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Optimizing Dietary Fiber Intake: Strategies for Human Nutrition and Food Science

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Abstract

Adequate dietary fiber intake from plant foods is critical for the prevention of noncommunicable chronic diseases (NCDs). However, across industrialized nations, consumption remains insufficient to meet established intake recommendations. This gap provides a strong rationale to include functional fibers in processed foods or use them as supplements, although their effectiveness in reducing NCD risk is inconclusive. In this review, we examine current nutritional strategies to optimize fiber intake, spanning whole-plant foods, processed foods made or enriched with fiber-containing ingredients, and fiber supplements. We examine the structure and physicochemical properties of the fiber types represented in these strategies and explore the mechanisms by which they influence the gut microbiome and NCD risk markers. Drawing on evidence from human intervention studies, we critically assess the strengths and limitations of each strategy to improve health outcomes and propose a framework for the effective and systematic integration of fiber into nutrition and food science.

1. INTRODUCTION: THE ROLE OF DIETARY FIBER IN HEALTH

Epidemiological studies have convincingly linked dietary fiber intake from whole-plant foods, such as vegetables, fruits, whole grains, legumes, and nuts, to a lower risk of noncommunicable chronic diseases (NCDs), such as type 2 diabetes (T2D) and cardiovascular disease (CVD). These findings underpin the dietary recommendations of 14 g of fiber per 1,000 kcal (~25 g/day for women and ~38 g/day for men) (Institute of Medicine 2006). Public health campaigns and food-based dietary guidelines consistently advocate for diets rich in fiber from whole-plant foods (Armet et al. 2022). However, despite its well-established health benefits, fiber intake remains below recommended levels across industrialized nations in North America, Europe, and parts of Asia (Fu et al. 2022), mirroring rising NCD rates (O'Keefe 2019).

NCDs: noncommunicable chronic diseases

T2D: type 2 diabetes

CVD: cardiovascular disease

Functional fiber: isolated or synthetic dietary fibers produced through physical, enzymatic, or chemical means that demonstrate a beneficial physiological effect

Intrinsic fiber: naturally occurring dietary fiber that is intact within the plant matrix and embedded in plant cell walls

RCTs: randomized controlled trials

Viscosity: the property of dietary fiber to form gels or thicken solutions in the digestive tract

Fermentability: the degree to which dietary fiber is broken down by microbes in the intestine through enzymatic activity

Bulking: the ability of dietary fiber to retain water, increase fecal mass, improve bowel regularity, and reduce transit time

With diet westernization, whole-plant foods have been displaced by low-fiber, energy-dense, processed foods that dominate dietary patterns (Cordain et al. 2005). In response, alternative strategies have emerged to enhance fiber intake such as fiber-fortified foods and fiber supplements. Although such products are often marketed as functional alternatives to whole-plant foods, they contain isolated and synthetic fibers (functional fiber) that differ from intrinsic fiber in whole-plant sources (Aguilera 2019). Compared to the well-established health-protective effects of intrinsic fiber from whole-plant sources (Puhlmann & de Vos 2022), evidence from randomized controlled trials (RCTs) demonstrating the efficacy of functional fibers in improving risk markers of NCDs is inconsistent and often inconclusive (Armet et al. 2020). Although some regulatory bodies recognize certain functional fiber ingredients for their physiological benefits (e.g., lower blood glucose), they are not broadly promoted in dietary guidelines (Armet et al. 2022).

Research over the past decades has substantially advanced our understanding of fiber's health-promoting potential. RCTs have demonstrated the beneficial effects of specific fibers, including functional ones, on cardiometabolic risk factors (Reynolds et al. 2022) and appetite regulation (Mah et al. 2023). Mechanistic work has clarified how physicochemical properties of different fibers, including viscosity, fermentability, and bulking capacity, translate into distinct physiological outcomes. Among these mechanisms, the gut microbiome has emerged as a compelling target and potential mediator of the effects of fiber (Deehan et al. 2022). Fermentable fibers can influence microbiome composition, metabolic activity, and mucosal integrity in ways that affect physiology, offering a mechanistic explanation for links between fiber intake and NCD risk (Makki et al. 2018). These converging lines of evidence underscore the considerable potential of fiber-based nutritional strategies to improve health outcomes.

Despite widespread promotion of whole-plant foods (Cordain et al. 2005) and increased availability of fiber-fortified processed foods and supplements (Thompson & Brick 2016), these strategies have yet to yield measurable improvements in population-level health outcomes. This justifies the need for coordinated innovation across public health, food systems, nutrition science, and microbiome research, grounded in mechanistic insight and systems-level integration. In this review, we critically examine current health-promoting strategies aimed at increasing fiber intake in relation to their forms (e.g., intrinsic versus functional) and physicochemical properties (viscosity, fermentability, and bulking capacity). We evaluate proposed mechanisms of action, including those mediated by the gut microbiome and its metabolic outputs, and assess the strength of evidence that supports health effects in human intervention studies. Finally, we propose a framework to guide a systematic, targeted, and effective integration of fiber into food systems.

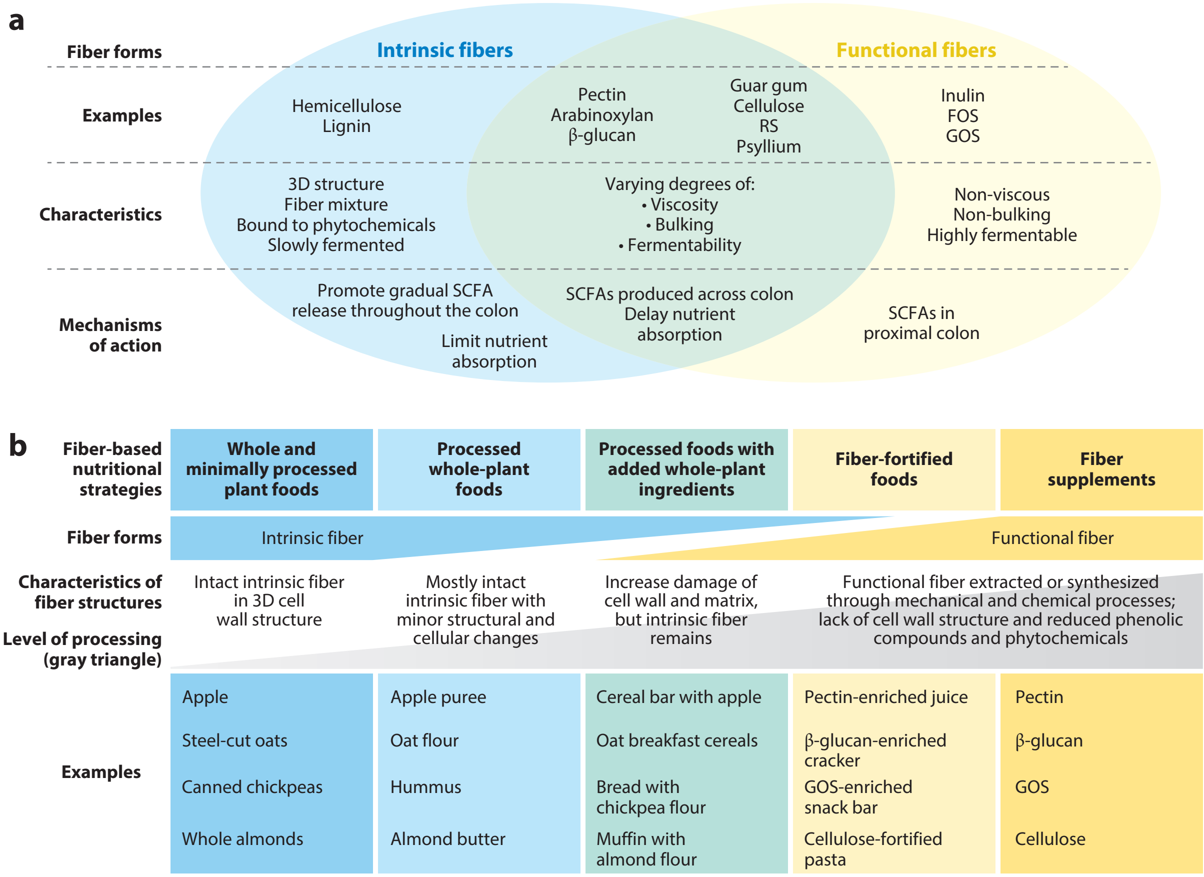

Figure 1

Fiber-based nutritional strategies and their mechanisms of action. (*a*) Venn diagram with examples of intrinsic and functional fibers, their functional characteristics, and the mechanisms for their physiological effects. (*b*) Fiber-based nutritional strategies, fiber forms represented in them, their degree of food processing, and examples of foods. Abbreviations: 3D, three-dimensional; FOS, fructo-oligosaccharides; GOS, galacto-oligosaccharides; RS, resistant starch; SCFAs, short-chain fatty acids.

2. DIETARY FIBER: DEFINITIONS, PROPERTIES, AND HYPOTHESIZED MECHANISMS OF HEALTH PROMOTION

Dietary fiber refers to nondigestible carbohydrates with at least three monomeric units (Jones 2014). Fibers are differentiated into intrinsic whole-plant or functional forms. Intrinsic fibers are naturally embedded in complex three-dimensional (3D) networks of plant cell wall structures, which vary in composition depending on the botanical source and location in the plant (Célino et al. 2014). They include non-starch polysaccharides such as cellulose, hemicelluloses [e.g., arabinoxylans (AX), xyloglucans, β-glucans], and pectin, along with lignin, small amounts of structural proteins, and phenolic compounds (**Figure 1*a***).

AX: arabinoxylan

RSs: resistant starches

Structural fibers, such as AX, cellulose, xyloglucans, β-glucans, and pectin, can be extracted from plant-based raw materials, often as by-products from food processing industries, and are then purified and sometimes chemically modified to enhance functionality. For example, resistant starches (RSs) are fibers that can be physically isolated from starchy foods (e.g., potato, wheat) or produced through chemical starch modification (RS type 4). Several purified fibers such as galacto-oligosaccharides (GOS) and fructo-oligosaccharides (FOS) are marketed as prebiotics. For a fiber to be classified as a prebiotic, it must have a defined structure, be selectively utilized by intestinal microorganisms, and have an associated health benefit (Hutkins et al. 2025).

GOS: galacto-oligosaccharides

FOS: fructo-oligosaccharides

Prebiotic: a substrate that is selectively utilized by host microorganisms, conferring a health benefit

Food matrix: refers to the structural and chemical environment surrounding nutrients that plays a central role in determining the accessibility and physiological impact of dietary fiber

Solubility: the ability of a dietary fiber to dissolve in water at a defined pH

SCFAs: short-chain fatty acids

In intact plant tissues, the 3D matrix of intrinsic fiber limits enzymatic access to both the fiber and associated nutrients, thereby slowing nutrient absorption and microbial fermentation. In contrast, functional fibers lacking this matrix are more readily accessible, which may lead to rapid proximal fermentation and distinct metabolic and immune responses (Tuncil et al. 2018). Given that many structural characteristics of intrinsic fiber are lost during isolation, most regulatory agencies (e.g., US Food and Drug Administration, Health Canada, Food Standards Australia New Zealand) require evidence from human studies demonstrating that functional fibers produce a physiological benefit to be classified as fiber (Institute of Medicine 2006, Jones 2014).

Differences in monosaccharide composition, glycosidic linkages, and polymer structure determine the physicochemical properties of dietary fibers, which directly influence their functionality (Gill et al. 2021). Solubility in water has historically been used to dichotomize fiber as soluble or insoluble; however, this physicochemical property is now considered of lesser importance as it poorly predicts physiological outcomes (Gidley & Yakubov 2019, McRorie & McKeown 2017). Instead, emphasis has shifted toward viscosity, fermentability, and bulking capacity, properties that may better correlate with health effects (**Figure 1*a***).

Upon ingestion, viscous fibers (e.g., psyllium) form gels that slow gastric emptying, enhance satiety, blunt nutrient absorption, and reduce postprandial glucose and lipid levels; they also bind bile acids, contributing to lower serum cholesterol (McRorie 2015). Fermentable fibers (e.g., inulin, RS) are anaerobically metabolized by gut microbes (Fu et al. 2022), producing gases, ethanol, organic acids, and short-chain fatty acids (SCFAs). SCFAs act as signaling molecules that can improve insulin sensitivity, promote satiety, and exert anti-inflammatory effects (Blaak et al. 2020, Koh et al. 2016). In addition, SCFAs stimulate mucin production by goblet cells, supporting a protective mucus layer and intestinal barrier function (Burger-van Paassen et al. 2009). Fibers with both high viscosity and fermentability (e.g., β-glucans, AX) may yield synergistic effects (La Torre et al. 2021). Nonviscous, nonfermentable fibers (e.g., cellulose) primarily contribute to stool bulking and accelerating intestinal transit (McRorie & McKeown 2017, Mudgil & Barak 2013). These properties contribute to improved bowel regularity and reduced exposure to potential carcinogens and can lead to mechanical stimulation of goblet cells, indirectly promoting mucus secretion (McRorie & McKeown 2017, Mudgil & Barak 2013).

In summary, dietary fibers are a complex group of nondigestible carbohydrates that differ in monosaccharide composition, glycosidic linkage patterns, and structural configurations. These differences influence their physiological effects and ultimately determine how different fiber-based nutritional strategies influence health.

3. STRUCTURAL AND FUNCTIONAL DIFFERENCES IN DIETARY FIBER ACROSS FIBER-BASED NUTRITIONAL STRATEGIES

Health and microbiome effects of fibers vary substantially according to their structural and functional characteristics, physicochemical properties, and source as well as the food matrix in which they are consumed. In the following section, we examine how these factors shape outcomes across different dietary strategies, ranging from whole-plant foods to fiber-fortified foods and fiber supplements (**Figure 1*b***).

3.1. Whole and Minimally Processed Plant Foods

Whole and minimally processed plant foods include vegetables, fruits, legumes, nuts, seeds, and grains that either are consumed raw or have undergone processing steps that have minimal effects on the intrinsic fiber structures (e.g., chopping, freezing, heating, steaming, boiling, drying, or canning without additives) (Puhlmann & de Vos 2022). The impact of processing on fiber integrity depends on both the nature of the treatment and the structural and chemical characteristics of the fiber. Although processes such as drying, freezing, and freeze-drying typically exert negligible effects, hydrothermal treatments, including boiling, steaming, and canning, can induce cell wall swelling and pectin dissolution. Dry thermal treatments like roasting or baking may compromise cell wall integrity while largely maintaining overall tissue architecture (Puhlmann & de Vos 2022). Moreover, the digestibility of RS type 2 increases with cooking, as gelatinization improves accessibility to amylases (Walsh et al. 2022) (**Figure 1*b***). Overall, however, despite some measurable structural modifications, minimal processing methods generally preserve the nutritional benefits of fiber in whole-plant foods.

3.2. Processed Whole-Plant Foods

To improve digestibility, shelf life, or functionality, many whole-plant foods are manufactured into products using processing steps (e.g., fine milling, blending) that may disrupt the intrinsic fiber structure, rupture cell walls, and alter tissue integrity (Puhlmann & de Vos 2022). Examples include nut butter, flour, and fruit purees. In these products, digestion kinetics and enzyme accessibility may be affected depending on the degree and type of processing applied (Holland et al. 2020). Processing techniques that disrupt cellular integrity in starch-rich tissues increase starch digestibility and influence postprandial physiology (Edwards et al. 2021). Similarly, the disruption of cell wall structures can increase the accessibility of fiber to bacterial enzymes in the colon, potentially accelerating fermentation and altering microbial metabolism (Holland et al. 2020) (**Figure 1*b***). Overall, although processing of whole-plant foods disrupts intrinsic fiber structures and alters fiber's physicochemical properties, these products remain whole food–based sources of fiber and other nutrients (e.g., vitamins, minerals, and phytochemicals, including polyphenols), retaining important health-promoting qualities.

3.3. Processed Foods with Added Whole-Plant Food Ingredients

Many commonly consumed processed foods such as bread, pasta, breakfast cereals, yogurts, and snack bars incorporate fiber-rich whole-plant food elements like seeds, nuts, legumes, pseudocereals, and whole grains. The nutritional and physiological impacts of these additions depend not only on the presence of whole-plant ingredients but also on their quantity and the degree of processing they undergo during product development. Depending on the exposure of whole-plant ingredients to processing treatments during product development, this fiber-based nutritional strategy has the capacity to deliver a variety of intrinsic plant fiber structures in otherwise nutritionally inferior products (Zheng & Xiao 2022) (**Figure 1*b***).

3.4. Fiber-Fortified Foods

Shifting from strategies that emphasize intrinsic fiber preservation, this category comprises products such as bread, pasta, breakfast cereals, yogurts, and beverages (e.g., sodas, juice) fortified with well-characterized functional fibers (e.g., RS, AX, β-glucan, psyllium, and prebiotic oligosaccharides). These purified ingredients lack the complex 3D structures and accompanying phytochemicals of intrinsic plant fiber but may retain some of their physicochemical properties. When incorporated into new food matrices, their physiological impact depends not only on fiber type but also on matrix characteristics, including water content, texture, food structure, and degree of processing (X. Li et al. 2024) (**Figure 1*b***).

3.5. Fiber Supplements

α-diversity: the within-sample richness and evenness of microbial taxa

β-diversity: the differences in microbial community composition between individuals, treatment groups, or timepoints

A diverse range of isolated and synthetic fibers are marketed as dietary supplements and have been investigated for their potential therapeutic properties (Deehan et al. 2024). These products may be administered as capsules or powders or blended into liquids and range from highly fermentable oligosaccharides such as GOS and FOS and slower-fermenting viscous fiber like β-glucan to non-fermentable long-chain fibers such as psyllium. Fiber supplements lack the 3D cellular matrices and associated phytochemicals present in whole-plant foods (Puhlmann et al. 2024), yet may retain some of their physicochemical properties (**Figure 1*b***).

3.6. Summary

The degree of processing of whole-plant foods, their incorporation into new food matrices, and subjection to further processing alters fiber structure and, consequently, its physiological functionality. Understanding how these structural differences influence physiological responses is essential for optimizing the efficacy of fiber-based nutritional strategies.

4. FIBER–MICROBIOME INTERACTIONS: MECHANISMS AND VARIABILITY

Although health effects of fiber can occur independently of microbial metabolism, its interactions with the gut microbiome have received growing attention. Fiber fermentation by colonic microbes drives changes in both community composition and metabolic activity (**Figure 2**), which is postulated to mediate certain health effects.

4.1. Effects of Dietary Fiber on Gut Microbiota Diversity and Composition

If consumed in sufficient doses, fermentable fiber alters both community diversity (referred to as α-diversity) and composition from baseline (often measured as intra-subject β-diversity) in human trials with whole-plant-food-based diets (Li et al. 2025, Rinott et al. 2022, Zhao et al. 2018) and functional fibers (Deehan et al. 2020, H. Li et al. 2024, Nguyen et al. 2020, Vandeputte et al. 2017).

The influence of fiber on α-diversity has been widely studied, yet results remain inconclusive. Although some studies report increases in α-diversity (especially with whole-plant-food diets and whole grains) (Kovatcheva-Datchary et al. 2015, Visuthranukul et al. 2024), others show no effect (Meslier et al. 2020, Rinott et al. 2022, Vanegas et al. 2017, Wastyk et al. 2021) or even a decrease with high doses of functional fibers (Deehan et al. 2020, Lancaster et al. 2022, Nguyen et al. 2020, Oliver et al. 2021, Rodriguez et al. 2024) or whole-plant-food diets (Li et al. 2025). Reduction in diversity may be driven by acidification of luminal pH (Li et al. 2025) or selective enrichment of specific fiber-utilizing taxa, which leads to a narrowing of community evenness (Cantu-Jungles & Hamaker 2023). In this respect, it is important to emphasize that α-diversity is not an established predictor of health, and reductions may merely constitute the ecological response of the community.

Microbiota compositional shifts are highly fiber-specific, determined by monosaccharide composition, glycosidic bond types, physical and chemical structure, physicochemical properties, dose, and food matrix complexity. Significant β-diversity shifts are detectable at higher fiber doses (Deehan et al. 2020, Li et al. 2025, Nguyen et al. 2020), although even lower doses (around 5 g) may induce changes in specific taxa abundances (Davis et al. 2010, 2011). Most evidence on taxonomic changes comes from intervention trials with functional fibers, particularly with prebiotics. Although traditional prebiotics such as FOS and GOS are reliably bifidogenic, they tend to promote broader and less selective enrichment patterns compared to more structurally diverse fiber types (Cantu-Jungles et al. 2021). For instance, short-chain GOS are rapidly fermented and

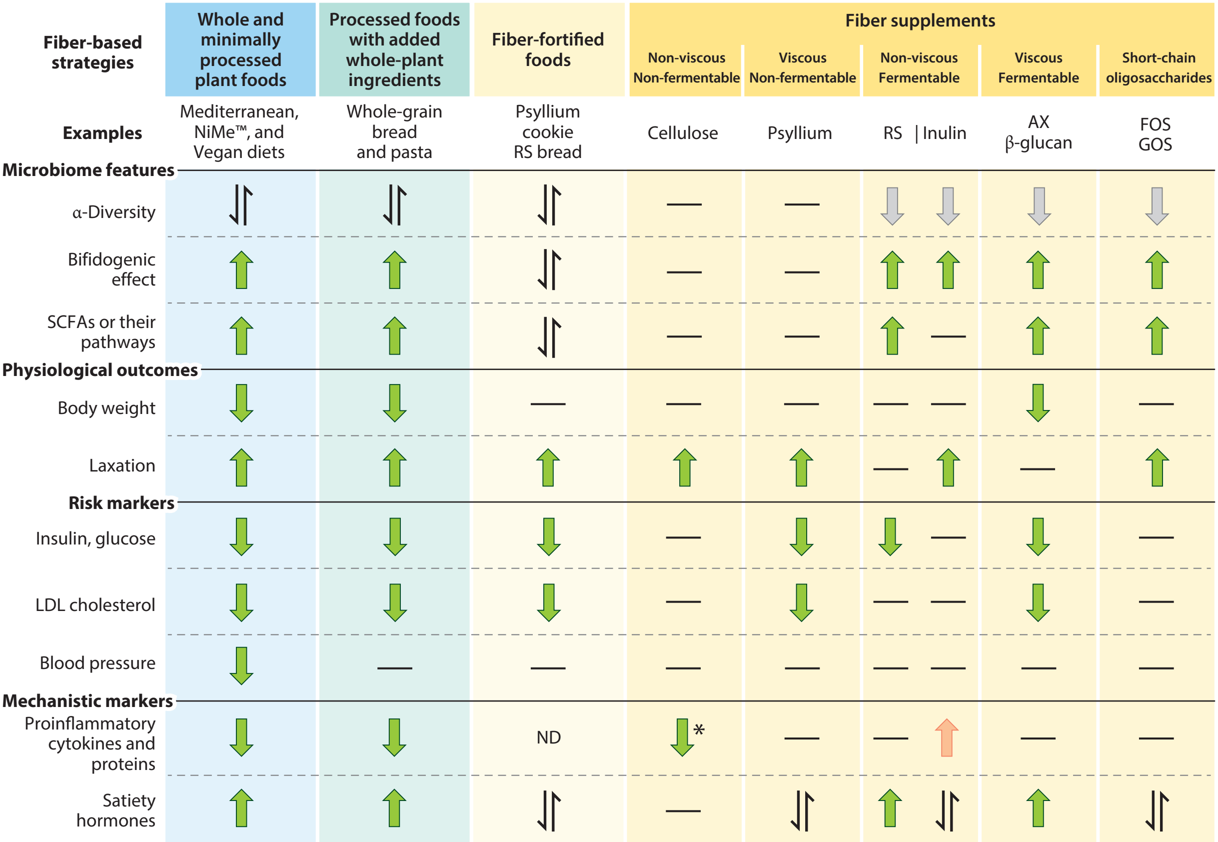

Figure 2

Effects of fiber-based nutritional strategies on microbiome features and clinical outcomes. Effects of various fiber interventions, ranging from plant-rich, whole-food diets (e.g., Mediterranean, Nordic, New Nordic, NiMe^{TM}, vegan) to fiber-fortified foods and fiber supplements, on gut microbiota features and a spectrum of clinical outcomes, including disease risk markers and mechanistic indicators. Owing to limited clinical data, the fiber-based nutritional strategy involving processed whole-plant foods (Strategy 2) is not included. Common effects of fiber on the gut microbiota include changes in α-diversity, enrichment of bifidobacteria, and SCFA levels or metabolic pathways involved in the formation of SCFAs. Commonly observed clinical effects of fiber include outcomes relevant to obesity (e.g., body weight, satiety hormones), constipation (e.g., laxation), T2D (e.g., glucose, insulin sensitivity), CVD (e.g., cholesterol, blood pressure), and systemic inflammation (e.g., C-reactive protein, tumor necrosis factor-α). Colors: green, beneficial effects; gray, no evidence for either beneficial or deleterious effects; red, deleterious effects. Abbreviations: ↑ or ↓, strong effects; ⇃↾, heterogeneous or variable effects; –, no significant changes or inconclusive effect; *, evidence based on a limited number of our own studies; AX, arabinoxylan; CVD, cardiovascular disease; FOS, fructo-oligosaccharides; GOS, galacto-oligosaccharides; LDL, low-density lipoprotein; ND, no data; RS, resistant starch; SCFA, short-chain fatty acids; T2D, type 2 diabetes.

consistently enriched for a variety of *Bifidobacterium* species (Davis et al. 2011), whereas chemically modified cross-linked RS type 4 is enriched for only one *Bifidobacterium* species (*Bifidobacterium adolescentis*) (Armet et al. 2025, Deehan et al. 2020, Martínez et al. 2010) (**Figure 2**).

Even minor differences in chemical structure, such as between RS variants, can distinctly influence microbiome composition by enriching for specialized taxa that possess the ability to utilize discrete fiber chemistries (Deehan et al. 2020). Crystalline (type 2 and type 4) and retrograded (type 3) RS selectively stimulate amylolytic taxa such as *Ruminococcus bromii* and *Eubacterium rectale*, whereas cross-linked RS type 4 is highly selective to *B. adolescentis* and *Parabacteroides* *distasonis* (Armet et al. 2025, Deehan et al. 2020, Martínez et al. 2010). Thus, structure-specific effects of fiber allow precise modulations of gut microbiome composition.

4.2. Effects of Fiber on Microbiome Metabolism and Function

Microbiome compositional shifts in response to fiber are tightly coupled with changes in metabolic function linked to fermentation, which result in SCFA production. However, measurements of SCFAs in both fecal and blood samples do not give a reliable account of their production in the gut. Indeed, in many intervention trials with whole-plant foods, whole grains, and fiber supplements, fecal SCFAs often remain unchanged (Lancaster et al. 2022, H. Li et al. 2024, Meslier et al. 2020, Roager et al. 2019, So et al. 2018). However, when fermentable dietary fiber is given in higher doses, fecal SCFA increases are often detectable (Armet et al. 2025, Jenkins et al. 2001, Li et al. 2025, Vanegas et al. 2017) (**Figure 2**).

Fiber categories, types, and structures differ vastly in the speed at which they are fermented. Rapidly fermented fibers (e.g., inulin, FOS) increase acetate and lactate concentrations, supporting downstream butyrate producers (e.g., *Agathobacter*, *Eubacterium coprostanoligenes*, and *Subdoligranulum*) (Visuthranukul et al. 2024). Intrinsic and structurally complex fibers can engage a wider range of taxa and are more slowly fermented, resulting in SCFAs (including propionate and butyrate) being produced throughout the entire length of the colon (Puhlmann & de Vos 2022). This is important, as consistent immunometabolic effects of dietary fiber have been shown with only distal SCFA delivery (Freeland & Wolever. 2010, van der Beek et al. 2016).

Although some interindividual variability is inevitable, functional fibers can direct the production of specific SCFAs in a structure-dependent way, allowing precise modulation of microbiome metabolism (Deehan et al. 2020). In addition to SCFAs, fiber also directs other health-related metabolites, such as indole derivatives from tryptophan metabolism (e.g., indole-3-propionic acid), via metabolic interactions (Sinha et al. 2024).

Reduced colonic pH is another important metabolic outcome of fiber fermentation (Brinck et al. 2025). Acidification of the intestinal content inhibits proteolytic fermentation, reflected in increases in branched-chain fatty acids, which is considered detrimental due to the release of potentially harmful metabolites such as ammonia, phenols, and cresol (Armet et al. 2022, Louis et al. 2014). These by-products have been associated with mucosal inflammation, DNA damage, and an increased risk of colorectal cancer (O'Keefe et al. 2015). The effects of fermentable fibers on pH might, therefore, be one key mechanism for the protective effect of fiber on colorectal cancer risk, but more work is needed to validate this mechanism (Brinck et al. 2025).

In the absence of adequate fiber, commensal bacteria shift their metabolism toward utilization of host-derived glycans, including those from the protective mucus layer covering the intestinal epithelium (Sonnenburg et al. 2005). This degradation compromises the integrity of the mucus barrier, increasing susceptibility to pathogens, inflammation, and immunometabolic pathologic states, a process that is well established in animal models (Earle et al. 2015, Schmit et al. 2023, Sonnenburg & Sonnenburg 2014, Wolter et al. 2024). Direct measurement of the colonic mucus layer in humans is technically difficult, but sequencing approaches have shown that a high-fiber, non-industrialized-type diet can remodel the microbiome's carbohydrate metabolism landscape, increasing plant-targeted CAZymes while reducing those that target host-derived glycans, which was associated with the diet's anti-inflammatory effects (Li et al. 2025).

4.3. Individualized Responses

Microbiome composition is highly individualized among humans (Lozupone et al. 2012). Accordingly, microbiome responses to fiber-based interventions vary considerably across participants in clinical trials. Although fiber often significantly alters microbiome composition and function in structure-dependent ways, these effects are usually limited to a subset of participants (responders) (Baxter et al. 2019, Kok et al. 2023, Nguyen et al. 2020). Baseline microbiome features have been shown to predict responder phenotypes, particularly ecological or functional features of the microbiome. For example, subsets of co-abundant taxa, representing cross-feeding interactions in ecological guilds, predicted propionate responses to AX (Nguyen et al. 2020), whereas baseline copy numbers of prebiotic-specific carbohydrate-associated genes predicted SCFA responses to FOS, inulin, and xylo-oligosaccharides (Kok et al. 2024).

LDL: low-density lipoprotein

4.4. Summary

Fiber-based nutritional interventions alter microbiome diversity (e.g., α- and β-diversity), composition (microbial taxa), and functions (e.g., SCFAs, fecal pH). Such shifts are highly structure specific and are dependent on physicochemical properties, dose, and the food matrix by which the fiber is delivered. Overall, fiber interventions induce highly individualized responses on microbiome composition and function, often linked to baseline microbiome composition. Understanding these responses is critical in designing strategies to harness microbiome modulation for clinical benefits.

5. CLINICAL EFFECTS OF FIBER-BASED NUTRITIONAL STRATEGIES

To optimize fiber use in nutrition, food science, and the overall food system, it is essential to evaluate the clinical effects of different fiber-based nutritional strategies. This section provides a critical appraisal of the clinical evidence, incorporating systematic reviews, meta-analyses, RCTs, and consideration of regulatory approvals of health claims and dietary guideline recommendations, which indicate expert consensus on the supporting evidence (**Figure 2**).

5.1. Clinical Effects of Whole and Minimally Processed Plant Foods

Plant-rich, high-fiber diets, particularly the Mediterranean, Nordic, and vegetarian dietary patterns, consistently show favorable effects on risk markers for NCDs (Landry et al. 2023, Rinott et al. 2022), including reduced risk of CVD, cancer, and overall mortality (Kastorini et al. 2011). Key cardiometabolic risk markers, such as total and low-density lipoprotein (LDL) cholesterol (Hall et al. 2021, Jenkins et al. 2001, Li et al. 2025, Meslier et al. 2020) and blood pressure (Rinott et al. 2022), are consistently improved by consuming diets rich in whole and minimally processed plant foods. Inflammation, a key underlying mechanism of most NCDs, is also attenuated by diets rich in whole-plant foods (Hall et al. 2021, Li et al. 2025, Temba et al. 2025). In addition to cardiometabolic benefits, these diets have been shown to increase laxation (Jenkins et al. 2001, Li et al. 2025, Wastyk et al. 2021) (**Figure 2**).

Individual whole-plant foods such as raw almonds have been shown to increase satiety-regulating hormones and reduce markers of systemic inflammation (Park et al. 2025). Similarly, apples (Ravn-Haren et al. 2013) and almonds (Dikariyanto et al. 2020) are associated with reduced CVD risk markers, including lower LDL and total cholesterol levels. Minimally processed grains like oats and barley are particularly health-promoting, with consistent evidence linking their consumption to reduced cardiometabolic risk (A. Li et al. 2024). Oat interventions have demonstrated reductions in total and LDL cholesterol levels (de Morais Junior et al. 2023, Xu et al. 2021). A recent systematic review further highlighted the anti-inflammatory potential of barley and oats (Cortijo-Alfonso et al. 2024), with specific trials showing reductions in the proinflammatory cytokine, interleukin-6, following barley intake (Martínez et al. 2013).

The beneficial outcomes discussed above cannot be solely attributed to fiber, as whole-plant foods provide a complex matrix of bioactive compounds, including phytochemicals, vitamins, and minerals, that act synergistically. Nonetheless, given the consistent association between diets rich in whole-plant-food-derived fiber and reduced NCD risk in observational studies (Ramezani et al. 2024), fiber is likely a central contributor to these effects. Taken together, numerous observational and experimental studies strongly support the clinical and mechanistic basis for prioritizing whole and minimally processed plant foods in dietary guidelines.

5.2. Clinical Effects of Processed Whole-Plant Foods

Processed whole-plant foods constitute an important part of modern diets and offer practical opportunities to increase fiber intake. Although well-controlled RCTs with processed whole-plant foods are limited, current evidence highlights that the degree and nature of processing play a critical role in determining physiological outcomes. For instance, a human intervention study observed that mechanical disruption through blending can increase metabolizable energy, as shown by greater energy availability in almond butter compared to whole or roasted almonds (Gebauer et al. 2016). Additionally, the structural breakdown of grains and legumes, such as in instant oats or broken-cell chickpeas (e.g., in hummus), has been associated with diminished glycemic control in clinical studies in comparison to their less processed alternatives (Cai et al. 2025, Musa-Veloso et al. 2021). A similar pattern is observed in fruits, where the cholesterol-lowering effects are retained in whole apples, apple pomace, and cloudy juice but are lost with clear apple juice (Ravn-Haren et al. 2013). Although invasive processing techniques can reduce the clinical effects of whole-plant foods, when processing preserves cellular integrity, they can remain valuable sources of fiber, micronutrients, and bioactive compounds. Owing to a scarcity of data, processed whole-plant foods are not represented in **Figure 2**.

5.3. Clinical Effects of Processed Foods with Added Whole-Plant Ingredients

Observational evidence strongly supports the health benefits of processed foods with whole-plant ingredients, particularly whole-grain products, such as whole-grain bread and pasta, which have been linked to reduced mortality and improved cardiometabolic profiles compared to refined grains (Aune et al. 2016).

Several RCTs demonstrate the ability of processed foods with whole-food ingredients to elicit health benefits. For instance, the addition of whole grains to processed cereal products has been associated with improved glycemic regulation (Kovatcheva-Datchary et al. 2015), increased stool bulk (Vanegas et al. 2017), and reduced body weight (Roager et al. 2019). Additionally, pasta formulated with whole-grain ingredients increased satiety-regulating hormones (Costabile et al. 2018).

Processed foods with added whole-plant ingredients have also demonstrated anti-inflammatory potential. Indeed, interventions using whole-grain-enriched processed foods have shown decreases in systemic inflammation markers such as C-reactive protein, interleukin-6, and interleukin-1β (Roager et al. 2019). Additionally, consumption of cereal-based products enriched with whole-plant ingredients (cranberries) has been associated with lower circulating lipopolysaccharide and calprotectin levels (Hornero-Ramirez et al. 2025) (**Figure 2**).

From a regulatory perspective, the European Food Safety Authority has approved health claims for processed foods that contain at least 6 g of added wheat bran, oat, or barley per 100 g of product, recognizing their role in increasing fecal bulk and supporting digestive health (EFSA Panel on Dietetic Products, Nutrition and Allergies 2010).

5.4. Fiber-Fortified Foods

Although fiber-fortified foods are not typically recommended in food-based dietary guidelines, clinical trials show positive effects in reducing NCD risk factors compared to low-fiber alternatives. Indeed, RCTs measuring health effects of fiber-fortified foods (e.g., pasta, bread, convenience foods) showed reduced risk markers of T2D (Hassan et al. 2020) and CVD (Brandl et al. 2022, Ranaivo et al. 2022), and psyllium-enriched cookies improved laxation (Noureddin et al. 2018). Moreover, a meta-analysis of 31 RCTs investigating the health impact of consuming fiber-fortified foods showed significant improvements in anthropometric and cardiometabolic markers, including reductions in body weight, fat mass, total cholesterol, LDL, triglycerides, fasting glucose, and HbA1c (Lee et al. 2023). Additionally, when fibers used in RCTs were further classified by solubility, soluble fibers significantly reduced triglycerides and insulin, whereas insoluble fibers significantly reduced body weight, body mass index (BMI), and HbA1c. Importantly, solid or semisolid formats (e.g., bread, pasta) typically yield stronger benefits than liquid forms (e.g., juice), highlighting the importance of food matrix interactions and physical properties such as texture and hydration (Lee et al. 2023) (**Figure 2**).

BMI: body mass index

The positive clinical effects observed in fiber-fortified foods have led to regulatory approval of certain health claims for isolated fibers, such as for RS in reducing postprandial glycemic responses (EFSA Panel on Dietetic Products, Nutrition and Allergies 2011b, Ingredion 2016) and β-glucan for lowering blood cholesterol and reducing postprandial blood glycemic response (EFSA Panel on Dietetic Products, Nutrition and Allergies 2011a).

Although fiber-fortified foods can confer specific metabolic and immunological benefits, these effects are more targeted, mechanistically narrower, and often of smaller magnitude than those from diets rich in whole-plant foods, whose structural integrity, diverse fiber types, and associated phytochemicals act synergistically to promote broader physiological and microbial interactions (**Figure 2**).

5.5. Clinical Effects of Fiber Supplements

Fiber supplements have been extensively investigated for their effects on NCD risk markers. These formulations deliver purified and synthetic fiber types whose health effects are narrower in scope than those of whole-plant foods and are strongly dependent on their specific physicochemical properties.

Nonviscous and nonfermentable fibers such as cellulose increase fecal bulk and contribute to improved laxation. Emerging evidence suggests that cellulose may also influence low-grade inflammation, possibly via its bulking effect and impact on intestinal transit (Armet et al. 2025, Deehan et al. 2022) (**Figure 2**).

Viscous, nonfermentable fibers such as psyllium have robust clinical evidence supporting their ability to improve markers of CVD, T2D, and obesity (Jovanovski et al. 2018). Meta-analyses confirmed significant reductions in LDL cholesterol (Jovanovski et al. 2018) and decreases in blood pressure (Clark et al. 2020) following psyllium supplementation (**Figure 2**).

Nonviscous, fermentable fibers such as RS lack gel-forming properties but are readily fermented in the colon, producing beneficial SCFAs that can improve insulin sensitivity and reduce systemic inflammation, although effect sizes are typically small (H. Li et al. 2024). Indeed, RS has also shown positive clinical effects in reducing NCD risk markers—including body weight (Snelson et al. 2019); fasting plasma glucose, insulin, and homeostatic model assessment for insulin resistance (HOMA-IR) (Xiong et al. 2021); and LDL cholesterol (Wang et al. 2019)—and increasing fecal wet weights (Shen et al. 2017). Additionally, RS supplementation has been shown to significantly reduce the inflammatory markers interleukin-6 and tumor necrosis factor-α (Vahdat et al. 2020) (**Figure 2**).

Among nonviscous fermentable fibers, some, such as inulin with an approved health claim for improved laxation (EFSA Panel on Dietetic Products, Nutrition and Allergies 2015), have shown inconsistent metabolic effects from supplementation (Chambers et al. 2019, Lancaster et al. 2022, Tan et al. 2023), and high doses (15–30 g/day) have elicited proinflammatory responses via increased interleukin-6 levels and hepatic inflammation (Lancaster et al. 2022).

Furthermore, supplementation elevated circulating tumor necrosis factor, interferon-γ, and monocytes (Tan et al. 2023). It is important to emphasize that these adverse or null effects on NCD risk have primarily been observed when inulin is consumed in a highly purified, isolated form. In contrast, when inulin is ingested within its natural food matrix with other structural fibers (e.g., pectin, cellulose), such as in whole chicory root, it has been shown to enhance insulin sensitivity and support cardiometabolic health (Omary et al. 2025) (**Figure 2**).

Finally, viscous and fermentable fibers, such as β-glucans (from oats or barley) and AX (typically from wheat or corn), exhibit both gel-forming and fermentative properties, offering potentially synergistic pathways for metabolic benefits. Several RCTs have supported the ability of these fibers to improve glycemic and lipid metabolism (Deehan et al. 2022, Lancaster et al. 2022, Pino et al. 2021) as well as positive clinical effects in reducing body weight, BMI, and waist circumference when consumed for at least 4 weeks in ad libitum diets (Jovanovski et al. 2020). Additionally, beneficial impacts have been observed for markers of T2D with doses of 13.1 g/day leading to significant reductions in HbA1c, fasting blood glucose, and HOMA-IR (Jovanovski et al. 2019). Moreover, improvements in CVD risk factors have been noted with viscous fiber supplementation, including reductions in LDL cholesterol and lowering of systolic and diastolic blood pressure (Khan et al. 2018) (**Figure 2**).

Surprisingly, blends of different fiber types often fail to elicit additive or synergistic metabolic benefits in RCTs (Lancaster et al. 2022, Mocanu et al. 2021, Tan et al. 2023). This may reflect antagonistic mechanisms, poor synergy, low doses, or the absence of a food matrix that typically enhances fiber functionality in whole-plant foods.

Although intervention studies with fiber supplements have shown positive clinical effects specific to their physicochemical properties (e.g., viscous fibers show stronger effects) (**Figure 2**), findings are often inconsistent, and many intervention studies show no effect (Armet et al. 2020). A potential reason could be the considerable heterogeneity in study designs with respect to fiber dosages and intervention durations. However, lack of efficacy could also stem from the loss of critical structural features (e.g., loss of the 3D matrix) during the purification of the fibers.

5.6. Summary

Whole-plant foods and diets high in intrinsic fiber show consistent protective effects against NCDs through improvements in glycemic control, lipid metabolism, inflammation, and bowel function. However, intensive processing of whole-plant foods may reduce these benefits by disrupting intrinsic fiber structures and altering nutrient accessibility. Processed foods with added whole-plant ingredients retain positive clinical effects supported by approved health claims. Fiber-fortified foods and fiber supplements show less consistent effects but might still reduce NCD risk factors when used in a targeted, structure-specific approach that considers the physicochemical characteristics of the individual fibers.

6. STRENGTHS AND LIMITATIONS OF FIBER-BASED NUTRITIONAL STRATEGIES

Given that different fiber-based nutritional strategies have distinct effects on both the gut microbiome and clinical outcomes, we next discuss their key advantages and limitations, as well as broader factors that may influence their adoption and impact at the population level (**Figure 3**).

6.1. Whole and Minimally Processed Plant Foods

Whole and minimally processed plant foods are the most effective evidence-based strategies for delivering health-promoting fiber, with both epidemiological studies and intervention trials consistently showing beneficial links to a reduction in NCD risk factors and changes in microbiome

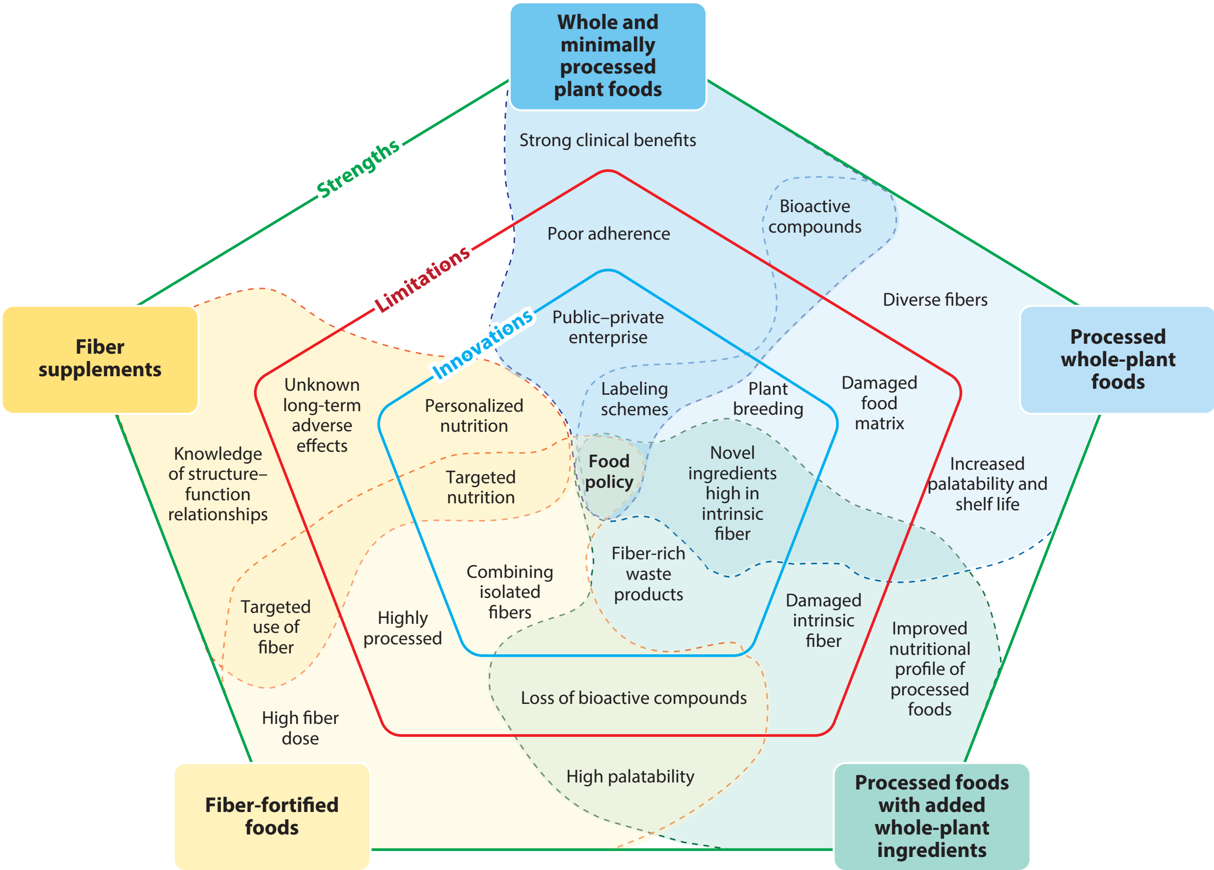

Figure 3

Strengths and limitations of the five fiber-based nutritional strategies and potential innovations for their improvements.

metabolism (**Figure 2**). However, a key limitation of this fiber-based nutritional strategy is its poor adoption in industrialized societies (Stephen et al. 2017). Limited long-term success has been achieved via attempts to increase consumption of whole-plant foods through dietary guidelines and government campaigns (Baenziger et al. 2023). The reasons are multifaceted, with cost, taste, availability, and convenience as the most commonly reported barriers limiting adherence (Clemens et al. 2012) (**Figure 3**).

6.2. Processed Whole-Plant Foods

Processed whole-plant foods maintain several beneficial properties of their unprocessed counterparts while offering greater palatability, longer shelf life, and easier digestibility. However, in addition to the reduced clinical benefits (Cai et al. 2025, Gebauer et al. 2016, Ravn-Haren et al. 2013), their consumption remains limited in Western societies, where dietary patterns often favor highly processed, low-fiber foods (**Figure 3**).

6.3. Processed Food with Added Whole-Plant Ingredients

Processed foods with whole-plant ingredients, including whole-grain products, were shown to meaningfully reduce NCD risk factors in clinical and observational studies. In addition, these foods generally offer longer shelf life and may be more economical and accessible than diets based solely on unprocessed plant foods. However, national dietary surveys show poor adherence to food-based dietary guidelines promoting increased whole-grain consumption (O'Donovan et al. 2019, Reicks et al. 2014). Moreover, whole-grain products are often perceived to be less palatable (e.g., coarser, denser, and darker in color) than refined alternatives, which may limit their consumption (Walsh et al. 2022) (**Figure 3**).

6.4. Fiber-Fortified Foods

Fortification of processed foods with functional fibers has shown positive clinical effects on NCD risk markers and has the potential to elicit specific modulations to gut microbiome composition and function (**Figure 2**). Fortification allows precise control over fiber dose and composition and can deliver high-fiber doses in foods with higher acceptability compared to whole-grain products, allowing nutritional improvements without requiring changes in dietary patterns (McMackin et al. 2013, Mohr et al. 2010).

Concern, however, has been raised about the use of isolated fibers in food reformulation, which would constitute highly processed foods that lack many of the benefits of intrinsic fiber and whole-plant foods. In addition, many fiber-fortified foods contain low-quality fibers at low doses, with commercial formulations being primarily based on cost and not the distinct functionality (**Figure 1**) and clinical effects (**Figure 2**) (Marinangeli et al. 2020). Moreover, increasing fiber content in a single, commonly consumed item such as bread may not be sufficient to elicit significant changes in NCD risk (Hjorth et al. 2025), and fiber-fortification strategies would have to be applied more systematically in a larger variety of foods within habitual dietary patterns to make such approaches successful (**Figure 3**).

6.5. Fiber Supplements

Fiber supplements are relatively easy to implement and have demonstrated structure-specific effects on clinical outcomes and NCD risk markers while eliciting highly specific effects on microbial ecology and function. This enables targeted approaches for boosting fiber intake, particularly for managing specific health conditions such as dyslipidemia, dysglycemia (Jovanovski et al. 2018, Wang et al. 2019), and constipation (van der Schoot et al. 2022).

Although this strategy shows considerable promise and many fibers are marketed as prebiotics, overall clinical evidence for efficacy remains limited (**Figure 2**). The clinical effects of fiber supplements are often inconsistent and narrow in scope when compared to whole-plant food approaches (McRorie 2015). Apart from differences in fiber type, dose, and intervention duration (Armet et al. 2020, Hughes et al. 2019), lack of intrinsic fiber structures and phytochemicals normally present in whole-plant foods are potential explanations (So et al. 2018). In addition, in some studies, especially with purified inulin, detrimental effects were observed (Lancaster et al. 2022, Tan et al. 2023). Therefore, further research is needed to determine long-term safety and efficacy of high-dose fiber supplementation. Although fiber-induced shifts in microbiome composition and metabolism are consistently observed, clear causal links to health outcomes are lacking (Hutkins et al. 2025), and microbiome responses do not always correspond to clinical benefits (**Figure 3**) (Armet et al. 2025).

6.6. Summary

Fiber-based nutritional strategies promoting whole-plant foods and whole-grain product consumption have shown the most beneficial long-term clinical effects (**Figure 3**). This may be attributed to the unique benefits of whole-plant food matrices, which include bioactive dietary compounds. However, their consumption in industrialized diets is concerningly low. Fiber-fortified foods and supplements may, therefore, appeal to modern consumers unwilling to change their dietary habits. However, they lack the complexity and diversity of whole-plant foods and have yet to prove long-term efficacy and safety at high doses. Given that fiber supplements elicit structure-specific clinical and microbiome effects, they still have potential if used in more targeted and/or personalized ways, particularly if regulatory and economic incentives can be aligned.

7. INNOVATIONS TO IMPROVE FIBER-BASED NUTRITIONAL STRATEGIES

The disconnect between current and recommended fiber intakes underscores the need for coordinated innovation across public health, food systems, and research to develop more effective and accessible strategies to optimize fiber intake and reduce the burden of NCDs (**Figure 3**).

7.1. Public Health and Policy

Public health and policy strategies are essential to optimize fiber intake at the population level, particularly through structural changes that promote awareness, accessibility, and affordability of fiber-rich foods. Owing to economic constraints, public health and policy actions are needed for all the fiber-based nutritional strategies described. Innovations in this space include multisector partnerships, front-of-pack labeling schemes, fiscal incentives, and regulatory approaches such as fortification.

7.1.1. Public health campaigns. Public health and policy innovations can improve consumer awareness of food-based dietary guidelines, accessibility to fiber-rich whole-plant foods and fiber-fortified foods, and adoption at the population level. Public–private partnerships, bringing together government, health nongovernmental organizations, and the food industry, offer a promising model for increasing fiber consumption. A notable example is the Danish Whole Grain Partnership, which employed a multistakeholder approach combining dietary guideline integration, education, and front-of-pack labeling schemes, all targeted to increasing whole-grain intake (Boyle et al. 2024). Since its launch, average whole-grain product intake in Denmark has risen by 128%, with adherence to intake recommendations increasing from 6% to 54%. Further public health initiatives such as "Action on Fiber" in the United Kingdom have successfully encouraged product reformulation and utilized front-of-pack labeling schemes to guide consumers to fiber-enriched options (Food and Drink Federation 2021). Successfully promoting fiber intake at the population level may, thus, require coordinated engagement across sectors to ensure that diverse, health-promoting options are accessible and aligned with dietary recommendations (**Figure 3**).

7.1.2. Subsidized foods. Given that cost is frequently reported as a barrier to fiber consumption from whole-plant foods, government-actioned economic strategies such as subsidies on fiber-rich foods may play a key role in increasing accessibility, particularly for low-income households. Modeling data from a US cohort suggest that a 20% subsidy applied to fruits and vegetables could increase fiber intake by 9.4%, highlighting the potential for fiscal policies to shift dietary patterns (Senia et al. 2019) (**Figure 3**).

7.1.3. Fortification. Fortification is a valuable tool for governments to enrich commonly consumed foods with at-risk nutrients to address nutritional deficiencies. The fortification of refined grains in the United States with B vitamins successfully eliminated the pellagra epidemic and reduced spina bifida and birth defects by nearly 50% (Baenziger et al. 2023) (**Figure 3**). Given the promising potential of fiber-fortified foods to reduce NCD risk factors (**Figure 2**) and that fiber has been declared a nutrient of public health concern, fortification of white flour could offer a pragmatic solution to close fiber gaps (Deehan & Walter 2016).

7.2. Technological Innovations

Food technology offers a powerful tool to increase fiber in commonly consumed foods without compromising on consumer preferences. Technological innovation is critical to preserve or enhance the functional properties of fiber across whole-plant foods, processed foods with whole-plant ingredients, and fiber-fortified foods, enabling strategies that effectively support population-level health.

7.2.1. Innovative ingredient development retaining intrinsic fiber structures. Retaining intrinsic plant cell structures in processed-food ingredients has the potential to enhance fiber functionality. As discussed, conventional processing techniques, including milling of pulses, typically compromise cell integrity, increasing starch digestibility (Cai et al. 2025). However, novel legume cell powders, created through gentle hydrothermal and mechanical processing, preserve intact starch-filled cells resistant to digestion (Butterworth et al. 2012, Edwards et al. 2020). Such powders, when incorporated into baked products, maintained sensory properties and reduced glycemic response by 40% compared to standard white bread (Bajka et al. 2021). Such innovations highlight the potential and greater need to explore food processing techniques to minimize the degradation of intrinsic fiber while enabling greater health benefits for the consumer (**Figure 3**).

7.2.2. Reformulation of processed foods. As discussed above, fiber fortification can be used to successfully develop palatable, functional food products. Although fiber-fortified foods typically focus on adding isolated fibers to processed foods, more innovative strategies have focused on systematically replacing refined carbohydrates (e.g., starch) with fiber (Walsh et al. 2022). This strategy can decrease the glycemic index and energy density and improve fiber accessibility to the microbiome.

Researchers are additionally exploring the benefits of combining isolated fibers to move beyond applying single fibers (Sempio et al. 2024b). Such innovations may be used to engineer combined fiber structures that more closely replicate the complex cell matrices of intrinsic plant fibers, which are physically and chemically entangled, potentially encapsulating digestible starch and limiting its enzymatic breakdown (Puhlmann & de Vos 2022). Early studies suggest synergistic effects of fiber blends on postprandial glycemia (Behall et al. 2006, Boll et al. 2016), although further research is needed to optimize combinations and evaluate health outcomes. Statistical tools like response surface methodology can help identify optimal blends that preserve product quality (Sempio et al. 2024a). In addition to isolated fibers, food industry by-products from fruit and vegetable processing, brewing, and cereal milling have been used to develop high-fiber reformulated baked goods. Such ingredients may naturally contain diverse fiber structures and bioactive compounds, aligning nutritional enhancement with sustainability goals (Sempio et al. 2024a) (**Figure 3**).

7.3. Scientific Innovations

Emerging scientific innovations, including plant breeding and precision nutrition, offer complementary strategies to optimize fiber intake at the population and individual levels. Advances in crop science aim to boost the fiber content of staples like wheat, making high-fiber foods more accessible. In parallel, personalized nutrition strategies are evolving to match specific fiber types to individual health needs and microbiome profiles, enhancing their effectiveness.

7.3.1. Plant breeding. Cereal grains, especially wheat, account for 25–55% of global dietary fiber intake (Shewry et al. 2023), with refined flour products dominating consumption despite dietary guidelines recommending whole grains. To bridge this gap, novel wheat genomic tools are being explored to enhance the fiber content of white flour by increasing RS and cell wall polysaccharides such as AX and β-glucan (Hazard et al. 2020). High-amylose wheat cultivars have, for example, been developed by altering starch biosynthesis pathways (Hazard et al. 2020), and flours made thereof have successfully been incorporated into bread and other cereal products (Baenziger et al. 2023). The development of commercial white wheat flours with increased fiber content may result in increased profits for farmers, food processors, and retailers, given the opportunity to market functional food ingredients and products. However, plant breeding techniques to increase fiber in wheat may lead to reduced grain yield and product quality and higher costs of raw material (Hazard et al. 2020). To achieve a meaningful public health impact, the development of high-fiber white wheat flour will require coordinated efforts to translate consumer interest into market demand and establish economic incentives that encourage breeders and the food industry to prioritize its production and commercialization (**Figure 3**).

7.3.2. Mechanistically targeted and personalized applications of dietary fiber. The application of fiber is increasingly moving beyond general recommendations toward precision strategies (Deehan et al. 2024, Jardon et al. 2022). In this context, precision can refer to both (*a*) targeted, mechanism-informed uses of specific fiber types and (*b*) personalization based on individual health status, physiology, and microbiome characteristics. These approaches can optimize the efficacy of fiber-based interventions across populations and individuals alike.

Research is elucidating how distinct fiber types influence specific physiological mechanisms, providing a basis for the targeted use of fibers in fortified foods, supplements, and medical nutrition products. As understanding grows around the role of the gut microbiome as a mediator of the health effects of fibers (Delzenne et al. 2025, Kovatcheva-Datchary et al. 2015, Zhao et al. 2018), they may also be selected to influence specific microbial pathways or metabolic outputs (Hindle et al. 2025), such as increasing SCFA production or modulating microbial-derived metabolites implicated in disease risk (**Figure 3**).

For such targeted approaches to be effective, clearer causal relationships between microbiome features and health outcomes are needed (Delzenne et al. 2025, Knight et al. 2018). Advances in metagenomic and metabolomic analyses are beginning to uncover microbial signatures associated with disease states and therapeutic responsiveness (Gilbert et al. 2018), opening opportunities for next-generation functional and medical foods and supplements.

These precision concepts extend naturally to personalized applications. Clinical and experimental data increasingly show that individuals respond differently to the same fiber, depending on baseline health status, metabolic phenotype, and microbiome composition. For instance, individuals with insulin resistance or prediabetes may benefit most from fibers that directly modulate glucose metabolism, such as viscous fibers that attenuate postprandial glycemic excursions (Jovanovski et al. 2019).

Personalized applications are supported by findings from dietary trials that used machine learning algorithms to accurately predict and tailor diets to lower glycemic responses (Nolte Fong et al. 2022, Rein et al. 2022).

Variability in fiber fermentation and SCFA production is often driven by differences in microbial gene content and baseline composition. Early work, including our own (Armet et al. 2025) and other trials (Devarakonda et al. 2024; Korpela et al. 2014; Kok et al. 2023, 2024), suggests that microbiome profiling can accurately predict responses to specific fiber types (Mills et al. 2019). Matching specific fiber structures to microbiome profiles could allow for more precise, reproducible health benefits across individuals. Although still in its infancy, the advancement of personalized fiber strategies has the potential to complement and refine existing guidance, ensuring that fiber interventions, whether delivered through foods, fortified products, or supplements, are not only widely accessible but also clinically meaningful.

7.4. Summary

Innovations across public health, policy, food technology, and nutrition science provide complementary pathways to optimize fiber intake (**Figure 3**). Public health campaigns and front-of-pack labeling schemes can raise awareness, improve access, and incentivize reformulation with intrinsic and functional fibers. Policies, including subsidies and fortification, further increase accessibility and public health impact. Additionally, technological and scientific advances can enable the development of palatable, accessible fiber-rich foods and targeted interventions. Collectively, these efforts offer an integrated model for improving fiber intake in daily diets.

8. CONCLUSIONS AND FUTURE STEPS FOR FIBER-BASED NUTRITIONAL STRATEGIES

Despite decades of research and consistent dietary recommendations around dietary fiber, fiber intake remains insufficient in industrialized populations, limiting its potential to reduce NCDs. Diets rich in whole-plant foods are the reference point for evaluating fiber-based nutritional interventions, but complementary dietary strategies are needed to address the persistent "fiber gap." Fiber-enriched products and supplements have shown promise, but their clinical and long-term health impacts remain less founded. Indeed, the term fiber encompasses a broad range of compounds with distinct physiological effects, and future strategies must consider this complexity and the different mechanisms (**Figure 1**) by which distinct fiber types exert clinical benefits (**Figure 2**). This may involve blending fibers with complementary properties or tailoring formulations to individual microbiome profiles and using this information to develop personalized approaches.

At a broader level, achieving a meaningful public health impact requires system-level solutions. The food industry must go beyond simply meeting fiber quantity thresholds to earn health claims; it should prioritize the use of high-quality functional fibers and whole-food ingredients and reformulate processed foods to optimize physiological benefits. Most processed products currently rely on fibers with limited physiological efficacy because functionally robust fibers often compromise texture, flavor, and shelf stability, and often increase formulation and processing costs. To change this, both regulation and product development need to move toward a functional view of fiber, linking ingredient chemistry and processing behavior to measurable health outcomes rather than compositional quotas. Such efforts should go beyond supplementing fiber to reformulate processed foods, for instance, by replacing digestible carbohydrates with functional fibers and increasing intrinsic or engineered fiber structures to limit nutrient accessibility (**Figure 3**). We hope that our review, by providing a mechanistic basis for how different forms and types of fibers work in a clinical context, contributes to a more functional and effective use of fiber in food science, nutrition, and food systems.

DISCLOSURE STATEMENT

Jens Walter has received research funding from companies that produce or market dietary fiber supplements, and he is a cofounder of Synbiotic Health, a company that develops probiotics and synbiotics. Jens Walter and Anissa Armet hold a trademark associated with the NiMe diet. The authors are aware of no other affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

AUTHOR CONTRIBUTIONS

S.K.W., A.M.A., M.O., and J.W. conceived the scope and conceptual framework of the review. S.K.W., A.M.A., and M.O. wrote the majority of the manuscript and generated the figures. J.W.

and D.D.N. wrote the gut microbiome sections. A.J.L. and J.F.M. supervised the nutritional strategy and clinical evidence sections, respectively. All authors contributed to the writing and organization of the review and approved the final version.

LITERATURE CITED

Aguilera JM. 2019. The food matrix: implications in processing, nutrition and health. *Crit. Rev. Food Sci. Nutr.* 59(22):3612–29

Armet AM, Deehan EC, O'Sullivan AF, Mota JF, Field CJ, et al. 2022. Rethinking healthy eating in light of the gut microbiome. *Cell Host Microbe* 30(6):764–85

Armet AM, Deehan EC, Thöne JV, Hewko SJ, Walter J. 2020. The effect of isolated and synthetic dietary fibers on markers of metabolic diseases in human intervention studies: a systematic review. *Adv. Nutr.* 11(2):420–38

Armet AM, Li F, Deehan EC, Nikolaeva DD, Delannoy-Bruno O, et al. 2025. Mechanistic insights into microbiome-dependent and personalized responses to dietary fibre in a randomized controlled trial. Preprint, medRxiv. **https://doi.org/10.1101/2025.11.20.25340625**

Aune D, Keum N, Giovannucci E, Fadnes LT, Boffetta P, et al. 2016. Whole grain consumption and risk of cardiovascular disease, cancer, and all cause and cause specific mortality: systematic review and dose-response meta-analysis of prospective studies. *BMJ* 353:i2716

Baenziger PS, Frels K, Greenspan S, Jones J, Lovegrove A, et al. 2023. A stealth health approach to dietary fibre. *Nat. Food* 4(1):5–6

Bajka BH, Pinto AM, Ahn-Jarvis J, Ryden P, Perez-Moral N, et al. 2021. The impact of replacing wheat flour with cellular legume powder on starch bioaccessibility, glycaemic response and bread roll quality: a double-blind randomised controlled trial in healthy participants. *Food Hydrocoll.* 114:106565

Baxter NT, Schmidt AW, Venkataraman A, Kim KS, Waldron C, Schmidt TM. 2019. Dynamics of human gut microbiota and short-chain fatty acids in response to dietary interventions with three fermentable fibers. *mBio* 10(1):e02566-18

Behall KM, Scholfield DJ, Hallfrisch JG, Liljeberg-Elmståhl HGM. 2006. Consumption of both resistant starch and beta-glucan improves postprandial plasma glucose and insulin in women. *Diabetes Care* 29(5):976–81

Blaak EE, Canfora EE, Theis S, Frost G, Groen AK, et al. 2020. Short chain fatty acids in human gut and metabolic health. *Benef. Microbes* 11(5):411–55

Boll EVJ, Ekström LMNK, Courtin CM, Delcour JA, Nilsson AC, et al. 2016. Effects of wheat bran extract rich in arabinoxylan oligosaccharides and resistant starch on overnight glucose tolerance and markers of gut fermentation in healthy young adults. *Eur. J. Nutr.* 55(4):1661–70

Boyle NB, Adolphus K, Caton SJ, Croden FC, Dye L, et al. 2024. Increasing fibre intake in the UK: lessons from the Danish Whole Grain Partnership. *Br. J. Nutr.* 131(4):672–85

Brandl B, Rennekamp R, Reitmeier S, Pietrynik K, Dirndorfer S, et al. 2022. Offering fiber-enriched foods increases fiber intake in adults with or without cardiometabolic risk: a randomized controlled trial. *Front. Nutr.* 9:816299

Brinck JE, Sinha AK, Laursen MF, Dragsted LO, Raes J, et al. 2025. Intestinal pH: a major driver of human gut microbiota composition and metabolism. *Nat. Rev. Gastroenterol. Hepatol.* 22(9):639–56

Burger-van Paassen N, Vincent A, Puiman PJ, van der Sluis M, Bouma J, et al. 2009. The regulation of intestinal mucin MUC2 expression by short-chain fatty acids: implications for epithelial protection. *Biochem. J.* 420(2):211–19

Butterworth PJ, Warren FJ, Grassby T, Patel H, Ellis PR. 2012. Analysis of starch amylolysis using plots for first-order kinetics. *Carbohydr. Polymers* 87(3):2189–97

Cai M, Folkerts J, Folkerts G, Maurer M, Braber S. 2025. Upper-gastrointestinal tract metabolite profile regulates glycaemic and satiety responses to meals with contrasting structure: a pilot study. *Nat. Metab.* 7:1459–75

Cantu-Jungles TM, Bulut N, Chambry E, Ruthes A, Iacomini M, et al. 2021. Dietary fiber hierarchical specificity: the missing link for predictable and strong shifts in gut bacterial communities. *mBio* 12(3):e0102821

Cantu-Jungles TM, Hamaker BR. 2023. Tuning expectations to reality: don't expect increased gut microbiota diversity with dietary fiber. *J. Nutr.* 153(11):3156–63

Célino A, Freour S, Jacquemin F, Casari P. 2014. The hygroscopic behavior of plant fibers: a review. *Front. Chem.* 1:43

Chambers ES, Byrne CS, Morrison DJ, Murphy KG, Preston T, et al. 2019. Dietary supplementation with inulin-propionate ester or inulin improves insulin sensitivity in adults with overweight and obesity with distinct effects on the gut microbiota, plasma metabolome and systemic inflammatory responses: a randomised cross-over trial. *Gut* 68(8):1430–38

Clark CCT, Salek M, Aghabagheri E, Jafarnejad S. 2020. The effect of psyllium supplementation on blood pressure: a systematic review and meta-analysis of randomized controlled trials. *Korean J. Intern. Med.* 35(6):1385–99

Clemens R, Kranz S, Mobley AR, Nicklas TA, Raimondi MP, et al. 2012. Filling America's fiber intake gap: summary of a roundtable to probe realistic solutions with a focus on grain-based foods. *J. Nutr.* 142(7):1390S–401

Cordain L, Eaton SB, Sebastian A, Mann N, Lindeberg S, et al. 2005. Origins and evolution of the Western diet: health implications for the 21st century. *Am. J. Clin. Nutr.* 81(2):341–54

Cortijo-Alfonso M-E, Romero M-P, Macià A, Yuste S, Moralejo M, et al. 2024. Effect of barley and oat consumption on immune system, inflammation and gut microbiota: a systematic review of randomized controlled trials. *Curr. Nutr. Rep.* 13(3):582–97

Costabile G, Griffo E, Cipriano P, Vetrani C, Vitale M, et al. 2018. Subjective satiety and plasma PYY concentration after wholemeal pasta. *Appetite* 125:172–81

Davis LMG, Martínez I, Walter J, Goin C, Hutkins RW. 2011. Barcoded pyrosequencing reveals that consumption of galactooligosaccharides results in a highly specific bifidogenic response in humans. *PLOS ONE* 6(9):e25200

Davis LMG, Martínez I, Walter J, Hutkins R. 2010. A dose dependent impact of prebiotic galactooligosaccharides on the intestinal microbiota of healthy adults. *Int. J. Food Microbiol.* 144(2):285–92

de Morais Junior AC, Schincaglia RM, Viana RB, Armet AM, Prado CM, et al. 2023. The separate effects of whole oats and isolated beta-glucan on lipid profile: a systematic review and meta-analysis of randomized controlled trials. *Clin. Nutr. ESPEN* 53:224–37

Deehan EC, Mocanu V, Madsen KL. 2024. Effects of dietary fibre on metabolic health and obesity. *Nat. Rev. Gastroenterol. Hepatol.* 21(5):301–18

Deehan EC, Walter J. 2016. The fiber gap and the disappearing gut microbiome: implications for human nutrition. *Trends Endocrinol. Metabol.* 27(5):239–42

Deehan EC, Yang C, Perez-Muñoz ME, Nguyen NK, Cheng CC, et al. 2020. Precision microbiome modulation with discrete dietary fiber structures directs short-chain fatty acid production. *Cell Host Microbe* 27(3):389–404.e6

Deehan EC, Zhang Z, Riva A, Armet AM, Perez-Muñoz ME, et al. 2022. Elucidating the role of the gut microbiota in the physiological effects of dietary fiber. *Microbiome* 10(1):77

Delzenne NM, Bindels LB, Neyrinck AM, Walter J. 2025. The gut microbiome and dietary fibres: implications in obesity, cardiometabolic diseases and cancer. *Nat. Rev. Microbiol.* 23(4):225–38

Devarakonda SLS, Superdock DK, Ren J, Johnson LM, Loinard-González AAP, Poole AC. 2024. Gut microbial features and dietary fiber intake predict gut microbiota response to resistant starch supplementation. *Gut Microbes* 16(1):2367301

Dikariyanto V, Smith L, Francis L, Robertson M, Kusaslan E, et al. 2020. Snacking on whole almonds for 6 weeks improves endothelial function and lowers LDL cholesterol but does not affect liver fat and other cardiometabolic risk factors in healthy adults: the ATTIS study, a randomized controlled trial. *Am. J. Clin. Nutr.* 111(6):1178–89

Earle KA, Billings G, Sigal M, Lichtman JS, Hansson GC, et al. 2015. Quantitative imaging of gut microbiota spatial organization. *Cell Host Microbe* 18(4):478–88

Edwards CH, Ryden P, Mandalari G, Butterworth PJ, Ellis PR. 2021. Structure-function studies of chickpea and durum wheat uncover mechanisms by which cell wall properties influence starch bioaccessibility. *Nat. Food* 2(2):118–26

Edwards CH, Ryden P, Pinto AM, van der Schoot A, Stocchi C, et al. 2020. Chemical, physical and glycaemic characterisation of PulseON®: a novel legume cell-powder ingredient for use in the design of functional foods. *J. Funct. Foods* 68:103918

EFSA Panel on Dietetic Products, Nutrition and Allergies. 2010. Scientific opinion on the substantiation of health claims related to wheat bran fibre and increase in faecal bulk (ID 3066), reduction in intestinal transit time (ID 828, 839, 3067, 4699) and contribution to the maintenance or achievement of a normal body weight (ID 829) pursuant to Article 13(1) of Regulation (EC) No 1924/2006. *EFSA J.* 8(10):1817

EFSA Panel on Dietetic Products, Nutrition and Allergies. 2011a. Scientific opinion on the substantiation of health claims related to beta-glucans from oats and barley and maintenance of normal blood LDL-cholesterol concentrations (ID 1236, 1299), increase in satiety leading to a reduction in energy intake (ID 851, 852), reduction of post-prandial glycaemic responses (ID 821, 824), and "digestive function" (ID 850) pursuant to Article 13(1) of Regulation (EC) No 1924/2006. *EFSA J.* 9(6):2207

EFSA Panel on Dietetic Products and Nutrition and Allergies. 2011b. Scientific opinion on the substantiation of health claims related to resistant starch and reduction of post-prandial glycaemic responses (ID 681), "digestive health benefits" (ID 682), and "favours a normal colon metabolism" (ID 783) pursuant to Article 13(1) of Regulation (EC) No 1924/2006. *EFSA J.* 9(4):2024

EFSA Panel on Dietetic Products, Nutrition and Allergies. 2015. Scientific opinion on the substantiation of a health claim related to "native chicory inulin" and maintenance of normal defecation by increasing stool frequency pursuant to Article 13.5 of Regulation (EC) No 1924/2006. *Nutr. Allerg.* 13(1):3951

Food and Drink Federation. 2021. Action on fibre. *Food and Drink Federation*. **https://www.fdf.org.uk/fdf/our-work/our-campaigns/action-on-fibre/**

Freeland KR, Wolever TMS. 2010. Acute effects of intravenous and rectal acetate on glucagon-like peptide-1, peptide YY, ghrelin, adiponectin and tumour necrosis factor-α. *Br. J. Nutr.* 103(3):460–66

Fu J, Zheng Y, Gao Y, Xu W. 2022. Dietary fiber intake and gut microbiota in human health. *Microorganisms* 10(12):2507

Gebauer SK, Novotny JA, Bornhorst GM, Baer DJ. 2016. Food processing and structure impact the metabolizable energy of almonds. *Food Funct.* 7(10):4231–38

Gidley MJ, Yakubov GE. 2019. Functional categorisation of dietary fibre in foods: beyond "soluble" versus "insoluble." *Trends Food Sci. Technol.* 86:563–68

Gilbert JA, Blaser MJ, Caporaso JG, Jansson JK, Lynch SV, Knight R. 2018. Current understanding of the human microbiome. *Nat. Med.* 24(4):392–400

Gill SK, Rossi M, Bajka B, Whelan K. 2021. Dietary fibre in gastrointestinal health and disease. *Nat. Rev. Gastroenterol. Hepatol.* 18(2):101–16

Hall KD, Guo J, Courville AB, Boring J, Brychta R, et al. 2021. Effect of a plant-based, low-fat diet versus an animal-based, ketogenic diet on ad libitum energy intake. *Nat. Med.* 27(2):344–53

Hassan OMS, Di Folco U, Nardone MR, Tubili F, Tubili C. 2020. Fiber enrichment of pasta: metabolic effects and diet adherence in obese subjects. *Mediterr. J. Nutr. Metab.* 13(1):53–62

Hazard B, Trafford K, Lovegrove A, Griffiths S, Uauy C, Shewry P. 2020. Strategies to improve wheat for human health. *Nat. Food* 1(8):475–80

Hindle VK, Veasley NM, Holscher HD. 2025. Microbiota-focused dietary approaches to support health: a systematic review. *J. Nutr.* 155(2):381–401

Hjorth T, Schadow A, Revheim I, Spielau U, Meyer K, et al. 2025. Effectiveness of regular oat β-glucan-enriched bread compared with whole-grain wheat bread on long-term glycemic control in adults at risk of type 2 diabetes: a randomized controlled trial. *Am. J. Clin. Nutr.* 122(3):724–32

Holland C, Ryden P, Edwards CH, Grundy MML. 2020. Plant cell walls: impact on nutrient bioaccessibility and digestibility. *Foods* 9(2):201

Hornero-Ramirez H, Morissette A, Marcotte B, Penhoat A, Lecomte B, et al. 2025. Multifunctional dietary approach reduces intestinal inflammation in relation with changes in gut microbiota composition in subjects at cardiometabolic risk: the SINFONI project. *Gut Microbes* 17(1):2438823

Hughes RL, Kable ME, Marco M, Keim NL. 2019. The role of the gut microbiome in predicting response to diet and the development of precision nutrition models. Part II: results. *Adv. Nutr.* 10(6):979–98

Hutkins R, Walter J, Gibson GR, Bedu-Ferrari C, Scott K, et al. 2025. Classifying compounds as prebiotics—scientific perspectives and recommendations. *Nat. Rev. Gastroenterol. Hepatol.* 22(1):54–70

Ingredion. 2016. FDA approves qualified health claim petition for high-amylose maize resistant starch and reduced risk of type 2 diabetes. *Ingredion*, Dec. 16. **https://www.ingredion.com/na/en-us/news-events/news/fda-approves-qualified-health-claim-petition-for-high-amylose-ma.html**

Institute of Medicine. 2006. *DRI*, *Dietary Reference Intakes*: *The Essential Guide to Nutrient Requirements*. National Academies Press

Jardon KM, Canfora EE, Goossens GH, Blaak EE. 2022. Dietary macronutrients and the gut microbiome: a precision nutrition approach to improve cardiometabolic health. *Gut* 71(6):1214

Jenkins DJA, Kendall CWC, Popovich DG, Vidgen E, Mehling CC, et al. 2001. Effect of a very-high-fiber vegetable, fruit, and nut diet on serum lipids and colonic function. *Metabolism* 50(4):494–503

Jones JM. 2014. CODEX-aligned dietary fiber definitions help to bridge the "fiber gap." *Nutr. J.* 13(1):34

Jovanovski E, Khayyat R, Zurbau A, Komishon A, Mazhar N, et al. 2019. Should viscous fiber supplements be considered in diabetes control? Results from a systematic review and meta-analysis of randomized controlled trials. *Diabetes Care* 42(5):755–66

Jovanovski E, Mazhar N, Komishon A, Khayyat R, Li D, et al. 2020. Can dietary viscous fiber affect body weight independently of an energy-restrictive diet? A systematic review and meta-analysis of randomized controlled trials. *Am. J. Clin. Nutr.* 111(2):471–85

Jovanovski E, Yashpal S, Komishon A, Zurbau A, Blanco Mejia S, et al. 2018. Effect of psyllium (*Plantago ovata*) fiber on LDL cholesterol and alternative lipid targets, non-HDL cholesterol and apolipoprotein B: a systematic review and meta-analysis of randomized controlled trials. *Am. J. Clin. Nutr.* 108(5):922–32

Kastorini C-M, Milionis HJ, Esposito K, Giugliano D, Goudevenos JA, Panagiotakos DB. 2011. The effect of Mediterranean diet on metabolic syndrome and its components: a meta-analysis of 50 studies and 534,906 individuals. *J. Am. Coll. Cardiol.* 57(11):1299–313

Khan K, Jovanovski E, Ho HVT, Marques ACR, Zurbau A, et al. 2018. The effect of viscous soluble fiber on blood pressure: a systematic review and meta-analysis of randomized controlled trials. *Nutr. Metab. Cardiovasc. Dis.* 28(1):3–13

Knight R, Vrbanac A, Taylor BC, Aksenov A, Callewaert C, et al. 2018. Best practices for analysing microbiomes. *Nat. Rev. Microbiol.* 16(7):410–22

Koh A, De Vadder F, Kovatcheva-Datchary P, Bäckhed F. 2016. From dietary fiber to host physiology: short-chain fatty acids as key bacterial metabolites. *Cell* 165(6):1332–45

Kok CR, Rose DJ, Cui J, Whisenhunt L, Hutkins R. 2024. Identification of carbohydrate gene clusters obtained from in vitro fermentations as predictive biomarkers of prebiotic responses. *BMC Microbiol.* 24(1):183

Kok CR, Rose D, Hutkins R. 2023. Predicting personalized responses to dietary fiber interventions: opportunities for modulation of the gut microbiome to improve health. *Annu. Rev. Food Sci. Technol.* 14:157–82

Korpela K, Flint HJ, Johnstone AM, Lappi J, Poutanen K, et al. 2014. Gut microbiota signatures predict host and microbiota responses to dietary interventions in obese individuals. *PLOS ONE* 9(3):e90702

Kovatcheva-Datchary P, Nilsson A, Akrami R, Lee Ys, De Vadder F, et al. 2015. Dietary fiber-induced improvement in glucose metabolism is associated with increased abundance of *Prevotella*. *Cell Metab.* 22(6):971–82

La Torre D, Verbeke K, Dalile B. 2021. Dietary fibre and the gut-brain axis: microbiota-dependent and independent mechanisms of action. *Gut Microbiome*. 2:e3

Lancaster SM, Lee-McMullen B, Abbott CW, Quijada JV, Hornburg D, et al. 2022. Global, distinctive, and personal changes in molecular and microbial profiles by specific fibers in humans. *Cell Host Microbe* 30(6):848–62.e7

Landry MJ, Ward CP, Cunanan KM, Durand LR, Perelman D, et al. 2023. Cardiometabolic effects of omnivorous versus vegan diets in identical twins: a randomized clinical trial. *JAMA Netw. Open* 6(11):e2344457

Lee DPS, Peng A, Taniasuri F, Tan D, Kim JE. 2023. Impact of fiber-fortified food consumption on anthropometric measurements and cardiometabolic outcomes: a systematic review, meta-analyses, and meta-regressions of randomized controlled trials. *Crit. Rev. Food Sci. Nutr.* 63(26):8301–19

Li A, Gao J, Li Y, Qi S, Meng T, et al. 2024. Efficacy of oats in dyslipidemia: a systematic review and meta-analysis. *Food Funct.* 15(7):3232–45

Li F, Armet AM, Korpela K, Liu J, Quevado RM, et al. 2025. Cardiometabolic benefits of a non-industrialized-type diet are linked to gut microbiome modulation. *Cell* 188(5):1226–47.e18
Li H, Zhang L, Li J, Wu Q, Qian L, et al. 2024. Resistant starch intake facilitates weight loss in humans by reshaping the gut microbiota. *Nat. Metab.* 6(3):578–97
Li X, Wang L, Tan B, Li R. 2024. Effect of structural characteristics on the physicochemical properties and functional activities of dietary fiber: a review of structure-activity relationship. *Int. J. Biol. Macromol.* 269:132214
Louis P, Hold GL, Flint HJ. 2014. The gut microbiota, bacterial metabolites and colorectal cancer. *Nat. Rev. Microbiol.* 12(10):661–72
Lozupone CA, Stombaugh JI, Gordon JI, Jansson JK, Knight R. 2012. Diversity, stability and resilience of the human gut microbiota. *Nature* 489(7415):220–30
Mah E, Liska DJ, Goltz S, Chu Y. 2023. The effect of extracted and isolated fibers on appetite and energy intake: a comprehensive review of human intervention studies. *Appetite* 180:106340
Makki K, Deehan EC, Walter J, Bäckhed F. 2018. The impact of dietary fiber on gut microbiota in host health and disease. *Cell Host Microbe* 23(6):705–15
Marinangeli CPF, Harding SV, Glenn AJ, Chiavaroli L, Zurbau A, et al. 2020. Destigmatizing carbohydrate with food labeling: the use of non-mandatory labelling to highlight quality carbohydrate foods. *Nutrients* 12(6):1725
Martínez I, Kim J, Duffy PR, Schlegel VL, Walter J. 2010. Resistant starches types 2 and 4 have differential effects on the composition of the fecal microbiota in human subjects. *PLOS ONE* 5(11):e15046
Martínez I, Lattimer JM, Hubach KL, Case JA, Yang J, et al. 2013. Gut microbiome composition is linked to whole grain-induced immunological improvements. *ISME J.* 7(2):269–80
McMackin E, Dean M, Woodside JV, McKinley MC. 2013. Whole grains and health: attitudes to whole grains against a prevailing background of increased marketing and promotion. *Public Health Nutr.* 16(4):743–51
McRorie JW. 2015. Evidence-based approach to fiber supplements and clinically meaningful health benefits, part 1: what to look for and how to recommend an effective fiber therapy. *Nutr. Today* 50(2):82–89
McRorie JW, McKeown NM. 2017. Understanding the physics of functional fibers in the gastrointestinal tract: an evidence-based approach to resolving enduring misconceptions about insoluble and soluble fiber. *J. Acad. Nutr. Dietetics* 117(2):251–64
Meslier V, Laiola M, Roager HM, De Filippis F, Roume H, et al. 2020. Mediterranean diet intervention in overweight and obese subjects lowers plasma cholesterol and causes changes in the gut microbiome and metabolome independently of energy intake. *Gut* 69(7):1258–68
Mills S, Lane JA, Smith GJ, Grimaldi KA, Ross RP, Stanton C. 2019. Precision nutrition and the microbiome Part II: potential opportunities and pathways to commercialisation. *Nutrients* 11(7):1468
Mocanu V, Zhang Z, Deehan EC, Kao DH, Hotte N, et al. 2021. Fecal microbial transplantation and fiber supplementation in patients with severe obesity and metabolic syndrome: a randomized double-blind, placebo-controlled phase 2 trial. *Nat. Med.* 27(7):1272–79
Mohr P, Quinn S, Morell M, Topping D. 2010. Engagement with dietary fibre and receptiveness to resistant starch in Australia. *Public Health Nutr.* 13(11):1915–22
Mudgil D, Barak S. 2013. Composition, properties and health benefits of indigestible carbohydrate polymers as dietary fiber: a review. *Int. J. Biol. Macromol.* 61:1–6
Musa-Veloso K, Noori D, Venditti C, Poon T, Johnson J, et al. 2021. A systematic review and meta-analysis of randomized controlled trials on the effects of oats and oat processing on postprandial blood glucose and insulin responses. *J. Nutr.* 151(2):341–51
Nguyen NK, Deehan EC, Zhang Z, Jin M, Baskota N, et al. 2020. Gut microbiota modulation with long-chain corn bran arabinoxylan in adults with overweight and obesity is linked to an individualized temporal increase in fecal propionate. *Microbiome* 8(1):118
Nolte Fong JV, Miketinas D, Moore LW, Nguyen DT, Graviss EA, et al. 2022. Precision nutrition model predicts glucose control of overweight females following the consumption of potatoes high in resistant starch. *Nutrients* 14(2):268
Noureddin S, Mohsen J, Payman A. 2018. Effects of psyllium versus placebo on constipation, weight, glycemia, and lipids: a randomized trial in patients with type 2 diabetes and chronic constipation. *Complement. Ther. Med.* 40:1–7

O'Donovan CB, Devlin NF, Buffini M, Walton J, Flynn A, et al. 2019. Whole grain intakes in Irish adults: findings from the National Adults Nutrition Survey (NANS). *Eur. J. Nutr.* 58(2):541–50

O'Keefe SJ. 2019. The association between dietary fibre deficiency and high-income lifestyle-associated diseases: Burkitt's hypothesis revisited. *Lancet Gastroenterol. Hepatol.* 4(12):984–96

O'Keefe SJD, Li JV, Lahti L, Ou J, Carbonero F, et al. 2015. Fat, fibre and cancer risk in African Americans and rural Africans. *Nat. Commun.* 6(1):6342

Oliver A, Chase AB, Weihe C, Orchanian SB, Riedel SF, et al. 2021. High-fiber, whole-food dietary intervention alters the human gut microbiome but not fecal short-chain fatty acids. *mSystems* 6(2):e00115-21

Omary L, Canfora EE, Puhlmann ML, Gavriilidou A, Rijnaarts I, et al. 2025. Intrinsic chicory root fibers modulate colonic microbial butyrate-producing pathways and improve insulin sensitivity in individuals with obesity. *Cell Rep. Med.* 6(7):102237

Park G, Johnson K, Miller K, Kadyan S, Singar S, et al. 2025. Almond snacking modulates gut microbiome and metabolome in association with improved cardiometabolic and inflammatory markers. *npj Sci. Food* 9(1):35

Pino JL, Mujica V, Arredondo M. 2021. Effect of dietary supplementation with oat β-glucan for 3 months in subjects with type 2 diabetes: a randomized, double-blind, controlled clinical trial. *J. Funct. Foods* 77:104311

Puhlmann M-L, de Vos WM. 2022. Intrinsic dietary fibers and the gut microbiome: rediscovering the benefits of the plant cell matrix for human health. *Front. Immunol.* 13:954845

Puhlmann M-L, van de Rakt E, Kerezoudi EN, Rangel I, Brummer RJ, et al. 2024. Analysis of the fermentation kinetics and gut microbiota modulatory effect of dried chicory root reveals the impact of the plant-cell matrix rationalizing its conversion in the distal colon. *Microbiome Res. Rep.* 3(3):28

Ramezani F, Pourghazi F, Eslami M, Gholami M, Mohammadian Khonsari N, et al. 2024. Dietary fiber intake and all-cause and cause-specific mortality: an updated systematic review and meta-analysis of prospective cohort studies. *Clin. Nutr.* 43(1):65–83

Ranaivo H, Thirion F, Béra-Maillet C, Guilly S, Simon C, et al. 2022. Increasing the diversity of dietary fibers in a daily-consumed bread modifies gut microbiota and metabolic profile in subjects at cardiometabolic risk. *Gut Microbes* 14(1):2044722

Ravn-Haren G, Dragsted LO, Buch-Andersen T, Jensen EN, Jensen RI, et al. 2013. Intake of whole apples or clear apple juice has contrasting effects on plasma lipids in healthy volunteers. *Eur. J. Nutr.* 52(8):1875–89

Reicks M, Jonnalagadda S, Albertson AM, Joshi N. 2014. Total dietary fiber intakes in the US population are related to whole grain consumption: results from the National Health and Nutrition Examination Survey 2009 to 2010. *Nutr. Res.* 34(3):226–34

Rein M, Ben-Yacov O, Godneva A, Shilo S, Zmora N, et al. 2022. Effects of personalized diets by prediction of glycemic responses on glycemic control and metabolic health in newly diagnosed T2DM: a randomized dietary intervention pilot trial. *BMC Med.* 20(1):56

Reynolds AN, Akerman A, Kumar S, Diep Pham HT, Coffey S, Mann J. 2022. Dietary fibre in hypertension and cardiovascular disease management: systematic review and meta-analyses. *BMC Med.* 20(1):139

Rinott E, Meir AY, Tsaban G, Zelicha H, Kaplan A, et al. 2022. The effects of the Green-Mediterranean diet on cardiometabolic health are linked to gut microbiome modifications: a randomized controlled trial. *Genome Med.* 14(1):29

Roager HM, Vogt JK, Kristensen M, Hansen LBS, Ibrügger S, et al. 2019. Whole grain-rich diet reduces body weight and systemic low-grade inflammation without inducing major changes of the gut microbiome: a randomised cross-over trial. *Gut* 68(1):83–93

Rodriguez CI, Isobe K, Martiny JBH. 2024. Short-term dietary fiber interventions produce consistent gut microbiome responses across studies. *mSystems* 9(6):e0013324

Schmit KJ, Garcia P, Sciortino A, Aho VTE, Pardo Rodriguez B, et al. 2023. Fiber deprivation and microbiome-borne curli shift gut bacterial populations and accelerate disease in a mouse model of Parkinson's disease. *Cell Rep.* 42(9):113071

Sempio R, Sahin AW, Walter J, Arendt EK, Zannini E. 2024a. Impact of isolated and chemically modified dietary fiber on bakery products: current knowledge and future directions. *Cereal Chem.* 101(1):7–37

Sempio R, Segura Godoy C, Nyhan L, Sahin AW, Zannini E, et al. 2024b. Closing the fibre gap—the impact of combination of soluble and insoluble dietary fibre on bread quality and health benefits. *Foods* 13(13):1980

Senia MC, Dharmasena S, Capps O. 2019. Can dietary fiber intake be increased through nutritional education and through subsidies on selected food products? *Agric. Resour. Econ. Rev.* 48(3):448–72

Shen D, Bai H, Li Z, Yu Y, Zhang H, Chen L. 2017. Positive effects of resistant starch supplementation on bowel function in healthy adults: a systematic review and meta-analysis of randomized controlled trials. *Int. J. Food Sci. Nutr.* 68(2):149–57

Shewry PR, Joy EJM, De La Revilla LS, Hansen A, Brennan J, Lovegrove A. 2023. Increasing fibre in white flour and bread: implications for health and processing. *Nutr. Bull.* 48(4):587–93

Sinha AK, Laursen MF, Brinck JE, Rybtke ML, Hjørne AP, et al. 2024. Dietary fibre directs microbial tryptophan metabolism via metabolic interactions in the gut microbiota. *Nat. Microbiol.* 9(8):1964–78

Snelson M, Jong J, Manolas D, Kok S, Louise A, et al. 2019. Metabolic effects of resistant starch type 2: a systematic literature review and meta-analysis of randomized controlled trials. *Nutrients* 11(8):1833

So D, Whelan K, Rossi M, Morrison M, Holtmann G, et al. 2018. Dietary fiber intervention on gut microbiota composition in healthy adults: a systematic review and meta-analysis. *Am. J. Clin. Nutr.* 107(6):965–83

Sonnenburg ED, Sonnenburg JL. 2014. Starving our microbial self: the deleterious consequences of a diet deficient in microbiota-accessible carbohydrates. *Cell Metab.* 20(5):779–86

Sonnenburg JL, Xu J, Leip DD, Chen CH, Westover BP, et al. 2005. Glycan foraging in vivo by an intestine-adapted bacterial symbiont. *Science* 307(5717):1955–59

Stephen AM, Champ MM, Cloran SJ, Fleith M, van Lieshout L, et al. 2017. Dietary fibre in Europe: current state of knowledge on definitions, sources, recommendations, intakes and relationships to health. *Nutr. Res. Rev.* 30(2):149–90

Tan J, Ribeiro RV, Barker C, Daien C, De Abreu Silveira E, et al. 2023. Functional profiling of gut microbial and immune responses toward different types of dietary fiber: a step toward personalized dietary interventions. *Gut Microbes* 15(2):2274127

Temba GS, Pecht T, Kullaya VI, Vadaq N, Mosha MV, et al. 2025. Immune and metabolic effects of African heritage diets versus Western diets in men: a randomized controlled trial. *Nat. Med.* 31(5):1698–711

Thompson HJ, Brick MA. 2016. Perspective: closing the dietary fiber gap: an ancient solution for a 21st century problem. *Adv. Nutr.* 7(4):623–26

Tuncil YE, Thakkar RD, Marcia ADR, Hamaker BR, Lindemann SR. 2018. Divergent short-chain fatty acid production and succession of colonic microbiota arise in fermentation of variously-sized wheat bran fractions. *Sci. Rep.* 8(1):16655

Vahdat M, Hosseini SA, Khalatbari Mohseni G, Heshmati J, Rahimlou M. 2020. Effects of resistant starch interventions on circulating inflammatory biomarkers: a systematic review and meta-analysis of randomized controlled trials. *Nutr. J.* 19(1):33

van der Beek CM, Canfora EE, Lenaerts K, Troost FJ, Olde Damink SWM, et al. 2016. Distal, not proximal, colonic acetate infusions promote fat oxidation and improve metabolic markers in overweight/obese men. *Clin. Sci.* 130(22):2073–82

van der Schoot A, Drysdale C, Whelan K, Dimidi E. 2022. The effect of fiber supplementation on chronic constipation in adults: an updated systematic review and meta-analysis of randomized controlled trials. *Am. J. Clin. Nutr.* 116(4):953–69

Vandeputte D, Falony G, Vieira-Silva S, Wang J, Sailer M, et al. 2017. Prebiotic inulin-type fructans induce specific changes in the human gut microbiota. *Gut* 66(11):1968–74

Vanegas SM, Meydani M, Barnett JB, Goldin B, Kane A, et al. 2017. Substituting whole grains for refined grains in a 6-wk randomized trial has a modest effect on gut microbiota and immune and inflammatory markers of healthy adults. *Am. J. Clin. Nutr.* 105(3):635–50

Visuthranukul C, Sriswasdi S, Tepaamorndech S, Chamni S, Leelahavanichkul A, et al. 2024. Enhancing gut microbiota and microbial function with inulin supplementation in children with obesity. *Int. J. Obes.* 48(12):1696–704

Walsh SK, Lucey A, Walter J, Zannini E, Arendt EK. 2022. Resistant starch—an accessible fiber ingredient acceptable to the Western palate. *Compr. Rev. Food Sci. Food Saf.* 21(3):2930–55

Wang Y, Chen J, Song YH, Zhao R, Xia L, et al. 2019. Effects of the resistant starch on glucose, insulin, insulin resistance, and lipid parameters in overweight or obese adults: a systematic review and meta-analysis. *Nutr. Diabetes* 9(1):19

Wastyk HC, Fragiadakis GK, Perelman D, Dahan D, Merrill BD, et al. 2021. Gut-microbiota-targeted diets modulate human immune status. *Cell* 184(16):4137–53.e14

Wolter M, Grant ET, Boudaud M, Pudlo NA, Pereira GV, et al. 2024. Diet-driven differential response of *Akkermansia muciniphila* modulates pathogen susceptibility. *Mol. Syst. Biol.* 20(6):596–625

Xiong K, Wang J, Kang T, Xu F, Ma A. 2021. Effects of resistant starch on glycaemic control: a systematic review and meta-analysis. *Br. J. Nutr.* 125(11):1260–69

Xu D, Feng M, Chu Y, Wang S, Shete V, et al. 2021. The prebiotic effects of oats on blood lipids, gut microbiota, and short-chain fatty acids in mildly hypercholesterolemic subjects compared with rice: a randomized, controlled trial. *Front. Immunol.* 12:787797

Zhao L, Zhang F, Ding X, Wu G, Lam YY, et al. 2018. Gut bacteria selectively promoted by dietary fibers alleviate type 2 diabetes. *Science* 359(6380):1151–56

Zheng J, Xiao H. 2022. Editorial: the effects of food processing on food components and their health functions. *Front. Nutr.* 9:837956