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THE ROLE OF FUNCTIONAL FOODS IN MANAGING CHRONIC INFLAMMATORY CONDITIONS – A SYSTEMATIC REVIEW

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review paper

Summary

Functional foods play an increasingly important role in the prevention and management of chronic inflammatory conditions due to their natural anti-inflammatory and antioxidant properties. Bioactive compounds such as polyphenols, flavonoids, omega-3 fatty acids, and probiotics have demonstrated positive effects in reducing inflammation and supporting immune function. Foods like turmeric, berries, green tea, garlic, and fatty fish have been linked to improvements in conditions such as rheumatoid arthritis, inflammatory bowel disease, and metabolic syndrome. The mechanisms behind these benefits include cytokine regulation, oxidative stress reduction, and modulation of the gut microbiota. However, while the current evidence is promising, it is mostly based on short-term or small-scale studies, with varying dosages and methodologies. Individual factors such as genetics and lifestyle also influence the effectiveness of these foods. Therefore, more robust, long-term clinical trials are needed to confirm their therapeutic potential and guide practical dietary recommendations. Overall, functional foods should not be seen as a replacement for conventional treatments, but rather as a complementary strategy. Future research should focus on personalized nutrition approaches and clearer guidelines to help integrate functional foods into routine healthcare and dietary practices.

Keywords: functional foods, chronic diseases, probiotics, prebiotics, functional peptides and proteins

Introduction

Chronic inflammatory diseases represent one of the leading public health challenges in modern society, with their prevalence continuously increasing (Bennett Jeanette et al., 2018). Low-grade inflammation is closely linked to the development of various diseases, including metabolic disorders, cardiovascular diseases, type 2 diabetes, neurodegenerative diseases, and certain types of cancer (Guarner and Rubio-Ruiz, 2015). The role of diet in modulating inflammatory processes has gained significant recognition, with functional food emerging as a potential factor in the prevention and management of chronic diseases. Functional food encompasses food products that, beyond their basic nutritional value, provide additional health benefits through components such as probiotics, prebiotics, dietary fibers, polyphenols, bioactive peptides and proteins (Vlaicu et al., 2023). An increasing number of studies are investigating their potential in modulating gut microbiota, regulating oxidative stress, and promoting anti-inflammatory responses. Therefore, the main goal of this literature review is to systematically explore and evaluate the role of functional foods in the prevention and management of chronic inflammatory diseases. The review aims to identify and analyze scientific evidence from recent human clinical trials that highlight the health benefits of various bioactive compounds found in functional foods, such as probiotics, prebiotics, dietary fibers, polyphenols, and functional proteins. By examining how these compounds influence inflammation, immune function, gut microbiota, and metabolic health, the review aims to better understand their therapeutic potential. Additionally, the objective is to provide insight into how functional foods can be integrated into modern dietary strategies as a complementary approach to traditional medical treatments, with the long-term goal of improving overall health outcomes and reducing the burden of chronic diseases. A literature search was conducted in the *PubMed/MEDLINE*, *ScienceDirect*, and *ResearchGate* databases using keywords related to functional food and chronic diseases. Studies published in the last five years (2020–2025) were included, provided they were open-access and represented randomized controlled trials (*RCTs*) conducted exclusively on human subjects. The study selection process was illustrated using a *PRISMA* flow diagram, and the final analysis included 37 studies that met the inclusion criteria.

Scientific Background on Functional Foods: Types and Importance

Functional foods are gaining increasing importance due to their ability to provide health benefits beyond basic nutrition (Ponte et al., 2025). These foods contain bioactive compounds such as probiotics, prebiotics, polyphenols, and peptides, which can help

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prevent chronic diseases like cardiovascular disorders, diabetes, and obesity (Fernandes Lemos Junior et al., 2025). The demand for functional foods is driven by consumer awareness of the link between diet and health, along with advancements in food science that enable the development of nutrient-enriched products.

Categories of Functional Foods and Their Mechanisms of Action

The term "*functional foods*" refers to foods that enhance well-being, both mental and physical, and reduce the risk of disease, thereby promoting overall health (Mitsuoka, 2014). Therefore, they are categorized based on their health benefits and mechanisms of action (Figure 1).

Probiotics are live microorganisms, such as *Bifidobacterium* and *Lactobacillus* that improve gut microbiota composition, modulate the immune system, and produce antimicrobial substances to inhibit pathogenic bacteria (Arapović et al., 2024).

Prebiotics, including inulin and fructooligosaccharides, serve as food for probiotics, enhancing their survival and activity while increasing the production of short-chain fatty acids (*SCFA*s) that support gut health and reduce inflammation. (Markowiak and Śliżewska, 2017). Dietary fiber (*DF)* found in plant-based foods such as whole grains, fruits, vegetables, legumes, and nuts, plays a vital role in human health. It is categorized into soluble fibers (e.g., pectin in apples, β-glucan in oats) and insoluble fibers (e.g., cellulose in whole wheat, lignin in nuts), each offering distinct benefits. In digestion, *DF* enhances satiety, slows nutrient absorption, and promotes gut motility. Fermentable fibers like inulin (found in chicory and onions) and resistant starch (in green bananas and legumes) support gut microbiota by producing short-chain fatty acids (*SCFA*s), which improve metabolic and immune functions. (Yang et al., 2022). The study suggests that β-glucan significantly influences the adsorption of polyphenols from traditional apple varieties, highlighting its potential role in enhancing the bioactivity of these compounds (Jakobek et al., 2020).

Bioactive lipids, including omega-3 fatty acids, conjugated linoleic acid (*CLA*), and polyunsaturated fatty acids (*PUFA*s), play a crucial role in cardiovascular and brain health by reducing inflammation and oxidative stress (Mazzocchi et al., 2021).

Symbiotics, a combination of probiotics and prebiotics, work synergistically to enhance probiotic colonization, improve digestive and metabolic functions, and strengthen immune responses. (Markowiak and Śliżewska, 2017). Fermented foods such as yogurt, kefir, kimchi, and miso naturally contain probiotics that promote gut microbiota balance, increase nutrient bioavailability, and support metabolic health.

Functional proteins and peptides, derived from dairy, soy, or marine sources, offer additional benefits due to their antimicrobial, antioxidant, and anti-inflammatory properties, contributing to muscle function and cardiovascular health. Lastly, plant-based functional foods, such as berries, nuts, seeds, and whole grains, are rich in polyphenols, flavonoids, and dietary fibers, acting as antioxidants and promoting overall metabolic health.

Together, these functional food categories provide a diverse range of bioactive compounds that support human health through various physiological pathways. (Tarrah, 2022).

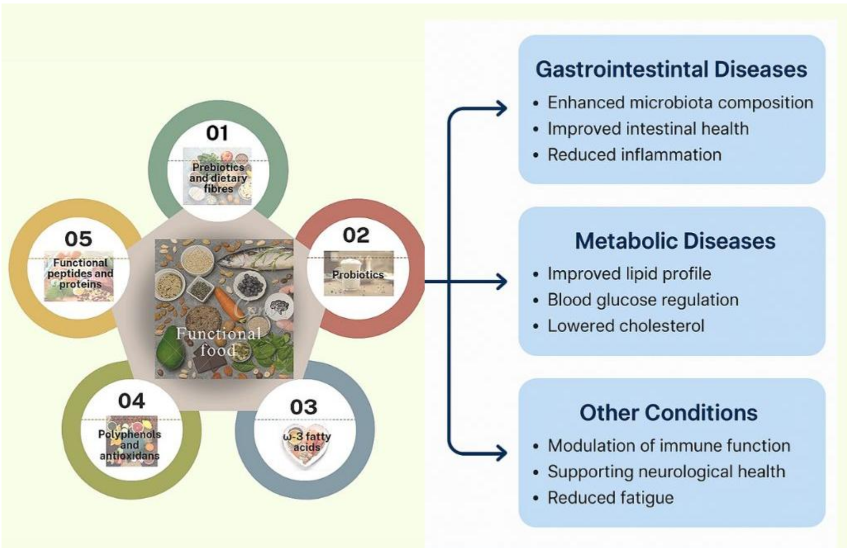

Figure 1. Categories of Functional Foods and health benefits

Materials and methods

A literature search was conducted in the *PubMed/MEDLINE, ScienceDirect* and *ResearchGate* databases using the following keywords: *functional food, chronic diseases, probiotics, prebiotics, dietary fibers, polyphenols, functional peptides, and proteins.* The inclusion criteria comprised studies published within the last five years (2020–2025), open-access availability, and randomized controlled trials (*RCTs*) conducted exclusively on human subjects. Exclusion criteria were review articles, studies without open access, and animal studies unless deemed relevant. The study selection process was carried out using the *PRISMA* flow diagram, which outlines the selection procedure. A total of 37 studies that met the inclusion criteria were analyzed (Figure 2).

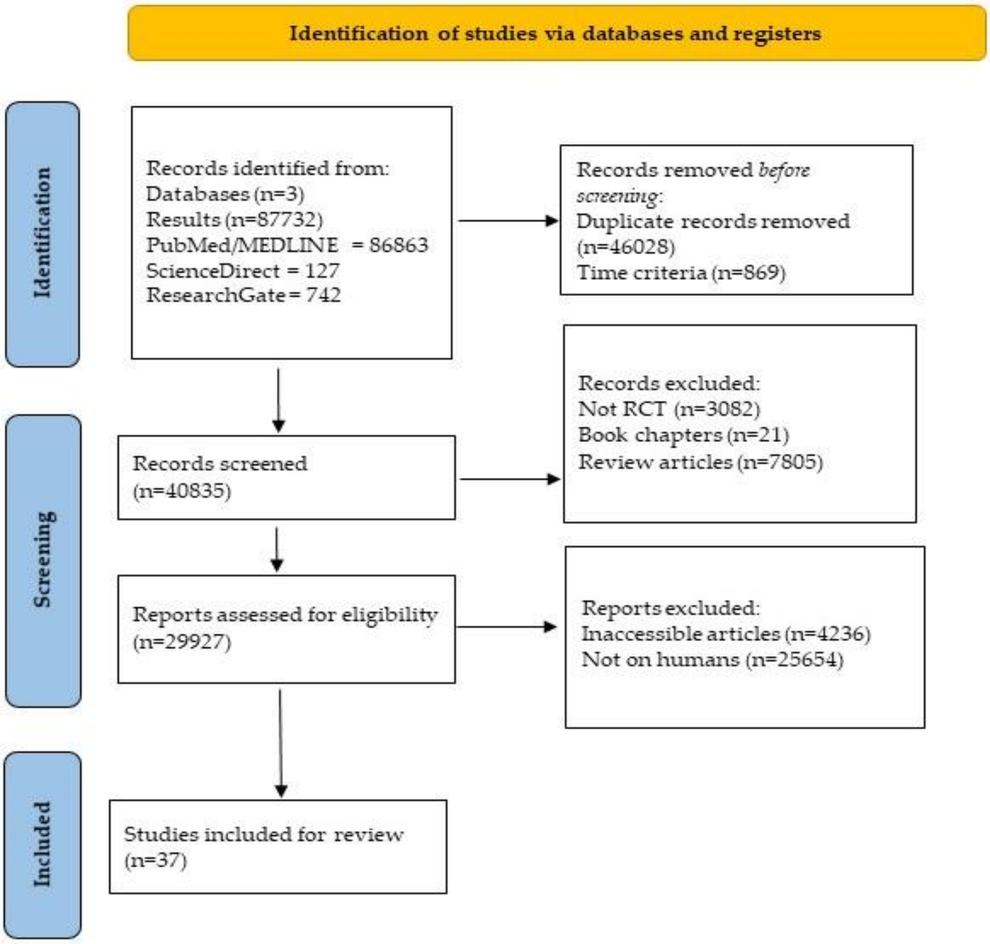

Figure 2. Utilization of the PRISMA flow diagram for conducting database searches and elucidating accessible articles for review

Results and discussion

Nutraceutical Effect of Functional Food Component

Prebiotics and probiotics play a crucial role in maintaining gut microbiota, which is essential for immune function and metabolic health. Vilander et al. (2022) investigated the roles of prebiotics in maintaining gut microbiota, which is crucial for immune function and metabolic health. They noted that rice is a major source of calories globally, and rice bran, a by-product of rice production, offers potential for further research. The food industry is continuously seeking innovative ways to utilize food by-products, and rice bran can be repurposed for health benefits. Their study found that rice bran supplementation increases gut microbiota diversity, enhances intestinal mucosal health, and elevates *IgA* levels in infants, indicating its immunomodulatory function (Table 1).

Table 1. Nutraceutical Effect of Functional Food Component

No.	Source	Type	Form	Findings	Reference
1.	Rice Bran	Prebiotic	Dietary Supplement	↑ gut microbiota diversity, improved gut mucosal health, elevated *sIgA* levels in infants	Vilander et al. (2022)
2.	*GI* Primer supplement	Prebiotic	Powder	Improved digestion, satiety, and overall well-being	Nekrasov et al. (2024)
3.	7 strain probiotic	Probiotic	Four seven-strain probiotic capsules (10^{10} *CFU*)	Probiotics could reduce inflammation and improve *GCS* in severe traumatic brain injury patients	Abbaszadeh et al. (2024)
4.	*L. plantarum*	Probiotic	Capsules	Treatment with probiotics showed clinical effectiveness in managing chronic diarrhea	Yang et al. (2021)
5.	*L.paracasei*	Probiotic	Capsules	*L. paracasei* capsules reduces *LDL*-C levels, oxidative stress, and inflammation in adults with high cholesterol	Khongrum et al. (2023)
6.	Beta-glucan	Fiber	80 g oat containing 3.0 g b-glucan	↓ *LDL* and total cholesterol, modulated gut microbiota, increased production of short-chain fatty acids	Xu et al. (2021)
7.	*DF* mixture	Fiber	10 g *DF* mixture	*DF* ameliorates renal anemia	Li et al. (2022)
8.	Inulin	Fiber	10 g/day of inulin	Dietary fiber supplementation may reduce inflammatory status in predialysis *CKD* patients in combination with low-protein diet	Chang et al. (2023)
9.	Resistant starch type 3 (*RS WM)*	Fiber	22 or 26 g/d for females and malesresistant starch type 3	Positively altered gut microbiota composition resulted in lower fasting glucose with no apparent change in appetite	Johnstone et al. (2020)
10.	Tapioca resistant maltodextrin (*TRM*)	Nutraceutical functional fiber	One serving (56 g) of *TRM*	Reduced HbA1C in both prediabetic and normoglycemic participants, decreased fasting plasma glucose in prediabetics, proved safe with no significant effects on liver and kidney function	Astina et al. (2022)
11.	*RPG** dietary fibre	Fiber	*RPG* powder, *RPG* capsules	*RPG* bread showing the best postprandial blood glucose-lowering effect, *RPG* dietary fiber powder and capsules improved satiety, reduced post-meal hunger, and increased serum *GLP-1*	Wu et al. (2023)
12.	Resistant maltodextrin (*RMD*)	Fiber	15 g or 25 g *RMD* crossover study	Effect of *RMD* on a specific microbial taxon that is potentially beneficial to human health, *F.saccharivorans*	Mai et al. (2022)
13.	Yeast beta-Glucan	Fiber	Four capsules (250 mg beta-glucan, 3.75 µg vitamin D_3, 1.05 mg vitamin B_6, and 7.5 mg zinc)	Yeast-derived beta-glucan may alleviate cognitive fatigue symptoms	Lacasa et al. (2023)
14.	ω-3 polyunsaturated fatty acid supplementation	ω-3 fatty acids	a high dose (3.5 g, n = 10) of *EPA* + *DHA*, a low dose (2.0 g, n = 10) of *EPA* + *DHA*, or placebo (olive oil, n = 12) via gel capsules	ω -3 *PUFA* supplementation improves protein homeostasis in *COPD* patients, with doses up to 3.5 g *EPA* and *DHA* being well tolerated and promoting protein gain	Engelen et al. (2022)
15.	Omega-3	ω-3 fatty acids	omega-3 (1.5 g of ω -3/day)	A diet supplemented with *EPA* and *DHA* is ideal for individuals with the *CC* genotype, as it provides direct products that bypass the affected synthesis step	Reyes-Pérez et al. (2024)
16.	Vitamin D3 and Marine Omega-3 Fatty Acids	ω-3 fatty acids	Supplementation	Vitamin D supplementation had a role in modulating the chronic inflammatory process, systemic inflammation, and possibly autoimmune disease progression	Dong et al. (2022)
17.	*Camu-camu*	Polyphenol	Capsules (1.5g/day)	Polyphenol-rich prebiotic may reduce liver fat in adults with overweight, reducing the risk of developing *NAFLD*	Agrinier et al. (2024)
18.	Resveratrol	Polyphenol	Capsules	*RSV* does not improve cardiometabolic risk factors, sympathetic activity, and endothelial function	Ferreira Gonçalinho et al. (2021)
19.		Polyphenol	2 capsules (480mg)	Helpful as an anti-inflammatory food supplement in chronic periodontitis patients	Nikniaz et al. (2023)
20.	Propolis	Polyphenol	Capsules (400 mg/day)	No significant reduction in uremic toxins, increase in gut microbiota richness and evenness	Fonseca et al. (2024)
21.	Beta- alanine	Functional peptides and proteins	supplementation (3.2 g/day)	Beta-alanine supplementation increased musclecar nosine in comparison with PL in patients with COPD (chronic obstructive pulmonary disease)	De Brandt et al. (2022)
22.	Casein	Functional peptides and proteins	20 g of whey protein or casein, diluted in 150 ml of water or juice	Acute supplementation with whey protein or casein similarly improves the HRQoL(health-related quality of life) of chronic liver disease patients	D'alessandro et al. (2021)

↑- increased value; ↓- decreased value; *sIgA*- total fecal secretory IgA; *GI*- gastrointestinal; *LDL*- low-density lipoprotein ; *DF*- dietary fiber; *GCS*- Glasgow Coma Scale; *CFU*- colony forming unit; *LDL-C*- low-density lipoprotein cholesterol; *EPA*- eicosapentaenoic acid; *DHA*- docosahexaenoic acid; *NAFLD*- non-alcoholic fatty liver disease; *PUFA*- polyunsaturated fatty acid; *COPD*- chronic obstructive pulmonary disease; *RSV*-; resveratrol; *RPG* - R+PolyGly dietary fiber products (bread, powder, and capsule); *CKD*- chronic kidney disease *; HbA1C*- hemoglobin A1C.

Nekrasov et al. (2024) conducted a study to investigate the effects of daily consumption of the *GI* primer supplement, which contains six functional blends, including prebiotics, fermented grasses, postbiotics, digestive enzymes, fruit and vegetable concentrates, spices, and select vitamins and minerals. Their findings showed that this supplement significantly improved digestive symptoms, stool consistency, energy, vitality, general health, and attitudes toward food and eating over a 14-day period. Notably, the positive effects began to emerge within just 1–2 days and persisted throughout the duration of the study. Furthermore, a seven-strain probiotic supplement has been shown to reduce inflammatory markers such as *IL-1β* and *TNF*-α while improving neurological outcomes in patients with severe traumatic brain injury (Abbaszadeh et al., 2024). Moreover, *Lactobacillus plantarum* and *Lactobacillus paracasei* have demonstrated potential in treating chronic diarrhea and lowering *LDL* cholesterol, contributing to atherosclerosis prevention (Yang et al., 2021; Khongrum et al., 2023). Dietary fibers exhibit a wide range of health effects, including lipid profile improvement, gut microbiota modulation, and blood glucose regulation. Oat-derived beta-glucan has been shown to reduce *LDL* and total cholesterol while promoting the production of short-chain fatty acids, highlighting its cardioprotective effect (Xu et al., 2021). Additionally, a dietary fiber blend has been found to improve anemia in patients with kidney disease (Li et al., 2022), whereas inulin reduces inflammatory markers in individuals with chronic kidney disease (Chang et al., 2023). Notably, resistant starch type 3 lowers fasting glucose and positively influences gut microbiota, suggesting its role in diabetes prevention (Johnstone et al., 2020). Similarly, the consumption of tapioca-resistant maltodextrin over 12 weeks resulted in reduced *HbA1c* (hemoglobin A1C) levels in individuals with prediabetes, further supporting its role in type 2 diabetes prevention (Astina et al., 2022). The study found that *RPG* (R+PolyGly -bread, powder, and capsule) dietary fiber improved the sensory properties of bread, enhanced satiety, reduced postprandial blood glucose, and increased serum insulin levels, with *RPG* capsules and powder showing the strongest appetite suppression and metabolic benefits, highlighting its potential as a functional food ingredient (Wu et al., 2023). Mai et al. (2022) in their study found that resistant maltodextrin (*RMD*) supplementation increased levels of *Fusicatenibacter saccharivorans* in healthy adults, with potential increases in *Akkermansia muciniphila* and *Faecalibacterium prausnitzii* observed in participants with low baseline levels, suggesting potential benefits for gut health that require further investigation. Finally, the study revealed that 36 weeks of yeast-derived beta-glucan supplementation significantly reduced cognitive fatigue in patients with *ME/CFS* (myalgic encephalomyelitis or chronic fatigue syndrome). This suggests it may be a beneficial nutritional supplement for alleviating cognitive dysfunction associated with this condition. However, further research is needed to understand the underlying mechanisms (Lacasa et al., 2023). Omega-3 fatty acids are essential for reducing systemic inflammation and metabolic syndrome. Omega-3 supplementation in patients with chronic obstructive pulmonary disease (*COPD*) has been found to improve protein homeostasis, potentially preventing muscle loss in this population (Engelen et al., 2022). Furthermore, omega-3 supplementation increased ω -3 fatty acids in red blood cells, but people with the *CC* genotype of the *FADS1 rs174547* variant showed a smaller increase compared to those with the TT genotype, confirming the variant affects fatty acid metabolism (Reyes-Perez et al., 2024). Additionally, vitamin D_3 and ω a-3 fatty acids have been associated with reduced chronic inflammation and the possible prevention of autoimmune diseases (Dong et al., 2022). Polyphenols are well known for their antioxidant and anti-inflammatory properties. Resveratrol, for example, improves lipid profiles and reduces systemic inflammation, while *camu-camu* exhibits hepatoprotective effects by reducing liver steatosis and regulating gut microbiota (Agrinier et al., 2024). Another study found that resveratrol increased total cholesterol and *apoB* but had no effect on plasma noradrenaline or endothelial function, suggesting it does not improve cardiometabolic risk factors or sympathetic activity (Gonçalinho et al., 2021). The study found that resveratrol supplementation significantly reduced plaque index (*PI*) in chronic periodontitis patients but did not significantly impact pocket depth (*PD*), clinical attachment loss (*CAL*), bleeding index, or inflammatory markers (*IL-8, IL-1β*), suggesting its potential as a complementary anti-inflammatory aid alongside standard periodontal treatments (Nikniaz et.al., 2023). Interestingly, propolis enhances gut microbiota diversity but does not significantly reduce uremic toxins in patients with kidney disease (Fonseca et al., 2024). Amino acid from functional peptides and proteins, beta-alanine has been shown to increase muscle carnosine levels by 54% in patients with *COPD;* however, it does not significantly improve exercise capacity (De Brandt et al., 2022). Casein and whey protein have demonstrated benefits in improving the quality of life in patients with chronic liver disease (D’Alessandro et al., 2021), further underscoring the importance of protein intake in maintaining metabolic health.

In summary, research shows that the food industry is exploring the repurposing of food byproducts like rice bran for potential health benefits. The *GI* primer supplement combines prebiotics, probiotics, digestive enzymes, and functional blends, improving digestive health, energy, and well-being within days. Key ingredients like beta-glucan, ω-3 fatty acids, and polyphenols support heart health, reduce inflammation, and regulate blood sugar. Dietary fibers such as oat-derived beta-glucan and resistant starch help lower cholesterol, enhance gut microbiota, and prevent diabetes. Additionally, probiotics like *Lactobacillus plantarum* and *Bifidobacterium longum* aid in reducing inflammation and supporting neurological health. These ingredients collectively offer wide-ranging benefits for metabolic, gastrointestinal, and cognitive health.

Functional Food Products for Managing Gut Microbiota and Chronic Diseases

Prebiotics such as inulin and agave fructans have been proven to influence the gut microbiota, improving digestion and the quality of life in patients with functional gastrointestinal disorders like irritable bowel syndrome (*IBS*). Studies have shown that the consumption of prebiotic snack bars enriched with inulin significantly increases the number of *Bifidobacterium* in the intestines (Reimer et al., 2020), while agave fructans in the form of jelly improve digestive function and psychological parameters in individuals with *IBS* (Camacho-Díaz et al., 2023) (Table 2). Although these results are promising, it is worth noting that much of the data comes from short-term or small-scale studies. Further large-scale trials are needed to validate these findings and assess long-term effects and safety.

Table 2. Functional Food Products for Managing Gut Microbiota and Chronic Diseases

No.	Source	Type	Enriched Product	Form	Findings	Reference
1.	Inulin	Prebiotic	Bars	Snack bar	Adding 3 or 7 g *ITF* to snack bars increased *Bifidobacterium* content	Reimer et al. (2020)
2.	Agave fructans	Prebiotic	Jelly	8g of jelly	Reduced anxiety, depression, enhanced quality of life in *IBS* constipation subtype patients, without laxative effects or intolerability	Camacho-Díaz et al. (2023)
3.	*Lacticaseibacillus paracasei* strain *Shirota* (LcS),	Probiotic	Milk	100 mL of a *LcS* beverage (108 *CFU*/mL)	Relieved constipation, improved potentially depressive symptoms, regulated intestinal microbiota associated with mental illness	Zhang et al. (2021)
4.	*L.gasseri*	Probiotic	Yogurt	85 g *LG21* strain-containing yogurt beverage	*LG21* strain have impact on mild to moderate delayed gastric emptying	Ohtsu et al. (2021)
5.	Cocoa	Polyphenol	Polyphenol-rich cocoa	Beverage (20 g cocoa powder)	↓postprandial *VLDL* and chylomicron particles, ↑*HDL-C*, reduced serum *IL-18* (inflammatory marker)	Davis et al. (2020)
6.	Fig	Polyphenol	Tea prepared from fig leaves	500 mL of fig leaf tea	Prolonged consumption of fig leaf tea may be a safe and effective alternative to current therapies for *AD* (atopic dermatitis)	Abe et al. (2022)
7.	*Thai mulberry*	Polyphenol	Tea	Concentrated beverage	*CMD* (concentrated mulberry drink) improved metabolic markers, particularly regarding its antihypertensive effects	Parklak et al. (2024)
8.	Mulberry leaf extract	Polyphenol	Tea	Beverage	Supplementation of *MLE* (Mulberry leaf extract) into real food could be practical and would potentially help to suppress postprandial blood glucose levels	Ding et al. (2023)
9.	Snack alternatives based on common beans	Fiber	Beans snack bar	32 g of the *CBBS*	The daily consumption of 32 g of a common bean baked snack (*CBBS*) reduces the blood levels of apolipoprotein *B-100*; this could positively influence cardiovascular health	Escobedo et al. (2021)
10.	β-glucan	Fiber	Whole grain barley	2 g, 4 g, and 6 g β-glucan	Postprandial glycemic response, high β-glucan whole grain barley foods could help to control blood glucose	Kellogg et al. (2025)

Table 3. Continued...

11.	β-glucan	Fiber	Oat product (*SoluOBC*)	3 g of β-Glucan (*OBG*) beverage	Reduce *SCI* and *CVD* risk in individuals with elevated baseline *LDL* cholesterol and *SCI*, suggesting that oats may benefit the inflammatory system and cardiovascular disease prevention in high-risk populations	Dioum et al. (2022)
12.	Barley dietary fiber	Fiber	Beverage	150 g of the beverage	*BDF* (barley dietary fiber) intake reduce hunger and increase satiety, may aid in managing postprandial glycemic responses and improving metabolic health	Kim et al. (2024)
13.	Gold Kiwifruit	Fiber	Gold Kiwifruit	2 pieces of kiwifruit	Effective as fiber-matched psyllium in treating constipation in adults, improved stool consistency, reduced straining	Bayer et al. (2022)
14.	Hemp seed protein (*HSP*)	. Functional peptides and proteins	Hemp seed	50 g casein/d, 50 g *HSP/d*, or 45 g *HSP* with an added 5 g of bioactive peptides (*HSPþ)*/d	Hemp protein consumption, as well as in combination with bioactive peptides, may have a role in the dietary management of hypertension	Samsamikor et al. (2024)
15.	The high protein investigational product (*IP*)	Functional peptides and proteins	Protein product	Ready-to-eat snack	Protein supplementation stimulated bacterial amino acid metabolism, protein supplementation alongside a mild energy restriction induces visceral fat mass loss and an activation of gut microbiota amino-acid metabolism	Kopecky et al. (2021)

ITF-inulin-type fructans; *IBS*- irritable bowel syndrome.; *VLD*L- very low density lipoprotein; *HDL-C*- high-density lipoprotein cholesterol, *IL-18*- interleukin-18, *CMD*- concentrated mulberry drink; *MLE*-; mulberry leaf extract *BDF*- barley dietary fiber; *SCI*- systemic chronic inflammation; *CVD* - cardiovascular disease; *HSP*- hemp seed protein.

Probiotic strains, such as *Lacticaseibacillus paracasei Shirota* and *Lactobacillus gasseri,* have also demonstrated the potential to modulate gut microbiota and alleviate symptoms of both constipation and depression (Zhang et al., 2021; Ohtsu et al., 2021). While the gut-brain axis represents an exciting frontier, current evidence largely relies on limited clinical trials, and more rigorous study designs are essential to determine strain-specific efficacy and optimal dosages.

Polyphenol-rich foods, including cocoa, fig leaf tea, and mulberry extracts, have been praised for their antioxidant and anti-inflammatory properties. Cocoa, for instance, has been shown to reduce postprandial *VLDL* and increase *HDL* levels, potentially supporting cardiovascular health (Davis et al., 2020). Meanwhile, fig leaf tea shows therapeutic promise for atopic dermatitis (Abe et al., 2022), and mulberry derivatives may aid glycemic control (Parklak et al., 2024; Ding et al., 2023). However, the bioavailability and mechanisms of action of polyphenols vary significantly across sources, raising questions about generalizability and clinical relevance of these outcomes.

Dietary fiber remains a cornerstone of functional nutrition, with a broad range of benefits supported by evidence. Fiber-rich snacks, such as those made from beans, may contribute to cardiovascular health by reducing apolipoprotein B-100 levels (Escobedo et al., 2021). Likewise, beta-glucan from oats and barley has shown cardiometabolic benefits, including reductions in postprandial glycemia and cholesterol levels (Kellogg et al., 2025; Dioum et al., 2022). Furthermore, satiety-enhancing fiber products, such as those used in bariatric formulations, appear to regulate appetite hormones like ghrelin and PYY (Kim et al., 2024). Even natural whole-food options like golden kiwis have been shown to rival psyllium in treating constipation (Bayer et al., 2022). These findings are encouraging, yet many studies lack long-term data and standardized interventions, which limits broader application.

Functional proteins, including hemp-derived proteins and those enriched with bioactive peptides, are gaining recognition for their potential roles in managing hypertension and improving metabolic health (Samsamikor et al., 2024). High-protein diets, particularly those implemented with mild energy restriction, have been linked to improved amino acid metabolism and reduced visceral fat (Kopecky et al., 2021). While these outcomes support the inclusion of protein-rich functional foods in metabolic interventions, their success is often context-dependent, varying with individual metabolic profiles and dietary patterns.

To sum up, research shows that probiotic strains like *Lacticaseibacillus paracasei* and *Lactobacillus gasseri* support gut health and improve digestion and mental health, alleviating symptoms of depression and constipation. Polyphenol-rich foods, including cocoa, fig leaf tea, and mulberry extracts, help reduce inflammation, improve metabolic parameters, and may aid in managing conditions like cardiovascular disease, diabetes, and atopic dermatitis. Fiber-rich foods, such as bean-based snacks, beta-glucan, and golden kiwis, enhance digestion, metabolism, and cardiovascular health, with benefits like reduced hunger and improved glycemic control. Protein products, including hemp-based proteins, aid in managing hypertension and support gut health, while high-protein diets can reduce visceral fat and improve amino acid metabolism.

Technological Challenges in Food Fortification with Bioactive Compounds – Innovations in the Food Industry

The fortification of foods with bioactive compounds presents several technological hurdles, primarily due to the instability and low bioavailability of these compounds. (Dahiya et al., 2023). Many bioactives, such as polyphenols, vitamins, probiotics, and omega-3 fatty acids, degrade easily when exposed to heat, light, oxygen, or certain pH levels, leading to a loss of their functional properties (Du et al., 2022). Additionally, some bioactives have poor solubility in water or fat, making their incorporation into various food matrices difficult without affecting sensory attributes like taste, texture, and color (Shahidi and Pan, 2021). To overcome these challenges, the food industry has adopted innovative strategies. Encapsulation technologies such as nanoencapsulation, microencapsulation, and liposomal delivery systems, help protect bioactives from environmental degradation and enhance their controlled release and absorption in the body (Pateiro et al., 2021). Banožić et al. (2025) explored the encapsulation of citrus aroma compounds from *Citrus reticulata* pomace using different coatings, such as gum arabic, maltodextrin, and carboxymethylcellulose, and found that freeze-drying effectively encapsulated volatile and semi-volatile compounds, with limonene, linalool, and α-terpineol being the most abundant aromas identified in disrupted microcapsules. Emulsification techniques, particularly nanoemulsions, improve the dispersion of lipophilic compounds, increasing their bioavailability. Furthermore, biopolymer-based carriers (such as alginate, chitosan, and protein-based matrices) provide structural stability to bioactive compounds, extending their shelf life (Gali et al., 2023). Recent advancements also include 3D food printing, which allows for precise placement and distribution of bioactives in food products, ensuring a consistent dosage (Mantihal et al., 2020). Additionally, the use of fermentation and enzymatic modifications has been explored to enhance the bioavailability of certain bioactives, making them more effective when consumed. These technological innovations are revolutionizing the functional food industry by improving the stability, efficiency, and sensory appeal of fortified foods, ensuring that consumers receive maximum health benefits without compromising on quality.

Conclusion

Functional foods possess significant potential in supporting the management of chronic inflammatory conditions. Their effectiveness lies primarily in the presence of bioactive compounds such as polyphenols, flavonoids, omega-3 fatty acids, and probiotics which exhibit anti-inflammatory, antioxidant and immunomodulatory properties. The integration of these foods into the daily diet shows promise in reducing systemic inflammation and improving clinical symptoms associated with diseases like rheumatoid arthritis, inflammatory bowel disease, and metabolic syndrome. However, despite these positive indications, the review highlights several limitations. Most available studies are short-term, involve small sample sizes, and often lack standardized methodologies. Variations in dosages, the bioavailability of active compounds and individual differences such as genetics and gut microbiota composition, also contribute to inconsistent outcomes. These factors underscore the need for more comprehensive, long-term clinical trials to fully validate the health benefits and therapeutic applications of functional foods. As a final point, functional foods should not be viewed as stand-alone treatments but as complementary elements within a broader, personalized dietary and medical strategy. Further interdisciplinary research is essential to develop clear, evidence-based guidelines for their effective use in managing chronic inflammation.

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