Dean&Francis
ISSN 2959-409X

Dietary Fiber in Public Health Nutrition: Chemical Traits and Mechanisms for Chronic Disease Prevention

Kaicheng Lei

Shenzhen Senior High School, Shenzhen, Guangdong, China
Corresponding author: leikc@cn-school.com

Abstract:

Dietary fiber is a key human nutritional component with multiple overall health benefits, especially for preventing chronic diseases like type 2 diabetes, cardiovascular diseases, obesity and colorectal cancer. Despite decades of research confirming its importance, many reviews fail to link its chemical properties to in vivo mechanisms and public health roles. This paper integrates these by summarizing its chemical composition, physical properties, classification and associating them with health-effect nutritional mechanisms. The results of this paper show that dietary fiber acts via multiple pathways. It regulates blood glucose and cholesterol, improves gut health, aids appetite control and reduces inflammation. Soluble fibers with high viscosity and fermentability, such as β-glucan and pectin, are most effective for better metabolic outcomes. However, global intake is far below the WHO's 25-30g daily recommendation. This gap highlights the need for nutrition education, improved food labeling and fiber-fortified foods. Future research should optimize fiber classification beyond "soluble vs. insoluble" and explore personalized nutrition to enhance its chronic disease prevention effects.

Keywords: Dietary fiber; chemical properties; nutritional mechanisms; chronic disease prevention.

1. Introduction

Non-communicable chronic diseases are now the leading causes of illness and death around the world. According to the WHO, conditions such as cardiovascular disease, diabetes, cancers and chronic respiratory illnesses are responsible for about 74% of all global deaths every year[1]. Among these, metabolic disorders like type 2 diabetes and obesity are increasing rapidly, fueled by unhealthy diets, less physical activity and population aging. The IDF reports that the global prevalence of diabetes has almost quadrupled since 1980, reaching around 537 million adults in 2021[2]. Similarly, cardiovascular diseases take 17.9 million lives each year and place heavy burdens on both healthcare systems and economies.

One dietary factor that stands out as consistently protective against these diseases is dietary fiber. It is defined as the edible parts of plants or similar carbohydrates that resist digestion and absorption in the small intestine, but which can be partly or fully fermented in the large intestine [3]. Over the past several decades, both epidemiological and clinical studies have shown that higher fiber intake is linked to better blood sugar control, lower cholesterol, healthier gut function, and a reduced risk of obesity, cardiovascular disease, and colorectal cancer [4]. Despite this strong evidence, actual fiber intake is still inadequate worldwide. In many Western countries, people consume only 15–20 grams per day, while several Asian countries report even lower averages because of shifts away from traditional high-fiber foods and toward refined grains and processed products [5]. Modern diets rich in sugar, saturated fats, and ultra-processed foods have largely replaced staples like whole grains, legumes, fruits, and vegetables, creating a widespread "fiber gap". Another important point is that dietary fiber is not a single nutrient but a chemically diverse group of compounds. The traditional categories of soluble and insoluble fiber are useful but overly simplistic. Recent studies suggest that viscosity, fermentability, and chemical structure are more precise ways to understand fiber's effects [6]. These characteristics explain why some fibers can slow glucose absorption, reduce cholesterol, influence the gut microbiota, or help regulate appetite. For example, soluble fibers such as β-glucans and pectins form gels that slow nutrient absorption and increase satiety, while insoluble fibers like cellulose mainly work by adding bulk and speeding intestinal transit [7]. Meta-analyses also provide strong evidence. Chen et al. found that every 10-gram increase in daily fiber intake was linked to a 10% reduction in all-cause mortality, as well as fewer cases of cardiovascular and metabolic diseases [8]. Similarly, Li et al. reported that high-fiber diets improve insulin sensitivity and lower the risk of obesity [9]. However, most current reviews only focus on the physiological effects of dietary fiber, failing to fully link it to its chemical properties. Understanding the chemical basis of dietary fiber's role is crucial. Firstly, it can explain the differences in health outcomes among different types of dietary fiber. Secondly, it aids in the design of functional foods and supplements with specific benefits. Lastly, it makes public health programs and personalized diet plans more targeted. This article aims to fill this gap, with specific objectives including elaborating on the chemical properties and classification of dietary fiber, explaining the nutritional mechanisms of dietary fiber in preventing chronic diseases, and discussing public health strategies to increase dietary fiber intake and reduce the global burden of chronic diseases. By integrating knowledge from the fields of chemistry, nutritional science, and public health, this article comprehensively reveals the potential of dietary fiber as an important tool in fighting chronic diseases.

2. Chemical Properties of Dietary Fiber

Dietary fiber is not a single substance, but a class of compounds derived from plants that cannot be fully digested by the gastrointestinal enzyme system of the human body. Its unique chemical properties are the core reasons for its potent physiological effects. This section will elaborate on the types, chemical structures, and physical properties of dietary fiber, the impact of food processing on it, and the role of functional fiber in the modern food industry (see table 1). Traditionally, dietary fiber is divided into two categories based on its solubility in water [10]. Soluble fiber (pectin, β-glucan, gum and part of hemicellulose) is soluble in water and forms a gel, which is easily fermented by intestinal bacteria in the colon, producing short-chain fatty acids (SCFAs) such as acetic acid, propionic acid, and butyric acid, thereby exerting various health benefits. Insoluble fiber (cellulose, lignin, and part of hemicellulose) is insoluble in water and has low fermentability, but it can increase fecal bulk and improve intestinal transit, thereby preventing constipation and diverticulosis. The new classification system breaks through this simple dichotomy and pays more attention to the following additional characteristics. The first is viscosity, which refers to the ability of dietary fiber to thicken or form a gel in the intestine, slowing down digestion and nutrient absorption. The second is fermentability, indicating whether intestinal microorganisms can decompose dietary fiber to produce SCFAs (fermentable fiber is beneficial to intestinal health, while non-fermentable fiber mainly plays a role in increasing capacity). The third is functional fiber, such as inulin, resistant starch, and other isolated or synthesized fibers, which are added to food to achieve specific health benefits [6].

Table 1. Chemical distinctions between major dietary fiber types and their functional implications

Fiber Type	Solubility	Viscosity	Fermentability	Key Health Effects
Cellulose	Insoluble	Low	Low	Increases fecal bulk
Hemicellulose	Partial	Low–Medium	Moderate	Improves gut motility
Pectins	Soluble	High	High	Lowers cholesterol, modulates glucose

ISSN 2959-409X

β-Glucans	Soluble	High	High	Improves lipid profiles, lowers glucose
Lignin	Insoluble	Low	Non-fermentable	Adds stool bulk
Inulin (functional)	Soluble	Low	High	Prebiotic effects, enhances mineral uptake
Resistant Starch	Insoluble	Low	Moderate–High	SCFA production, improves gut health

This novel classification system facilitates a better explanation of the functional differences of various dietary fibers in the body, rather than simply defining them as „soluble“ or „insoluble“. The chemical structure of dietary fibers directly affects their solubility, fermentability, and efficacy. Most dietary fibers are composed of non-starch polysaccharides (NSPs), which are polymers of monosaccharides such as glucose, galactose, xylose, arabinose, mannose, and uronic acid. Their molecular weight and the connection mode of monosaccharide units determine the water-holding capacity and fermentability of dietary fibers [7]. Below are examples of the chemical structures of several key dietary fibers. Cellulose consists of a straight-chain structure of β-1,4-linked glucose units, forming a solid crystalline state, which is insoluble and non-fermentable, with the main function of increasing fecal bulk. Hemicellulose includes branched polysaccharides such as xylan, mannan, and arabinogalactan, which are partially soluble and have moderate fermentability. Pectin is a complex polysaccharide rich in galacturonic acid, with gel-forming ability, high solubility, and high fermentability, which helps to lower blood glucose and cholesterol. β-glucan, mainly found in oats and barley, consists of β-1,3 and β-1,4 linked glucose units, with solubility, high viscosity, and high fermentability, and is known for reducing low-density lipoprotein (LDL) cholesterol and improving blood glucose control. Lignin, unlike the aforementioned fibers, is a phenolic polymer (non-carbohydrate), insoluble and non-fermentable, but it can increase fecal bulk and may help to bind bile acids.

In addition, non-carbohydrate components such as resistant proteins can also affect the anti-digestibility and overall function of dietary fiber. The effects of dietary fiber in the body stem from its physical properties. In terms of solubility, soluble fiber forms a viscous solution with water, slowing down digestion and improving blood glucose and lipid levels. Insoluble fiber is insoluble in water but can increase fecal bulk. In terms of viscosity, viscous fibers such as β-glucan and psyllium can slow down carbohydrate digestion and nutrient diffusion, thereby reducing postprandial blood glucose excursions and reducing cholesterol absorption [8]. In terms of water retention, fibers with water-holding capacity can increase fecal mass, making bowel movements smoother. In terms of fermentability, fermentable fibers exert a prebiotic effect, nourishing beneficial gut bacteria and producing short-chain fatty acids (SCFAs), thereby reducing inflammation and improving colon health [11]. Food processing can alter the effects of dietary fiber in the body. Thermal processing (cooking, baking) may break down polysaccharide chains, increasing the solubility and fermentability of dietary fiber, but sometimes reducing its water-holding capacity. Mechanical processing (grinding, crushing) reduces fiber particle size, increasing the surface area for microbial action and potentially altering its viscosity. Industrial processing (extrusion, enzymatic hydrolysis) can produce resistant starch or alter the structure of β-glucan, with health effects depending on the specific processing method [12].

In addition to natural dietary fiber, the food industry also utilizes functional fibers. These fibers are isolated or synthesized and then added to food products. Common types include inulin, resistant starch, and modified cellulose. Inulin is a soluble fructan that acts as a prebiotic, promoting the growth of beneficial gut bacteria and improving mineral absorption. Resistant starch is a type of starch that cannot be digested and functions similarly to fiber, producing SCFAs during fermentation. Modified cellulose is cellulose that has undergone chemical or physical treatment and is used as a fat substitute and thickener in low-calorie foods. Functional fibers enable food companies to achieve additional health benefits through food fortification, helping individuals meet the recommended dietary fiber intake [5].

The health benefits of dietary fiber are directly attributed to its chemical and physical properties. These properties influence nutrient absorption, intestinal function, immune response, and even the regulatory process of hormones on appetite. These factors work together to reduce the risk of chronic diseases such as type 2 diabetes, cardiovascular disease, obesity, and colorectal cancer. One of the most important roles of dietary fiber is glycemic control. Soluble fiber forms a viscous gel in the small intestine, slowing down gastric emptying and the rate of glucose entry into the bloodstream, thereby reducing postprandial blood glucose spikes, decreasing insulin requirements, and improving long-term glycemic control [4]. Fermentable fiber can also be metabolized by gut microorganisms into short-chain fatty acids (SCFAs), primarily propionate and butyrate. Propionate reduces hepatic glucose production and cholesterol synthesis, while butyrate serves as an energy source for colonic cells, enhancing intestinal barrier function [11]. Furthermore, SCFAs can stimulate the secretion of hormones such as glucagon-like peptide-1 (GLP-1) and peptide YY (PYY), further improving glycemic regulation and enhancing satiety (see Fig. 1) [9].

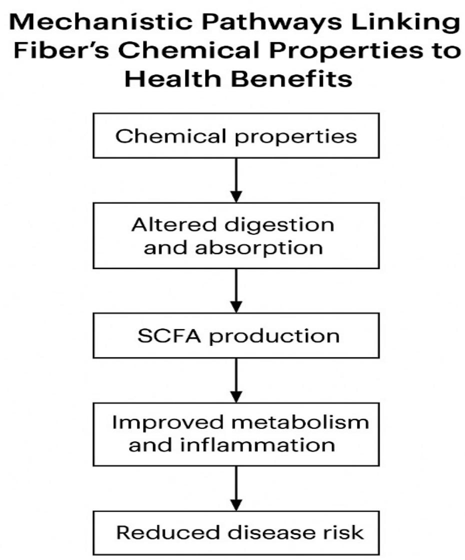

Fig. 1 Mechanistic pathways linking dietary fiber's chemical properties to chronic disease prevention

Dietary fiber also aids in the regulation of cholesterol and lipid metabolism. High-viscosity fibers such as β-glucan, psyllium, and pectin can bind bile acids in the intestine, reducing their reabsorption. At this point, the liver needs to consume cholesterol to synthesize new bile acids, thereby lowering total cholesterol (especially LDL cholesterol) levels [8]. Additionally, short-chain fatty acids (SCFAs) produced through fermentation also affect lipid metabolism in the body. Propionic acid reduces liver cholesterol synthesis, while butyric acid promotes lipid oxidation. These effects collectively improve blood lipid levels and reduce the risk of atherosclerosis and heart disease [12].

The intestine is the core site where dietary fiber exerts its direct effects. Insoluble fiber increases stool volume, accelerates intestinal transit, and prevents constipation and diverticulosis [3]. Meanwhile, fermentable fibers such as inulin and resistant starch exert a prebiotic effect, nourishing beneficial bacteria such as bifidobacteria and lactobacilli. The SCFAs produced by these bacteria can lower colonic pH, inhibit the growth of harmful bacteria, and improve mucosal immune function. Among them, butyric acid exerts an anti-inflammatory effect by reducing pro-inflammatory cytokines and supporting regulatory T cells, maintaining the stability of the intestinal environment [11]. Chronic low-grade inflammation is associated with various non-communicable chronic diseases such as cardiovascular disease and metabolic syndrome. Dietary fiber mainly alleviates such inflammatory responses through SCFAs. For example, butyric acid can inhibit the activation of nuclear factor-kappa B (NF-κB) and reduce the production of pro-inflammatory cytokines such as interleukin-6 (IL-6) and tumor necrosis factor-α (TNF-α). Propionic acid, on the other hand, affects the development of immune cells and promotes anti-inflammatory responses (see Fig. 1) [4].

Another important mechanism is the improvement of intestinal barrier integrity by soluble fiber. Preventing toxins such as lipopolysaccharide (LPS) from entering the bloodstream reduces systemic inflammation and enhances insulin sensitivity. Dietary fiber intake affects appetite and energy balance. High-viscosity fiber prolongs the retention time of food in the stomach, stretches the stomach wall, and transmits a „satiety signal“ to the brain. At the same time, SCFAs stimulate the secretion of gut hormones such as GLP-1 and PYY, further enhancing satiety and reducing food intake [9]. Dietary fiber may also reduce the level of „hunger hormone“ ghrelin. In the long run, this also explains why people with high fiber intake usually have healthier body weight and fewer obesity-related complications (see Fig. 1) [12].

The aforementioned mechanisms work together to significantly reduce the risk of developing major chronic diseases. For type 2 diabetes, long-term studies have shown that high fiber intake can improve insulin sensitivity, reduce fasting blood glucose and glycated hemoglobin (HbA1c) levels, and decrease the incidence rate of diabetes by up to 30% [8]. For cardiovascular diseases, dietary fiber reduces the risk of coronary heart disease and stroke by lowering LDL cholesterol, blood pressure, and inflammatory response. A daily increase of 7 grams in dietary fiber intake can reduce the risk of cardiovascular diseases by 9% [12]. For obesity, a high fiber diet provides fewer calories per gram of food and enhances feelings of fullness, which helps prevent weight gain. For colorectal cancer, dietary fiber dilutes potential carcinogens in the intestine, shortens intestinal transit time, and promotes butyrate production. Butyrate has an anti-proliferative effect on colon cells (see Fig. 1) [4].

3. Public Health Implications

Despite numerous studies unequivocally confirming the protective effects of dietary fiber on chronic diseases, the intake of dietary fiber among most populations globally remains significantly below the recommended levels. The World Health Organization recommends a daily intake of at least 25-30 grams of dietary fiber for adults, yet the

ISSN 2959-409X

average intake in most countries is only 15-20 grams [1]. This gap underscores the urgency of developing effective public health strategies to enhance dietary fiber intake levels among different populations. Figure 2 illustrates the global average dietary fiber intake (grams/day) in various regions compared to the WHO-recommended amount. The average intake in North America is approximately 16 grams/day, in parts of Africa, approximately 18 grams/day, and in East Asia, approximately 17 grams/day, all of which fall below the WHO recommended range of 25-30 grams/day (see Fig. 2).

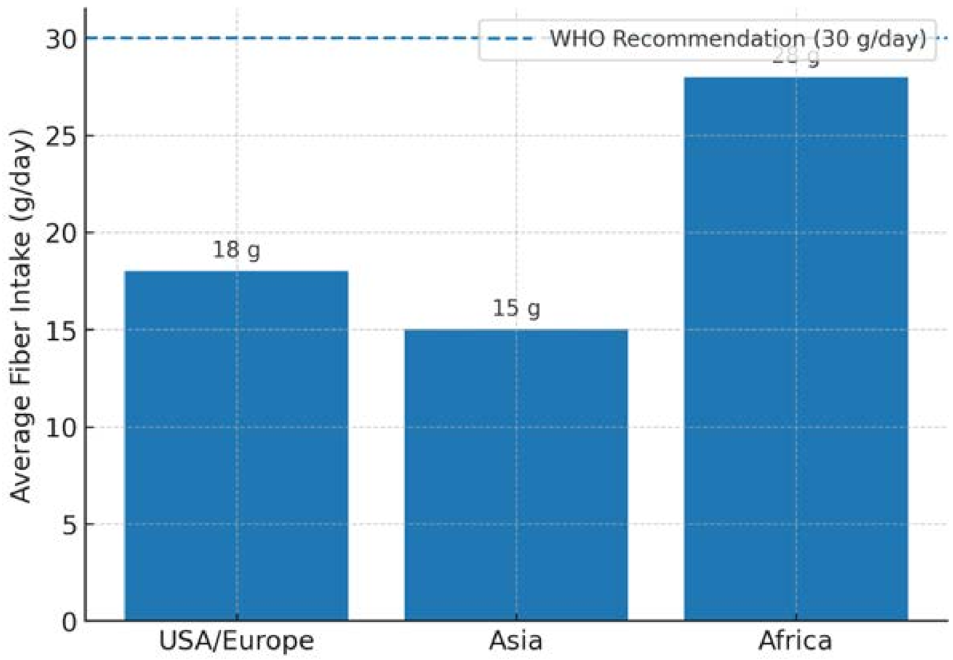

Fig. 2 Global average dietary fiber intake (g/day) by region compared to WHO recommendations

Dietary fiber intake is unevenly distributed globally. In the United States, Canada, and most high-income countries in Europe, due to diets dominated by refined grains and ultra-processed foods, daily intake is far below the recommended standard. In many middle-income countries, including China and India, traditional high-fiber diets are rapidly transitioning to Western dietary patterns, leading to a similarly prominent issue of insufficient dietary fiber intake [5]. There are also differences in intake among different age groups. Children and adolescents often have lower dietary fiber intake than adults due to the lack of fruits and vegetables in school meals and snacks [13]. Older adults may have insufficient intake due to decreased appetite, dental issues, or difficulty chewing. These differences suggest that strategies to increase dietary fiber intake need to be tailored to specific populations.

Most countries have incorporated dietary fiber into their official dietary guidelines. For instance, the „Dietary Guidelines for Americans (2020-2025)" recommends a daily intake of 28 grams for women and 34 grams for men [14]. The European Food Safety Authority (EFSA) has set an adequate daily intake of dietary fiber for adults at 25 grams [15]. Some Asian countries' guidelines suggest a daily intake of 30-35 grams, but actual intake often falls far below this standard [5]. However, public awareness of the importance of dietary fiber remains limited. Many people only associate dietary fiber with „preventing constipation," ignoring its core role in blood sugar control, cholesterol reduction, and chronic disease prevention. Public health campaigns need to expand the scope of information to fully highlight the health benefits of dietary fiber. Government policies and actions by the food industry can help improve the accessibility of high-fiber foods. For example, front-of-pack labeling systems (such as the „traffic light" labeling in the UK and the „health star rating" in Australia) help consumers quickly identify high-fiber foods. School meal programs that prioritize whole grains, fruits, and vegetables have effectively increased children's dietary fiber intake. Reforms in workplace cafeterias have helped adults obtain healthier, high-fiber diets. In addition, encouraging food companies to add functional fibers (such as inulin and resistant starch) to everyday foods can also help bridge the „dietary fiber gap". Some countries have also indirectly guided dietary patterns towards a high-fiber, healthier direction through tax policies (such as the taxation of sugary beverages in the United

Kingdom and Mexico) [5]. Education is another key aspect in increasing dietary fiber intake. Programs that combine nutritional education with the accessibility of healthy foods have shown particularly effective results. School-based programs provide high-fiber diets while conducting nutritional education, helping children develop healthy eating habits. Community projects such as urban gardening and cooking workshops make it easier for families to understand and consume traditional high-fiber foods. Personalized dietary advice provided by healthcare providers has been proven to effectively increase dietary fiber intake and improve metabolic outcomes [9].

To achieve long-term progress, future strategies must simultaneously address multiple challenges. Firstly, it is crucial to ensure the accessibility of food, making fruits, vegetables, and whole grains affordable and widely available. Secondly, there is a need for cognitive enhancement, educating the public on the diverse health benefits of dietary fiber, rather than solely emphasizing „preventing constipation". Lastly, market regulation is essential to reduce the promotion of low-fiber, ultra-processed foods. New tools can also provide assistance. For instance, digital nutrition apps and AI-driven meal planning tools can guide individuals in a more practical way to increase their dietary fiber intake. Integrating government policies, industry reforms, educational outreach, and technological applications holds promise for achieving long-term improvements in population health.

4. Future Public Health Strategies

Despite sufficient evidence supporting the health benefits of dietary fiber, there are still several important limitations in current research. Firstly, most of the evidence comes from observational studies. This type of research can only reveal associations and cannot prove causal relationships. For example, people with high fiber intake may also have other healthy habits (such as regular exercise and low alcohol consumption), as well as consume more antioxidants, making it difficult to define the specific role of dietary fiber and distinguish its protective effect on chronic diseases. Randomized controlled trials (RCTs) have higher evidence credibility, but existing trials have differences in study duration, fiber type testing, and population selection, resulting in insufficient consistency of results [6]. Secondly, the classification of dietary fiber is still too simplified. The traditional binary method of „soluble vs insoluble" cannot fully reflect its diverse characteristics, and key factors such as viscosity, fermentability, and detailed chemical structure are often overlooked. In addition, the lack of standardized laboratory testing methods makes it difficult to compare the results of different studies and populations [7]. Thirdly, there are still shortcomings in the mechanism research (i.e., the study of explaining the specific pathways of dietary fiber in the body). Although scientists have recognized the importance of short-chain fatty acids (SCFAs) and gut microbiota, the specific pathways of action between specific fiber types, microbial activity, and long-term health outcomes are not yet fully understood. New technologies such as metabolomics and microbial sequencing are expected to help reveal these complex associations. Looking ahead, research should focus on the following directions. Firstly, conduct long-term, strictly controlled randomized controlled trials to clarify the causal relationship between dietary fiber and the prevention of chronic diseases. Secondly, establish a more functional dietary fiber classification system that incorporates chemical and biological characteristics. Thirdly, explore personalized nutrition plans, taking into account factors such as genetics, gut microbiota, and lifestyle that affect individual fiber response. Fourth, research new functional fibers and advanced food technologies to increase dietary fiber intake and achieve targeted health benefits.

5. Conclusion

Dietary fiber is a type of human nutrient with diverse chemical compositions, but is essential for physiological functions. Its key characteristics, such as solubility, viscosity, fermentability, and water holding capacity, determine its role in improving blood sugar control, reducing cholesterol, supporting intestinal health, reducing inflammation, and promoting satiety. These mechanisms work together to reduce the risk of major chronic diseases such as type 2 diabetes, cardiovascular disease, obesity and colorectal cancer. However, the current global dietary fiber intake is still far below the recommended standard. This gap highlights the urgency of developing more comprehensive public health strategies, including optimizing nutrition labels, strengthening education programs, improving food formulas, and promoting community interventions. At the same time, future research needs to optimize the classification system of dietary fiber, deepen the understanding of mechanisms, and develop personalized nutrition plans. Through these efforts, dietary fiber can serve as a low-cost and practical tool to more effectively address the increasing global burden of chronic diseases. The core information is concise yet powerful. Increasing dietary fiber intake (mainly through whole plant foods rich in high viscosity fermentable fibers such as beta-glucan and pectin, as well as functional fiber fortified foods) is one of the simplest and most effective ways to improve population health worldwide.

ISSN 2959-409X

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