gut. A promising area of future research is investigating the impact of dietary fiber on the gut, specifically how different types of fiber can alter the microbiome in various populationsIt is evident that fiber has potential to improve bacterial and SCFA production, but how different fiber types impact microbial diversity and functioning within various demographic groups or health states remain relatively unexplored (Benítez-Páez *et al.*, 2016; Bishehsari *et al.*, 2018). For instance, fiber-rich diets have been investigated for their potentially protective effects through host microbiome interactions and inflammation-related mechanisms against various diseases, including cancer (Bishehsari *et al.*, 2018) and CVDs or metabolic diseases (Bailén *et al.*, 2020). The emergence of these research areas underscores that much additional work is required to elaborate the many-layered benefits of dietary fiber. Table 5 outlines key emerging research areas and their focus within the fiber and gut health field.

Personalized Nutrition

What might work best in optimizing fiber intake for improving gut health and prevent chronic diseases is personalized nutrition that focuses on individual's specific gut microbiota (Tobar *et al.*, 2023). Fiber modulates the composition of microbiota, encouraging beneficial bacteria to maintain the reliability of intestinal barricade and metabolic health (Semenkovich *et al.*, 2016; Tobar *et al.*, 2023). Specific microbial interactions alter immune functions, circadian rhythms, and gut–liver interference that impact disease consequences, such as obesity, diabetes, and inflammatory illnesses (Watkins *et al.*, 2018; Zhang *et al.*, 2023). Structural elements of gut bacteria further shape gut health, including the S-layer musters and serine-rich repeat proteins that mediate host interfaces (Sagmeister *et al.*, 2024; Sequeira *et al.*, 2018). In addition, it has been shown that dietary sugar evokes beneficial colonization factors, emphasizing the need for high-fiber diets (Townsend *et al.*, 2019). Microbial attempts to detoxify toxins and maintain symbiosis further illustrate the role of fiber in maintaining a stable gut environment (Wexler *et al.*, 2016). It is established that drugs such as trametinib may reduce the pace of aging-associated degradation of the gut, thus paving the way for targeted nutritional strategies (Ureña *et al.*, 2024). Customized fiber therapies must be developed to enhance long-term health outcomes by considering these complex interactions of microbes.

Personalized nutrition, the idea that the diet is modified based on an individual's genetics and lifestyle, to better maintain health status, such as body composition and functioning, is considered as a new concept for improving health outcomes (Carlson *et al.*, 2018). As the importance of gut microbiome in influencing dietary fiber-mediated human health outcomes grows further, personalized nutrition allows for more precise dietary interventions. For example, certain types of fibers that selectively enhance the growth of beneficial microbes or the production-specific SCFAs (Afzaal *et al.*, 2022) could have greater benefits for individuals with a distinct gut microbiota composition. This can be considered as one

Table 5. Emerging research areas in fiber and gut health.

Research area	Focus	Key mechanisms	Potential impact	Challenges	Future directions	References
Gut microbiome and fiber interactions	Exploring how different types of fiber interact with the gut microbiome, influencing its composition and functioning	Fermentation by gut bacteria, production of short-chain fatty acids (SCFAs), modulation of microbial diversity	Personalized dietary recommendations for improving gut health	Individual variability in microbiome composition, lack of standardized fiber classifications	Integration of metagenomics and AI for personalized nutrition strategies	Loo *et al.*, 2020; Makki *et al.*, 2018
Fiber and immune system modulation	Investigating the role of fiber in modulating immune responses and its impact on inflammatory conditions, such as IBD and allergies	Regulation of gut-associated lymphoid tissue (GALT), SCFA-mediated immune modulation	Dietary strategies to reduce inflammation and improve immune-related diseases	Complex interactions between fiber, immune cells, and gut microbiota	Development of precision fiber-based therapies for immune disorders	Malipatlolla *et al.*, 2021; Mayrhofer, 2019
Role of fiber in metabolism	Understanding how fiber influences metabolic processes, including insulin sensitivity, lipid metabolism, and weight regulation	SCFA effects on glucose metabolism, gut hormone modulation, and bile acid recycling	Improved metabolic health, new dietary interventions for diabetes and obesity	Differences in fiber types and metabolic responses	Personalized fiber intake recommendations based on metabolic phenotypes	Liu *et al.*, 2020; Mao *et al.*, 2021
Prebiotic fiber and gut–brain axis	Researching how fiber affects the gut–brain connection, particularly in terms of mental health and cognitive functioning	Microbial metabolite signaling (SCFAs, neurotransmitters), vagus nerve modulation	Potential interventions for depression, anxiety, and cognitive decline	Limited clinical trials, difficulty in measuring direct effects	Multi-omic approaches to link fiber intake with mental health biomarkers	Liang *et al.*, 2018; Mörkl *et al.*, 2020
Fiber and gut barrier functioning	Examining how dietary fiber affects intestinal barrier functioning, reducing gut permeability, and preventing "leaky gut."	SCFA reinforcement of tight junctions, mucus layer enhancement	Prevention and treatment of gastrointestinal disorders such as IBS	Need for more human trials to confirm findings	Development of fiber-based nutraceuticals targeting gut integrity	Morrison *et al.*, 2020; Perler *et al.*, 2023
Individual variability in fiber response	Studying how genetic, environmental, and microbiome factors influence individual responses to fiber intake	Host–microbiome interactions, genetic polymorphisms affecting fiber digestion	Personalized fiber recommendations for optimal health outcomes	Complexity of data integration, cost of personalized nutrition	AI-driven dietary planning based on microbiome sequencing	Armstrong *et al.*, 2021; Guan *et al.*, 2021
Fiber and SCFAs	Investigating the role of fiber in producing SCFAs through fermentation and their effects on gut and systemic health	Microbial fermentation, SCFA signaling pathways in host metabolism	Potential use of SCFAs in therapeutic applications for inflammation and metabolism	Inter-individual differences in SCFA production	Targeted microbiome interventions to enhance SCFA benefits	Martin-Gallausiaux *et al.*, 2021; Perler *et al.*, 2023

(*continues*)

Table 5. Continued.

Research area	Focus	Key mechanisms	Potential impact	Challenges	Future directions	References
Sustainable fiber sources	Identifying alternative and sustainable sources of dietary fiber, including plant-based fibers and fiber-rich byproducts	Extraction and fortification techniques, environmental impact assessment	Eco-friendly solutions to meet global dietary fiber needs while supporting sustainability	Cost and scalability of fiber extraction methods	Development of novel fiber-enriched food products with minimal processing	Tanes *et al.*, 2021; Ye *et al.*, 2022
Fiber and microbial diversity	Investigating the impact of fiber on gut microbial diversity and its role in maintaining microbiome balance	Prebiotic effects, competition among microbial species for fiber fermentation	Enhanced digestive health, reduced chronic disease risk, improved microbiome resilience	Need for more long-term human studies	Use of next-generation sequencing to track microbial shifts with fiber intake	He *et al.*, 2022; Venter *et al.*, 2022
Fiber in pediatric health	Examining the effects of fiber on childhood growth, development, and prevention of childhood diseases	Gut microbiome development, immune system priming, metabolic programming	Improved guidelines for fiber intake in pediatric populations	Variability in dietary habits and early-life microbiome exposure	Inclusion of fiber in early-life nutrition policies and public health initiatives	Armstrong *et al.*, 2021; Jha and Mishra, 2021

of the most promising strategies that would lead to personalized nutrition and try to understand why the same quantity of dietary fiber might cause a different effect in different individuals. Age, gender, and underlying medical conditions could influence such differences. Research should help to suggest specific types and amounts of fiber that would minimize the adverse effects of bloating or pain but maximize health benefits by exploring an individual's microbiota (So *et al.*, 2021a; Wang *et al.*, 2019). Further investigation is required to deliver easy-to-access methods to monitor microbiota variations and connect them to fiber functionality to fully understand the possibility of tailored nutrition (De Roos and Brennan, 2017; Moore, 2020).

Chronic diseases, particularly those associated with gut health, can be better controlled through personalized nutrition, which tailors recommendations based on individual's genetic profile, microbiome composition, and lifestyle considerations (Fu *et al.*, 2022a). Knowing how specific dietary fibers may interact with a person's microbiome could potentially improve the health outcome in cases such as CVDs and type 2 diabetes (Makki *et al.*, 2018). Because some of the fibers selectively induce the growth of beneficial gut microorganisms responsible for creating SCFAs that are essential in maintaining healthy guts, it may also vary according to individual's microbiome (Fu *et al.*, 2022a). Personalized fiber-based therapies have shown great promise in managing chronic diseases, such as type 2 diabetes (Zou *et al.*, 2021). Inulin, a fermentable fiber, increases the production of SCFAs, such as butyrate and propionate, and improves insulin sensitivity and glycemic control in type 2 diabetes patients (Zou *et al.*, 2021). In addition, resistant starch is another type of fiber that has a beneficial effect on gut microbiota composition, thus enhancing metabolic health, managing diabetes, and preventing obesity (Liu *et al.*, 2020).

Personalized intake of fiber leads to health benefits through consumption of fiber without any adverse affects, such as bloating (Liu *et al.*, 2020). Moreover, because it has been associated with improved lipid profiles and low inflammation, a personalized diet carries a lot of promise as a CVD therapy (Kaye *et al.*, 2020; Reynolds *et al.*, 2022). Preventing and managing cardiovascular complications could be possible with the proper utilization of different fiber types that work best with the given metabolic profiles of individuals. More research in the field of customized nutrition is required to better implement its application with microbiome analysis and the functioning of fibers at clinical levels (Ioniță-Mîndrican *et al.*, 2022). Advances through these techniques can produce customized nutrition to be a part of life that can lead toward precise as well as effective management and treatment of chronic diseases.

Although well-recognized as beneficial, dietary fiber is globally underconsumed by populations. This gap illustrates the necessity of public health strategies to enhance fiber intake at population levels (Loo *et al.*, 2020). In addition, policy efforts need to focus on producing more readily available and cheaper fiber-rich foods. Eventually that means subsidizing fruit and vegetable cultivators or pushing food manufacturers to fortify their products with whole grains. Schools and workplaces could also play a role by providing fiber-rich meals and by raising awareness about fiber to improve the general health status (Adams *et al.*, 2018). Moreover, studies investigating optimal public health strategies to improve fiber intake among diverse populations are required to help facilitate broader dietary changes.

Conclusion and Future Perspectives

In summary, dietary fiber is an important nutrient for maintaining gut health and preventing chronic diseases. The benefits of fiber for the overall health include enhancing digestive health by modulating gut microbiota, fermentation into healthy SCFAs, and fiber's role in gut barrier integrity. A fiber-rich diet is linked to lower instances of chronic diseases, such as diabetes, cancer, and CVD, improved weight management, and a reduced risk of GI disorders. Although fiber offers many benefits, it has been found that its intake varies with individual body response, and some may experience GI adverse effects. Promoting ideal gut health and long-term prevention of diseases could be possible by promoting a diverse and adequate intake of fiber from whole food items.

While further research is needed, the future of dietary fiber is promising, particularly in areas like gut health, personalized nutrition, and the connection between fiber and brain function. However, translating these scientific advancements into practical, population-wide strategies to increase fiber intake remains a challenge. These investigations are a key to unleashing the powerful ability of dietary fiber to support health and prevent diseases. More research is needed to fully understand the health benefits of fiber for the gut. Studies must probe into how different fiber types affect human body in ways other than by just resulting in bulk stool, identify potential dietary recommendations based on individualized gut microbiomes, and overcome the obstacles that prevent its adequate intake. Personalized nutrition to optimize the advantages of dietary fiber is important when considering differences in gut flora, chronic diseases, and metabolic responses. Future studies should aim toward developing specific dietary guidelines that could improve gut health and prevent chronic illnesses. Public health campaigns should feature increased fiber consumption as a merit worthy of public discourse and their goals must include targets to reach various communities with knowledge followed by act as changing the policies promoting anti-fiber foods in all their forms. In theory and practice refined dietary fiber science has shown that we can unlock natural fibers potential within health promotion and disease prevention through an improved understanding of optimal methods to understand the food matrix and perform real world applications. Overall, incorporating fiber-rich foods in daily dietary practices (backed by solid research) and sometimes public health efforts have a large potential to combat poor gut health plaguing the modern society.

Author Contributions

Sammra Maqsood conducted the literature review, analyzed the data, and wrote the manuscript. Matteo Bordiga was involved in writing of original draft, reviewing, and editing, visualization as well as supervision. Baojun Xu guided the research process, reviewed the manuscript, and contributed to writing and editing the final document. All the authors approved the submission of the final version of the manuscript.

Conflict of Interest

The authors declared that there was no conflict of interest regarding the publication of this paper.

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