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Dietary Fiber and Gut Health: Mechanisms and Benefits

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Abstract

Dietary fiber serves an essential function in maintaining digestive health and overall wellness. This review examines the mechanisms through which various types of dietary fiber modulate gastrointestinal physiology, microbial profile, and immune activity. Soluble and insoluble fibers affect digestion, regulate gut motility, and act as substrates for microbial fermentation, generating short-chain fatty acids (SCFAs) including butyrate, propionate, and acetate. These SCFAs have been reported to enhance gut epithelial integrity, decrease inflammation, and modulate whole-body metabolic processes. Furthermore, diets containing high fiber content are linked to improved gut microbiota diversity and the expansion of good bacteria, contributing to the mitigation and control of various gut related disorders such as irritable bowel syndrome (IBS), inflammatory bowel disease (IBD), and colorectal cancer. comprehending the multiple roles of dietary fiber highlights its importance in dietary approaches focused on improving gut health and averting long-term illness.

Keywords: Dietary Fibers, Gastrointestinal Disorders, Irritable Bowel Syndrome (IBS), Gut Health

1 Introduction

Dietary fibers play important roles in both the structure and energy storage of plant-based foods, and they have significant effects on human health, largely through interactions with the gut microbiota, especially in the colon, as shown in Figure 1 (Barber et al., 2020; Buttriss & Stokes, 2008). Researchers have devoted substantial effort to understanding how different types of fiber

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are utilized by the gut microbiota, often focusing on isolated, purified fibers (Delzenne et al., 2025). While analyzing these isolated fibers can reveal specific effects, this approach overlooks how fibers are actually consumed in real diets, as part of complex plant structures (Blanco-Pérez et al., 2021; Zeng et al., 2014). In reality, as in the diets of our ancestors, fibers are consumed within intricate plant cell wall networks that enclose and protect intracellular substances such as fructose and other compounds from being digested immediately (Delzenne et al., 2025). The way intrinsic fibers behave physiologically and are broken down by gut microbes differs notably from that of isolated, purified fibers (Bang et al., 2018). This difference may lead to distinct and underexplored health benefits. In this mini-review, we clarify the distinction between intrinsic and isolated dietary fibers and examine how each affects digestion (Buttris & Stokes, 2008; Holscher et al., 2017). We also discuss how various food processing techniques alter the structure of intrinsic fibers and provide a summary of human intervention studies investigating their effects on the gut microbiota and related health outcomes (Basuray et al., 2024). Additionally, we identify gaps in current research and highlight how the structure of plant tissues may guide future studies (Cronin et al., 2021; Slavin, 2013). Rather than further refining already highly processed foods, we argue for reducing food processing to preserve the natural health benefits of plant fibers embedded in their original cellular matrix (Puhlmann & de Vos, 2022). While the health benefits of dietary fiber are widely acknowledged and supported globally, the concept of prebiotics, first introduced in 1995, is still developing. The impacts of prebiotic fibers are, in particular, not yet fully understood. This review clarifies what defines a prebiotic dietary fiber and underscores the specific fibers for which studies confirm their prebiotic categorization (Carlson et al., 2016). Public health organizations advocate high-fiber intake to promote general well-being (Brownawell et al., 2012). Epidemiological studies have shown that greater fiber consumption may be linked to a lower risk of several chronic diseases.

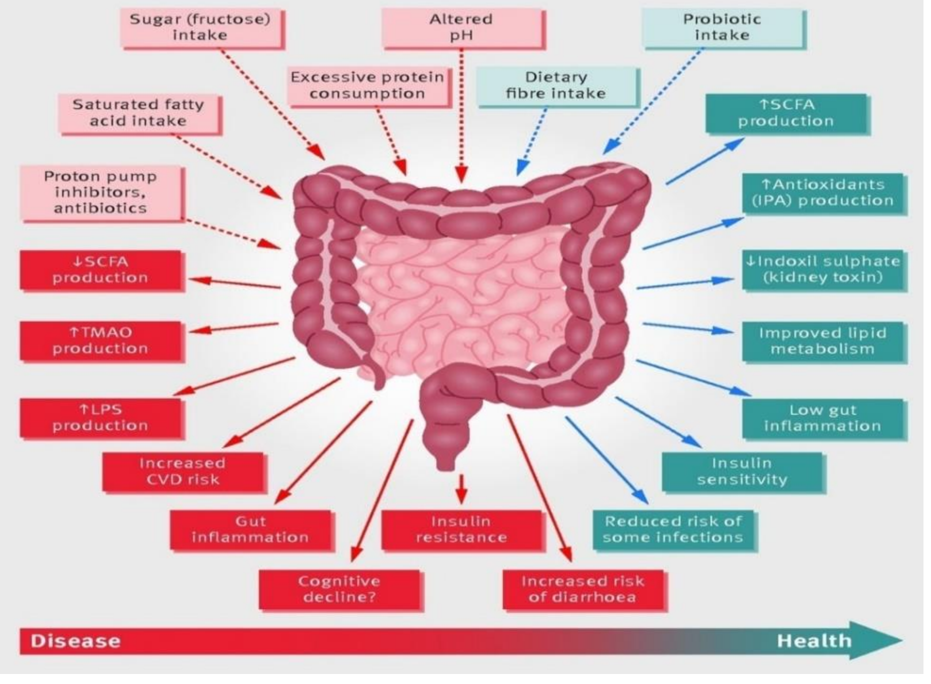

Figure 1: Function of the Gut Microbiota in Nutrition and Health

The human gastrointestinal tract (GIT) hosts one of the most intricate ecosystems on Earth, composed of a vast and diverse microbial population that has co-evolved with its host. It is estimated that the gut microbiota collectively encodes around 3.3 million genes (Cronin et al., 2021). Among the factors shaping an individual's gut microbiota, diet plays a primary role, although age, physical activity, and antibiotic use also contribute (Ye et al., 2022). Notably, the composition of gut microbiota is often altered in metabolic disorders such as obesity, type 2 diabetes (T2DM), and cardiovascular disease (CVD). The prevalence of these conditions, particularly in industrialized countries, has been associated with the low-fiber Western diet. In response, several strategies are being explored to modify the gut microbiota for health benefits, including fecal microbiota transplantation (FMT) (Cronin et al., 2021). Fiber intake strategy is another effective approach for modulating gut microbial composition to affect the health positively. Fiber is widely believed to maintain metabolic function and prevent from long-term digestive disorder (O'Keefe, 2019). The latest findings have uncovered the intricate relationship among fiber, the intestinal microbial population, and human health conditions (O'Grady & Grabrucker, 2025). The human gastrointestinal tract harbors vast numbers of microbes, including up to 1,000 unique bacterial strains (He et al., 2022; Hall & Mah, 2017). These microbes are critical for controlling host metabolic processes, immune response, and endocrine balance. Imbalances in gut microbiota have been associated with an increased likelihood of metabolic disorders including diabetes, cardiovascular diseases, and IBD (Portune et al., 2017).

The human gastrointestinal tract contains almost 40 trillion bacteria, mainly from the Firmicutes and Bacteroidetes phyla, as well as Proteobacteria, Actinobacteria, and Verrucomicrobia. Firmicutes is the largest and most diverse group, accounting for about 70% of gut microbiota diversity. In contrast, Bacteroidetes, especially genera like Bacteroides, Alistipes, Parabacteroides, and Prevotella, are characterized by their capacity to generate a wide range of enzymes that degrade complex carbohydrates (Lapebie et al., 2019).

1.1 Biochemical Composition and Functional Properties of Plant Cell Wall-Derived Dietary Fibers

The majority of dietary fibers (DF)is derived from plant cell walls (PCW), which are crucial for plant structural integrity and function. In chemical terms, DF is primarily composed of carbohydrate chains that cannot be easily broken down by digestive enzymes in the small intestine but are fermentable by gut microbes, especially in the large bowel. The beneficial effects of DF are mainly due to its physical and mechanical properties, its function as a structural matrix, and its biochemical traits. The fiber's permeability is key to its benefits, affecting gut microbiota composition and function, including the production of fermentation metabolites (Williams et al., 2017). There are various classification schemes for DF, primarily based on the specific requirements of practitioners such as dietitians and animal nutritionists (Wu et al., 2019). The most commonly used classification of human nutrition separates DF into two main types based on solubility in water, as this is a useful indicator of potential biological effects and effects in monogastric animals (Wu et al., 2019).

Regarding behavior in the digestive tract, water solubility is a key determinant of the water retention ability of fiber, viscosity, and the extent of microbial fermentation. For instance, the fermentability of plant cell wall polysaccharides differs considerably. Lignin is largely non-soluble and is minimally fermentable, whereas pectin is strongly soluble and is typically fully fermented. Historically, it has been believed that soluble fibers are broken down faster than insoluble fibers, although this perspective is changing (Tosh & Bordenave, 2020). Nonetheless, it is crucial to recognize that there is no uniform procedure for distinguishing soluble from insoluble dietary fibers, as shown in Figure 2. The applied conditions, namely temperature, the solvent used (usually water or a buffer), and the fiber-to-solvent ratio, can all determine how fibers are grouped, contributing to notable limitations in this categorization approach (Williams et al., 2017).

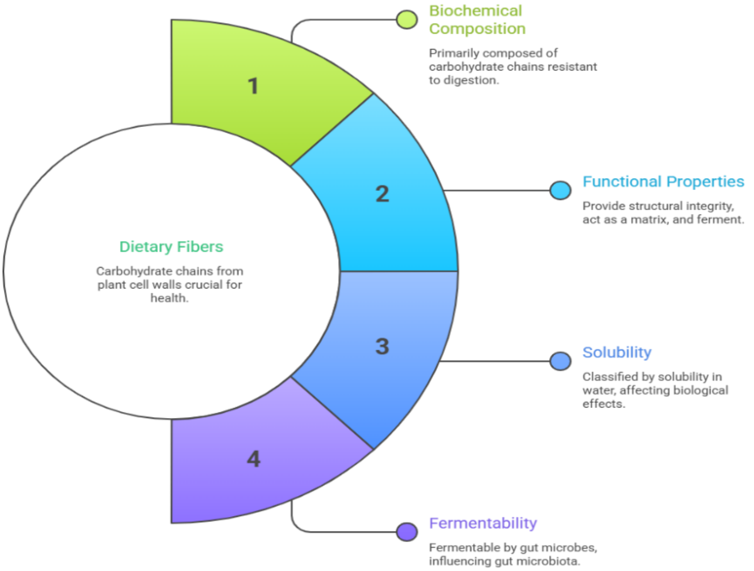

Figure 2: Unveiling the Multifaceted Role of Dietary Fibers

1.2 Soluble Dietary Fibers as a Modulator of Postprandial Glycemia and Insulin Sensitivity

Soluble dietary fibers (DF) can raise the thickness of intestinal contents, which is governed by their chemical composition and molecular mass. These factors influence how the polymers act in solutions. Consequently, soluble fibers help lower the blood glucose levels by reducing the rate of gastric emptying and availability of nutrients, as well as inhibiting α-amylase function (Larsen et al., 2019), which in turn modulates blood sugar, which is an important process in protecting against insulin resistance and the onset of Type 2 diabetes. Soluble fibers are widely present in plant cell walls, though they vary in structure, molecular size, and, notably, dissolution capacity (Abuajah et al., 2015).

2 Structural Domains and Gelation Properties of Pectic Polysaccharides

Pectin is a class of covalently bonded compounds primarily composed of galacturonic acid occurring in cell walls of many plant species, mainly in vegetables and fruits (Beukema et al., 2020). The pectin's structural backbone is mainly made up of homogalacturonan, containing α (1-4) linked D-galacturonic acid units. A considerable proportion of these acids are methyl esters, with an extent of esterification usually between50-80% in plants. This esterification degree (DE) is important in deciding the physical attributes of pectin. Pectin is grouped into high methoxyl (DE > 50%) and low methoxyl (DE < 50%) forms. Highly esterified pectin can develop gels at low pH conditions or with elevated levels of sugars such as sucrose, whereas low DE pectin needs metal cations including calcium to develop a stable gel. Homogalacturonan represent about 65% of pectic polysaccharides in fruits and vegetables (Vinelli et al., 2022). The other primary types of pectin are rhamnogalacturonan-I (RG-I), which consists of a backbone with alternating galacturonic acid and rhamnose, and rhamnogalacturonan-II (RG-II), an intricate polymer with multiple sugar components (Amos et al., 2022). Recent findings on RG-II suggest that our structural understanding may require revision and further clarification.

3 Crosslinking Behaviour and Gastrointestinal Fermentation of Arabinoxylan (AX):

Arabinoxylan (AX) is a class of hemicellulose, an essential polysaccharide in cell walls of the plants, particularly in cereal grains like wheat and rye. AX contains a backbone composed of β-D-xylose linked by β-(1,4) bonds, with α-L-arabinose side chains attached to certain xylose residues. The ratio of arabinose to xylose determines AX's structural features. AX accounts for about 20% of wheat bran and has been shown to be readily fermentable both in vitro and in the cecum of grower pigs (Williams et al., 2017). Research also suggests that different rye milling fractions containing AX have different fermentability, which is linked to variations in lignin crosslinking as opposed to the AX inherent structure (Pascale et al., 2022). Furthermore, a recent study has emphasized a specific xylan-degrading mechanism in the large intestinal microbiota that responds to diverse polysaccharides.

4 Mixed-Linkage Glucans (MLG) in Glycemic Control and Lipid Regulation

Mixed-linkage glucans (MLG) are polysaccharides present in the cereal grain cell walls, mainly oats, rye, and barley, with lower levels in wheat. MLG consists of long chains of β-(1,4) glucosyl residues interrupted by β-(1,3) linkages, typically in a ratio of 1:3 or 1:4. This irregular structure increases water solubility and gel-forming properties. MLG has been shown to have several health benefits, including hypoglycemic effects and reductions in circulating bile acids and cholesterol. It has also been shown to undergo fermentation in vitro and in vivo across various animal models and human subjects (Gunness et al., 2016).

5 Physicochemical Properties of Insoluble Dietary Fibers and their Impact on Gut Microbial Utilization

Insoluble fibers present a challenge for gut bacteria due to their reduced accessible surface area and the strong hydrogen-bonding networks that hold the carbohydrate chains together (Jha & Berrocoso, 2015). This makes fermentation by gut bacteria more difficult (Gidley, 2024).

6 Molecular Organization and Physicochemical Properties of Cellulose:

Cellulose is the most abundant organic polymer on Earth. It consists of β-glucosyl residues linked by β (1-4) bonds, and the cellulose chains are synthesized directly at the cell surface into the plant cell wall (PCW). These chains then associate to form semi-crystalline microfibrils, typically composed of 18 to 24 chains (Samami et al., 2025). These microfibrils may further aggregate to form characteristic fiber ribbons. The combination of cellulose, cross-linked hemicelluloses, and interwoven pectins provides the PCW with strength and rigidity, making it highly resistant to both mechanical and chemical degradation (Grundy et al., 2016). Cellulose is generally considered soluble only in strong alkali solutions (4–6 M), although there is a portion of cellulose that is more easily hydrolyzed in acidic conditions (Wang et al., 2020).

7 Functional Implications and Limitations of Conventional Fiber Categorization

While individual fiber polysaccharides can be identified and quantified by their unique chemical compositions, they are rarely consumed in purified form. The majority of dietary fiber is consumed in the form of plant cell walls (PCWs) from cereals, fruits, vegetables, and other plant-based foods (Plakantonaki et al., 2023). In these natural forms, soluble polysaccharides typically coexist with insoluble cellulose in a hydrated but insoluble state. This has two key implications for their functional classification (Rodríguez-Daza et al., 2021). First, classifying food PCWs as insoluble implies they behave similarly to cellulose, whereas their high water-holding capacity and rheological properties are more akin to those of soluble fibers. Second, a chemical classification would categorize components such as pectins and arabinoxylans as soluble, even though in food, they are often found in insoluble plant cell walls. Therefore, a more functional classification of fiber types in food is needed to address these limitations (Rodríguez-Daza et al., 2021).

8 Phytonutrient Composition and Structural Integration of Polyphenolic Compounds

The nutritional benefits of plant-based foods are partly attributed to phytochemicals, which are secondary metabolites such as polyphenolic compounds and carotenoids. These compounds are abundant in fruits, vegetables, and grains. Soluble polyphenols build up in the vacuoles and may adhere to plant cell walls following food processing or digestion. Some simple flavonoids and ferulic acid esters are embedded in the cell wall structure (Williams et al., 2017). Polyphenols are a diverse group of compounds made up of hydroxylated phenyl units. They comprise of many simple phenols or phenolic acids with varying numbers of phenolic rings and substituents. Polyphenols are generally divided into two primary categories, including flavonoids as well as non-flavonoids (Williams et al., 2017).

9 Conclusion

Dietary fiber is crucial for supporting healthy gut function because of its complex and diverse interactions with the intestinal microbiota. As an important constituent of cell wall of plants, fiber affects multiple bodily functions, including digestion, gut microbiota variation, and metabolic control (Samami et al., 2025). the fermentation capacity of different types of fiber, mainly soluble fibers like pectin, arabinoxylan, and mixed-linkage glucans, is crucial for their beneficial health effects, including promoting glycemic control, promoting gut microbiota activity, and aiding in prevention of long-term diseases such as Type 2 diabetes and heart-related conditions (Ötles & Ozgoz, 2014). Even though the physicochemical traits of dietary fibers are well characterized, a system based on functionality is needed to more accurately reflect their effects in their natural food matrix. Consuming a fiber-rich whole plant diet offers a natural and effective way to promote gastrointestinal health and overall wellbeing. Moreover, the growing awareness of plant derived compounds like polyphenols and carotenoids size the wide-ranging health advantages of whole plant foods, supporting the effects of dietary fibers. Current studies on fiber's interaction with gut microbiome and its wider health effects remains crucial (Bull & Plummer, 2014). As knowledge of these interaction advances, dietary fiber will remain a key focus in developing strategies for preventing and managing diverse metabolic and digestive disorders. Including a variety of high fiber foods in daily meals is not only crucial for gut health but also beneficial for overall metabolic and immune health well-being, highlighting the value of whole-food dietary patterns that focusing on natural fiber sources (Ye et al., 2022).

Author Contributions

Samina Kauser, Mehak Fatima, Eesha Zubair, Emaan Farooq, Ayesha Ejaz, Aqib Ishaq, Kanz Ul-Eman, Muhammad Soban Mumtaz, Hamna Siddique, and Fatima Haroon contributed to the conceptualization, literature search, review and interpretation of the relevant literature, organization of the scientific content, and preparation of the manuscript. All authors contributed to writing—original draft and writing—review and editing. All authors read and approved the final version of the manuscript and agreed to be accountable for all aspects of the work.

Conflict of Interest

The authors declare that they have no financial, professional, institutional, or personal conflicts of interest that could have influenced the content or conclusions of this article.

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Data Availability

No new data were generated or analysed in this study. All information supporting the conclusions of this review was obtained from the published literature cited in the article.

Informed Consent

Not applicable. The study did not involve the recruitment of human participants or the collection of primary personal data.

Use of Generative AI

The authors declare that no generative artificial intelligence tools were used to generate the scientific content, conduct the literature analysis, interpret the evidence, or formulate the conclusions presented in this article.

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