fermentation

Review

Certain Fermented Foods and Their Possible Health Effects with a Focus on Bioactive Compounds and Microorganisms

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Abstract: Fermented foods refer to beverages or foods made by carefully regulated microbial growth and the enzymatic conversion of dietary components. Fermented foods have recently become more popular. Studies on fermented foods suggest the types of bacteria and bioactive peptides involved in this process, revealing linkages that may have impacts on human health. By identifying the bacteria and bioactive peptides involved in this process, studies on fermented foods suggest relationships that may have impressions on human health. Fermented foods have been associated with obesity, cardiovascular disease, and type 2 diabetes. In this article, fermented dairy products, vegetables and fruits, legumes, meats, and grains are included. Two elements in particular are emphasized when discussing the fermentation of all of these foods: bioactive chemicals generated during fermentation and microorganisms involved during fermentation. Organic acids, bioactive peptides, conjugated linoleic acid, biogenic amines, isoflavones, phytoestrogens, and nattokinase are a few of the bioactive compounds included in this review. Also, certain bacteria such as *Lactobacillus*, *Bifidobacterium*, *Streptococcus*, and *Bacillus* species, which are utilized in the fermentation process are mentioned. The effects of both substances including anti-fungal and antioxidant properties; the modulation of intestinal microbiota; anti-inflammatory, antidiabetes, anti-obesity, anticancer, and antihypertension properties; and the protection of cognitive function are explained in this review.

Keywords: fermentation; fermented foods; bioactive compounds; health; microorganisms

1. Introduction

Fermentation is a food processing technique, and its origins date back many centuries. The existence of fermented products has been demonstrated to be started in India, Iraq, and Egypt in the years BC [1]. The definition of fermentation according to the International Scientific Probiotic and Prebiotic Association (ISAPP) is "foods made through desired microbial growth and enzymatic conversions of food components". Fermentation has been used by humans for as long as recorded history to preserve and modify food, resulting in more stable and varied food with distinctive organoleptic, sensory, and functional features [2]. Due to their distinctive flavors, fermented foods are being produced and consumed in greater quantities. There has also been a scientific concentration on the health benefits of fermented foods and their components [3]. In the fermentation procedure, microorganisms, specifically bacteria, yeasts, and mycelial fungus, as well as their enzymes, produce fermented foods. Milk, cereals, vegetables, fruits, legumes, meats, and products are food groups used in fermentation [4].

Food fermentation's main purposes are to increase food safety and lengthen shelf life; additionally, fermented foods have grown to be known for their positive effects on health [5]. Foods that have undergone fermentation may produce bioactive compounds as byproducts of the process, and fermented foods may contain live microorganisms that have health benefits [6]. The main metabolites and microorganisms involved in food fermentation may be divided into categories: alcohol, carbon dioxide (from yeast), propionic acid (from *Propionibacterium freudenreichii*), lactic acid (from lactic acid bacteria (LAB) from genera such as *Lactobacillus* and *Streptococcus*), acetic acid (from *Acetobacter*), ammonia, and fatty acids (from *Bacillus* and molds) [7]. The metabolites produced by the fermenting organisms limit the expansion of spoilage, and pathogenic organisms during food fermentation extend the shelf life of perishable foods [8]. During fermentation, macronutrients are broken down, and digestion is facilitated. Many fermented foods include probiotic-potential bacteria in them [5]. Probiotics are defined in the FAO/WHO report as "Live microorganisms which when administered in adequate amounts confer a health benefit on the host" [9]. According to the ISAPP, these concentrations of probiotics can vary daily from 100 million to over a trillion CFU. The majority have been studied at concentrations of 1 to 10 billion CFU/d [10]. Fermented foods may serve as probiotic carriers, effectively delivering the probiotic to the host and conferring health advantages [11]. Although there may be a fermentation process involved, consumed fermented foods may not contain live bacteria. The term "probiotic" is only used when a product has clearly shown health advantages brought about by the action of well-defined and characterized living microorganisms [2]. The metabolic activity of microorganisms during fermentation results in a number of biochemical alterations that have impacts on the nutritive and bioactive qualities of fermented foods. The bioactive components showing health benefits include exopolysaccharides, bioactive peptides, phenolic compounds, short-chain fatty acids (SCFAs), conjugated linoleic acid (CLA), and γ-aminobutyric acids (GABAs) [12]. Fermented foods and their components can have many health effects such as antioxidant, antidiabetes, anti-inflammatory, anti-hypercholesterolemic, and microbiota modulation effects [13–16].

This review focuses on the advantages of bioactive compounds for health and the probiotic microorganisms that occur in some foods during fermentation or are derived from fermented foods. This article focuses on fermented foods that are frequently consumed in the food groups of dairy, fruits, vegetables, meats, cereals, and legumes. Some fermented foods and the health effects of the components that occur during fermentation, as well as the health effects of probiotic microorganisms in fermented foods, are included. In summary, this article seeks to investigate the possible health effects of fermented foods by focusing on the following: (i) the general effects of fermented foods on health, (ii) the compounds that occur in bioactive components during fermentation and their health effects, and (iii) the health effects of bacteria with probiotic properties that are contained in or isolated from fermented foods.

2. Fermented Dairy Products

Milk is an important source of macro- and micronutrients. Protein, conjugated linoleic acid, calcium, riboflavin, and phosphorus are macro- and micronutrients that are commonly found in milk. These nutrients have impacts on health and diseases [17]. Milk proteins (whey and casein) have positive effects on satiety and body weight control; have hypotensive, antimicrobial, anti-inflammatory, anticancer, and antioxidant effects; and cause insulin release and glucose regulation [18]. Many fermented products such as yogurt, cheese, and kefir are obtained via the fermentation of milk. In the production of fermented milk products, LAB play a crucial role [19]. Milk fermentation using yeasts, propionibacteria, and LAB may result in the synthesis or increase in the number of bioactive compounds that show some health benefits. These include vitamins, CLA, exopolysaccharides (EPSs), GABAs, bioactive peptides, and oligosaccharides [20]. For example, lactic acid bacteria and propionibacteria can increase the amounts of B_{12} and folic acid in fermented milk products [21–23]. In addition, the fermentation of lactic acid in milk reduces the amount of lactose, which may make fermented dairy products tolerable for people with lactose intolerance [24]. The bioactive components and health effects of kefir, yogurt, and cheese, which are widely consumed fermented dairy products, are examined in detail below.

2.1. Kefir

Kefir is an acidic alcoholic fermented dairy product with a creamy consistency and a slightly acidic taste, originating from the Balkans, Eastern Europe, and the Caucasus. Traditionally, kefir is produced using cow, sheep, goat, or buffalo milk [25]. Kefir grains are used as a starter in the production of kefir. The bacteria and yeasts commonly found in kefir grains are *Lactobacillus kefiranofaciens*, *Lacticaseibacillus paracasei*, *Lactiplantibacillus plantarum*, *Lactobacillus acidophilus*, *Lactobacillus delbrueckii* subsp. *bulgaricus*, *Kluyveromyces marxianus* ssp. *Marxianus Candida kefyr*, *Saccharomyces cerevisiae*, and *Saccharomyces unisporus* [26]. Kefir is thought to include more than 300 distinct microbial species [27]. The microorganisms present in kefir grains may vary depending on the source of kefir, climatic conditions, geographical origin, substrate used in the fermentation process, and production methods [28–31].

Kefir exerts its positive effects on health through whole kefir, kefir grains, lactic acid bacteria, yeasts, organic acids, polysaccharides (kefiran and exopolysaccharides), and various other metabolites [32]. As a result of fermentation, there is an increase in lactic acid and antioxidant activity in kefir compared to normal milk [33]. In addition, *Propionibacterium freudenreichii* bacteria in kefir grains can cause an increase in B_{12} and folate levels [22]. Studies on kefir, kefir grains, and kefir components (lactic acid bacteria, organic acids, bioactive peptides, and polysaccharides) have shown that they have antihypertensive [34], anticancer [35], antioxidant [36], anti-inflammatory [37], antidiabetic [38], and hypocholesterolemic effects [39] in addition to effects on bone health [40], cognitive function [41], and microbiota modulation [42].

The bacteria and yeasts identified in kefir can have positive effects on health. *Kluyveromyces marxianus* is one of the yeasts in kefir. Its strain, obtained from kefir, has been shown to remain alive in the digestive system [43]. *Kluyveromyces marxianus* B0399 supplementation decreased proinflammatory cytokines (tumor necrosis factor alpha (TNF-α), interleukin (IL)-6, macrophage inflammatory protein-1 (MIP-1) α, IL-12, IL-8, interferon (IFN)-γ) and increased SCFAs (acetate and propionate). Although there was no change in the total bacterial count, the *Bifidobacterium* genus count increased [44]. *Kluyveromyces marxianus* A4 and A5 supplementation showed good adhesion in Caco-2 cells. *Kluyveromyces marxianus* A4 increased *Bacteroidetes*, *Bacteroidales*, and *Bacteroides*, and *Kluyveromyces marxianus* A5 increased *Corynebacteriales* and *Corynebacterium* [45]. In another study, a high concentration of *Kluyveromyces marxianus* A5 decreased IL-6 [46]. In this direction, kefir is effective in immune response and colonic microbiota modulation. The lactic acid bacteria obtained from kefir have immunomodulatory and antioxidant effects [39,47].

As a result of fermentation in kefir, kefiran and exopolysaccharides are formed. Polysaccharides have been described to have anticancer, anti-inflammatory, antioxidant, anti-atheroscle rosis, and microbiota modulation effects [42,48–61]. In the study by Bengoa et al. [62], *Lacticaseibacillus paracasei* exopolysaccharides isolated from kefir increased the fecal total SCFA, propionic acid, and butyric acid levels [62]. Lim et al. [63] found that kefir exopolysaccharides reduced intracellular lipid accumulation and enhanced the abundance of *Akkermansia* spp. in feces. Since there are many studies on the effects of kefir and its fermented components on health, Table 1 summarizes the components and their effects.

Table 1. Possible health effects of kefir and its components.

Bioactive Components	Health Effects	Specific Effects	References
Kefir and kefir grains	Antihypertensive	ACE inhibitory activity Blood pressure ↓	[34]
		Mean arterial pressure ↓ Cardiac hypertrophy ↓ TNF-α/IL-10 ↓ ACE activity ↓	[64]
	Anticancer	TGF-α downregulation and TGF-β1 mRNA expression upregulation has antiproliferative effects <u>Dose-dependent effects:</u> Transcriptional levels of TGF-α ↓ Transcriptional levels of TGF-β1 ↑ Apoptotic cells ↑	[35]
		Expression of TGF-α ↓ TGF-β1 ↓ p53-independent p21 expression ↑ Upregulation in Bax/Bcl-2 ratio Kefir may induce apoptosis and inhibit proliferation	[65]
		Tumor growth 64.8% ↓	[66]
		The size and the amount of tumor ↓ <u>In colon tissue:</u> The mRNA expression levels of mRNA of TNF-α, IL-6, and IL-17a ↓ TNF-α, IL-6, and IL-17a ↓ Proliferating cell indicators (Ki67, NF-κB, β-Catenin) ↓ Claudin 1, ZO-1 mRNA, and protein levels ↑ Serum LPS ↓ <u>In feces:</u> Butyric acid, acetic acid, and propionic acid ↑ *Ascomycota/Basidiomycota* ratio and *Firmicutes/Bacteroidetes* ratio ↓ *Lactobacillus* and *Bifidobacterium* ↑ The relative abundance of probiotics ↑ The pathogenic bacteria (*Aspergillus*, *Clostridium sensu stricto*, and *Talaromyces*) ↓	[67]
	Antioxidant	TAS ↑	[36]
		Serum levels of $^{\cdot}O_2^-$, H_2O_2, and $ONOO^-/OH^-$ ↓ NO levels ↑ Protein oxidation ↓ p53 expression↑ DNA fragmentation ↓ Apoptosis ↓	[37]
		MDA↓, CAT ↑, SOD ↑, GPx ↑	[68]
		DNA damage ↓ Antioxidant capacity of kefir according to milk ↑	[69]
	Anti-inflammatory	TNF-α, IL12p70, and IL-8 ↓ IL-8/IL-10 and IL-12/IL-10 ↓	[37]
		TNF-α, IFN-γ ↓	[38]

Table 1. *Cont.*

Bioactive Components	Health Effects	Specific Effects	References
Kefir and kefir grains	Microbiota modulation	*Bifidobacterium bifidum* PRL2010 ↑	[48]
		Lactobacillus quantity of treatment group for Crohn's disease ↑ *Lactobacillus* quantity of treatment group for ulcerative colitis ↑	[70]
		Relative abundance of *Actinobacteria* ↑	[38]
		Firmicutes/Bacteroidetes ratio, *Ascomycota/Basidiomycota* ratio ↓ *Lactobacillus* and *Bifidobacterium* ↑ Probiotics' relative abundance ↑ The pathogenic bacterium (*Clostridium sensu stricto*, *Aspergillus*, and *Talaromyces*) ↓ *Clostridium_sensu_stricto_1*, *Bacteroides*, *Lachnospiraceae_NK4A136_group*, *Oscillospiraceae*, *Desulfovibrio* ↓ *Muribaculaceae* and *Alloprevotella* ↑	[67]
		Milk kefir had a free radical scavenging activity of 76.640.42% <u>In the colon</u>: SOD and CAT ↑ Brain butyrate and propionate ↑ Fecal butyrate ↑ *Lachnospiraceae* and *Lachnoclostridium* ↑ Relative abundance of *Firmicutes* ↑ *Proteobacteria* and *Epsilonbacteraeota* ↓	[71]
	Bone health	Prevented estrogen-deficiency-induced bone loss Bone volume/total volume ↑ Bone mineral density ↑ Trabecular thickness ↑ Trabecular number↑ Average cortical elastic moduli, hardness ↑ Trabecular separation ↓ Type I collagen levels ↓	[40]
	Antidiabetic	Insulin ↓, HOMA-IR ↓	[38]
		Serum glucose ↓ HbA1c ↓	[72]
	Cognitive function	Improvement in performance in the MMSE Improvement in the memory test	[37]
	Hypocholesterolemic	Serum LDL-C ↓ LDL-C/HDL-C ratio ↓ Serum HDL-C ↑	[39]
Lactic acid bacteria	Immunomodulatory	Mucins (MUC-1 and MUC-2) and IgA gene expression ↑	[39]
	Antioxidant	*Lactiplantibacillus plantarum MA2* had antioxidant potential	[47]
Organic acids	Antimicrobial	Milk fermentation with kefir grains antagonizes *Bacillus* cereus through the organic acids (lactic acid and acetic acid) produced during fermentation	[73]
		Escherichia coli, *Salmonella*, and *Bacillus Cereus* pathogenic strains' growths were inhibited This related to the concentration of lactic acid	[74]

Table 1. *Cont.*

Bioactive Components	Health Effects	Specific Effects	References
Bioactive peptides	Antihypertensive	ACE activity inhibition	[75]
		Peptides defined in kefir have previously shown an ACE inhibiting effect	[76]
		ACE inhibitory activity	[77]
	Antifibrosis	Kidney cells Relative expression of α-SMA) ↓ Relative expression of ET-1 ↓ Relative expression of MMCP-1) ↓ Kidney tissues Protein expression of ET-1 ↓ Protein expression of α-SMA ↓	[78]
	Anti-inflammatory	Pro-inflammatory cytokines ↓	[34]
		NF-kB protein expression ↓ TGF-β protein expression ↓ NLPR3 protein expression	[78]
	Antioxidant	Total antioxidant capacity of the FRAP ↑	[41]
		ABTS and DPPH radical scavenging activity	[79]
		ROS production ↓ Lipid peroxidation ↓	[34]
		Renal effects: SOD activity ↑ ROS activity ↓	[78]
	Antimicrobial	*Escherichia coli* ATCC 25922, *Pseudomonas aeruginosa* ATCC 27853, *Klebsiella pneumoniae* ATCC 29665, *Bacillus subtilis* ATCC 6633, *Bacillus cereus* ATCC 33019, and *Staphylococcus aureus* ATCC 6538 growths were inhibited	[79]
		Increasing the outer and inner membrane permeability of *Escherichia coli*, causing damage to the cell membrane, and promoting intracellular material leakage	[80]
	Neuromodulation	Neurodegeneration index ↓ Acetylcholinesterase activity ↓ Lower amyloid content	[41]
	Bone health	Preventing menopausal osteoporosis Trabecular number ↑ Trabecular bone volume ↑ Trabecular thickness ↑ Average cortical elastic moduli, hardness ↑ Bone mineral density ↑ Trabecular separation ↓	[81]
	Microbiota modulation	Restored the abundances of *Alloprevotella*, *Parasutterella*, *Anaerostipes*, *Ruminococcus_1*, *Romboutsia*, and *Streptococcus genera*	[81]
Polysaccharide			

Table 1. *Cont.*

Bioactive Components	Health Effects	Specific Effects	References
Kefiran	Anticancer	MCF7 cancer cells ↓, PBMC ↑	[49]
		Anti-proliferative effect on HeLa and HepG2 Cell viability of HeLa and HepG2 ↓	[50]
	Anti-inflammatory and immunomodulatory roles	Proinflammatory cytokines (NF-kB, IL-1β, TNF-α) ↓ Overexpression of TLR4 ↓	[51]
		BALB/c mice Small intestine: IgA, IL-10, IL-6, IL-12 ↑ Serum: IL-4, IL-6, IL-10 ↑ Intestinal fluid: IL-4, IL-12 ↑ Large intestine: IgA, IgG, IL-6, IL-10, IL-4, IFN, TNF ↑	[52]
		Inhibition percentage of nitric oxide radical production	[53]
	Antioxidant	Scavenging of superoxide and hydroxyl radicals	[53]
		DPPH free radicals scavenging activity ↑	[54]
		Lipid peroxide of βVLDL ↓	[55]
	Microbiota modulation	Intestinal *Bifidobacteria* ↑	[42]
		Bifidobacterium bifidum PRL2010 ↑	[48]
Exopolysaccharide	Anticancer	Antitumor activity against colon cancer HT-29 cells Upregulate the expression of Cyto-c, BAD, BAX, caspase3, caspase8, and caspase9 Downregulate BCl-2	[56]
	Anti-inflammatory and immunomodulatory roles	Cell viability of the RAW264.7 cells ↑ NO concentration ↑ TNF-α, IL-1β concentration ↑ iNOS concentration ↑ Proliferation and phagocytosis are increased to combat infection and inflammation	[57]
		Dose-dependent effects: Cell viability of the RAW264.7 cells ↑ NO concentration ↑ TNF-α, IL-1β concentration ↑ Enhanced the proliferation, phagocytosis	[58]
		Dose-dependent effects: NO concentration ↑ TNF-α, IL-6, IL-1β, IL-10 concentration ↑ Increasing the activity of acid phosphatase Enhancing macrophages' phagocytosis Viability of macrophages	[59]
	Antioxidant	GPx 21.55%, SOD 33.14%, CAT 61.09% Total antioxidant capacity 38.18% MDA ↓	[61]
		Certain scavenging activities: ➢ DPPH free radical scavenging activity ➢ ABTS free radical scavenging activity ➢ Hydroxyl free radical scavenging activity	[60]

Table 1. *Cont.*

Bioactive Components	Health Effects	Specific Effects	References
	Microbiota modulation	The abundance of *Flexispira* ↓ The abundances of *Blautia* and *Butyricicoccus* ↑ Content of SCFA ↑ Content of NO ↓	[61]
		Total SCFA ↑ Propionic acid and Butyric acid ↑ Proportion of the genera *Victivallis*, *Acidaminococcus*, and *Comamonas* ↑ Proportion of *Enterobacteria* ↓	[62]
		The abundance of the phyla *Bacteroidetes*, *Verrucomicrobia*, and *Proteobacteria* ↑ The abundance of the *Firmicutes* and *Actinobacteria* ↓ The enhanced abundance of *Akkermansia* spp. in feces	[63]
	Anti-obesity	Lower intracellular lipid accumulation Epididymal adipose tissue weight 19% ↓ Body weight gain ↓ VLDL-C 36% ↓	[63]

↑: increased, ↓: decreased, ACE: angiotensin-converting enzyme, TNF-α: tumor necrosis factor alpha, IL: interleukin, TGF-α: transforming growth factor alpha, TGF-β1: transforming growth factor beta, TAS: total antioxidant status, LPS: lipopolysaccharide, CAT: catalase, MDA: malondialdehyde, SOD: superoxide dismutase, GPx: glutathione peroxidase, α-SMA: α-smooth muscle actin, ET-1: endothelial-1, MCP-1: monocyte chemoattractant protein-1, HOMA-IR: homeostasis model assessment of insulin resistance, ABTS: 2,2′-azino-bis(3-ehtylbenzothiazoline-6-sulfonate), DPPH: 2,2-diphenyl-1-picrylhydrazyl, iNOS: inducible nitric oxide synthase, NO: nitric oxide, SCFA: short-chain fatty acid, LDL-C: low-density lipoprotein cholesterol, HDL-C: high-density lipoprotein cholesterol, VLDL-C: very-low-density lipoprotein cholesterol, TLR-4: Toll-like receptor 4, Ig: immunoglobulin, IFN: interferon, DNA: deoxyribonucleic acid, MMSE: mini-mental state examination, HbA1C: glycated hemoglobin, NF-Kb: nuclear factor kappa B, PBMC: peripheral blood mononuclear cells, NLPR3: nucleotide-binding oligomerization domain (NOD)-like receptor family pyrin domain containing 3, HeLa: human cervical cancer cells, HepG2: human liver hepatocarcinoma cells.

2.2. Yogurt

One of the products of the lactic acid fermentation of milk is yogurt. The lactose in its content is converted into lactic acid by bacteria. In this way, it can be tolerated in the case of lactose intolerance. It also has benefits for health due to its protein content, vitamins such as riboflavin, minerals such as calcium, and metabolites that result from fermentation [82]. One of the components in yogurt that may have a positive effect on health is the CLA content. As a result of the increase in fermentation time, the CLA level in yogurt may increase [83]. The CLA contents of natural yogurt, probiotic yogurt, and Greek yogurt obtained from goat milk were found to be 3.28 ± 0.10 mg/g fat, 4.07 ± 0.08 mg/g fat, and 4.19 ± 0.14 mg/g fat, respectively [84]. The CLA contents of cow, sheep, and goat milk yogurts were found to be 0.128–1.501, 0.405–1.250, and 0.433–0.976 g CLA/100 g fat, respectively [85]. In another study, 0.24–0.45 g/100 g fat was found in cow yogurt, and 0.47–0.76 g/100 g fat was found in sheep yogurt. When the effect of storage time on the CLA level was evaluated, the CLA level increased significantly in yogurt obtained from sheep milk after 14 days of storage, while it decreased in yogurt obtained from cow milk [86]. When yogurts from Polish markets were evaluated, the highest CLA content was found in bio yogurt. Probiotics and natural yogurt did not differ in the CLA content [87]. CLA has positive effects on obesity, cancer, cardiovascular diseases, bone health, and immune response [88].

Studies on the consumption of conventional/probiotic yogurt have evaluated its microbiota modulation [89], hypocholesterolemic [90], antidiabetic, antioxidant [91], and anti-obesity effects [92]. It was found that visceral fat decreased, and the abundances of *Streptococcus thermophilus* and *Bifidobacterium animalis* subsp. *Lactis* species increased in individuals who consumed yogurt. A correlation was observed between *Bifidobacterium animalis* subsp. *Lactis* and increased fecal 3-hydroxyoctanoic acid contents [89]. Yogurt supplementation (220 g/day) decreased fasting insulin, insulin resistance, intrahepatic lipid, hepatic fat fraction, serum lipopolysaccharide (LPS), fibroblast growth factor 21, triglycerides, TNF-α, total cholesterol, glutathione peroxidase (GPH-Px), and superoxide dismutase (SOD). In addition, it regulated the microbiota composition [91]. Hasegawa et al. [92] reported that yogurt supplementation in obese mice resulted in decreased the levels of Homeostasis Model Assessment of Insulin Resistance (HOMA-IR), serum TNF-α, plasma LPS binding protein, and colonic LPS expression, and altered the diversity of cecal microbiota. In addition, body weight gain was reduced in obese mice [92]. Compared to no snack consumption, yogurt consumption reduced afternoon hunger and delayed the desire to start the next meal. Although this effect was observed for all yogurts, the highest and most significant effect was observed in yogurt containing 24 g of protein [93].

When the effects of probiotic and conventional yogurts were evaluated, the total cholesterol and total cholesterol/high-density lipoprotein cholesterol (HDL-C) ratio decreased as a result of consuming both yogurts. Both yogurts showed hypocholesterolemic effects [90]. In the study by Rezazadeh et al. [94], probiotic yogurt decreased blood glucose, insulin, HOMA-IR, Quantitative Insulin Sensitivity Calculation Index (QUICKI), vascular cell adhesion molecule cell (VCAM)-1, and plasminogen activator inhibitor (PAI)-1 values [94]. Various *Lactobacillus* and *Bifidobacterium* species in probiotic yogurts have been shown to lower cholesterol; regulate plasma glucose levels; have antioxidant, anti-inflammatory, and microbiota modulation effects; and have positive effects on cancer and ulcerative colitis [95–100]. El-Dein et al. [101] compared fermented yogurt with *Lactiplantibacillus plantarum* KU985438 or *Lacticaseibacillus rhamnosus* KU985439 and found that *Lacticaseibacillus rhamnosus* KU985439 provided a greater reduction in blood glucose, triglycerides, total lipids, total cholesterol, triglycerides, NF-κB expression, and lipid peroxidation [101]. Similarly, Gu et al. [15] found that probiotic yogurt (*S. thermophilus* ST447, *Lactobacillus acidophilus* NCFM, *Lacticaseibacillus rhamnosus* GG, and *B. lactis* HN019) decreased blood glucose, glycated hemoglobin (HbA1C), HOMA-IR, insulin, low-density lipoprotein cholesterol (LDL-C), and LPS levels, and increased PYY in mice. Yogurt increased the levels of butyric and acetic acids and *Lactobacillus* and *Streptococcus* bacterial species [15]. In addition, probiotic yogurts have been shown to have a positive effect on diarrhea in adults and children [102,103]. There are also studies showing that probiotics and conventional yogurt are not effective in glucose control in cardiovascular risk factors, diabetes, and obesity [104,105]. The effect of storage time on bacterial counts in probiotic yogurts was also evaluated. *Lacticaseibacillus casei*, which has probiotic properties in yogurt, remained at more than 10^8 CFU/g at the end of the 21 days of storage [106]. In another study, the Lactobacillus bulgaricus content was found to be 8.13 log cfu/g on the 1st day of storage and 7.51 log cfu/g on the 28th day [107]. In the study by Mari lopez et al. [108], the number of S. thermophilus decreased between 1.8 and 3.5 log during storage. Although the probiotic bacteria content decreased, they maintained a content of $\geq 10^7$ cfu/mL at the end of 3 weeks. The vitality of probiotic bacteria in yogurts varied; *Lactobacillus acidophilus* $\geq 10^7$ cfu/mL was maintained for 35 days, *Lacticaseibacillus casei* was maintained for 7 days, and *Limosilactobacillus reuteri* was maintained for 14 days [108].

Bioactive peptides, which are one of the components formed by the fermentation process in yogurts, can show antioxidant, antibacterial, angiotensin-converting enzyme (ACE) inhibitor, opioid antagonist, antihypertensive, and immunomodulatory effects [109–111]. When three groups of yogurts were used as starter cultures, *Lactobacillus acidophilus* 20552 ATCC and *Lactobacillus helveticus* CH5 were evaluated; *Lactobacillus acidophilus* 20552 ATCC and *Lactobacillus helveticus* CH5 had variable proteolytic activity. However, the peptides obtained from yogurt containing *Lactobacillus helveticus* CH5 showed the highest antioxidant and antimicrobial effects. All yogurts showed antimicrobial activity against *Escherichia coli* [109]. In another study, the addition of *Lactobacillus helveticus* CH 5 to yogurt increased the ACE inhibitory effect compared to normal yogurt. In particular, it supported the formation of bioactive α_{S1}-casein (CN) f(24–32) and β-CN f(193–209) peptides [112]. The β-CN (94–123) peptide fraction in yogurt may provide intestinal homeostasis by increasing the expression of intestinal mucin (Muc2 and Muc4) and antibacterial factors (lysozyme and rDefa5) depending on the dose [113].

Storage time is one of the factors affecting the level of bioactive peptides in yogurt. The proteolytic activity of yogurt increased significantly after 14 days of storage and showed ACE-1 activity, antithrombotic activity, cholesterol-lowering activity, and antioxidant activity. All of these activities were found to be the highest in yogurt that was stored in a cold environment for 14 days with skim milk powder and trypsin added [114]. Heydari et al. [115] showed that proteolysis, antimutagenic, and 2,2-diphenyl-1-picrylhydrazyl (DPPH) antioxidant activity were found to be the highest at the end of the 28th day in yogurt that was obtained using *Saccharomyces thermophilus* + *Lactobacillus bulgaricus* + Iranian strain of *Bifidobacterium lactis* species [115]. The enrichment of yogurt with whey proteins, the proteinase and peptidase activities of the added coculture (probiotic bacteria), and the addition of trypsin were effective in the formation and increase in the amount of peptides with antihypertensive, antioxidant, antimicrobial, hypocholesterolemic, antimutagenic, and cholesterol-lowering effects [114,115]. Macro- and micronutrients, bioactive peptides, and probiotic bacteria species all have roles in the health benefits of yogurt.

2.3. Cheese

Cheese has been produced and consumed for many years. There are 1500 cheese varieties defined in the world. The microorganism content of cheese varies based on the milk used, cheese type, and production [116]. The pH changes that occur during the production and ripening of cheese are heavily influenced by both lactic acid bacteria and yeasts [117]. A meta-analysis study evaluating cheese consumption and its health effects found that cheese consumption (especially 40 g/day) had neutral to moderate benefits for human health, and was moderately inversely connected with all-cause mortality, cardiovascular disease, coronary heart disease, and stroke incidence. It also showed a negative association with the risks of type 2 diabetes and dementia. It is emphasized that these effects are due to the nutrients and bioactive components in cheese [118]. Hu et al. [119] also found that cheese consumption was connected with a reduced risk of type 2 diabetes, coronary artery disease, ischemic stroke, heart failure, and hypertension [119]. There were also inconclusive results showing no connection between cheese consumption and cardiovascular disease risk, and unclear results suggesting that it may be associated with increased and decreased risks. It was suggested that the potential effect of cheese on cardiovascular disease may be due to its calcium content, high protein content, fermentation, and fatty acid content (CLA) [120].

One of the components of cheese that have positive effects on health is bioactive peptides. The type of milk used during cheese ripening, starter culture, and native milk microbiota affect the bioactive peptides formed. Bioactive peptides are composed of certain protein fragments and offer various advantages for regulating bodily processes [121–123].

Bioactive peptides in different types of cheese have been shown to have antioxidant, antihypertensive (ACE inhibitory), antimicrobial, and dipeptidyl-peptidase-IV (DPP-IV) inhibitory activity effects [123–127]. In one study, *Lactobacillus helveticus* A1, which releases the peptide as a key factor in ACE inhibition, was the strain with the strongest ACE inhibitory activity [128]. The number of peptides with angiotensin-converting enzyme (ACE), dipeptidyl peptidase-IV (DPP-IV), and antioxidant activity increased with ripening [129]. The proteolysis of cheese for more than 90 days resulted in increased antioxidant activity. Bioactive peptides derived from αs1-casein and β-CN were detected in cheese. The radical scavenging activity, reducing power, chelate capacity, and ACE inhibition effects of cheese extract derived from these peptides were revealed [124]. In another study on bioactive peptides obtained from whey, peptides were found to have antioxidant and ACEI inhibitory effects [125]. The use of ultrasonic, high-pressure, and microwave pretreatments to the milk used in cheese making affected proteolysis both during cheese making and ripening. These treatments increased the ACE inhibitory activity and antioxidant (total flavonoids, total phenolics, total antioxidants, and DPPH radical scavenging activity) activity of the cheese [130].

The consumption of 30 g/day of Grana Padano cheese reduced blood pressure (systolic and diastolic pressure) in people with hypertension after two months [131]. Helal et al. [123] used six cheese varieties and found that Gouda cheese showed the highest antioxidant, ACE-inhibitory and DPP-IV-inhibitory activity. The findings suggested that 10–20 g of Gouda cheese, 50–100 g of Domiati, and 100 g of Edam cheese might be sufficient to exhibit an antihypertensive effect [123]. The salt content, packaging type, and storage time of the cheeses can also affect ACE inhibitor and antioxidant activities. The highest antioxidant activity was found on the first day of vacuum packaging, at a 1% NaCl concentration, and decreased with the increasing storage time. The highest ACE inhibitor activity and peptide concentration were also found on the seventh day of vacuum packaging with no added salt or 1% NaCl [132]. In another study in which the effect of storage time on bioactive peptides in cheeses was evaluated, an increase in the amount of some bioactive peptides in cheeses occurred in long storage times. At 90 days of storage, αS1-CN f(24–32) peptides increased in vacuum packaging and αS1-CN f(1–16–32) and αS1-CN f(17–22) peptides increased in modified atmosphere packaging [133].

The other compound of cheese associated with health is conjugated linoleic acid. The CLA content in cheeses was found to be 0.44 to 1.04 g/100 g of fat in the study by Donmez et al. [134], and 7.5 to 7.9 mg/g of fat in the study by Luna et al. [134]. It was shown that there is an increase in the CLA levels during cheese ripening, but increased storage time decreases the concentration [135]. CLA may have antidiabetic, anticancer, anticarcinogenic, anti-atherosclerotic, antihypertensive, and endothelial function effects [136–138].

The development of biogenic amines may occur in cheese as a result of the bioactivities of some microorganisms. Histamine, cadaverine, putrescine, spermine, spermidine, and tyramine biogenic amines have been detected in different cheese types. High levels of biogenic amine consumption have some drawbacks. For example, histamine has effects such as nausea, vomiting, diarrhea, and stomach upset, while tyramine may cause hypertensive effects and may have a negative relationship with monoamine oxidase inhibitors (MAOIs) [139]. It was emphasized that *Lacticaseibasillus casei* 4a and 5b isolated from cheese reduced tyramine and histamine accumulation, and therefore may be suitable to be used as co-cultures in order to lessen the amount of biogenic amines [140]. In addition, some Lactobacillus species isolated from cheese may have probiotic, antimicrobial, and antioxidant effects [141–143].

It is emphasized that the potential health effects of cheese are due to bioactive peptides, conjugated linoleic acid, calcium, bacteria with probiotic properties, and some prebiotic effects. Due to these components, it is stated that it may be effective in conditions such as blood pressure, diabetes, cardiovascular diseases, and diabetes [144].

3. Fermented Meats

Red meat is any unprocessed mammalian muscle flesh, including frozen or minced meat (such as cattle, veal, pork, or lamb). Meat that has undergone salting, fermenting, smoking, curing, or other methods so as to improve preservation or flavor is well known as processed meat. Pork or beef are typically found as processed meats [145]. The majority of the time, it is agreed that meat and its products provide excellent and high biologic values of proteins, B group vitamins, minerals, trace elements, and some other bioactive components [146].

The process of fermentation is passed down from generation to generation [4]. Different substances are produced by the fermentation technique, which is also preferred in meat products. Carboxylic acids, lactic acid, aldehydes, pyruvic acid, alcohols, and ketones are just a few of the substances that are created during this transition [147]. The fermentation of meat products involves the use of starting cultures and live organisms. These organisms are responsible for carrying out fermentation, reducing pathogenic bacteria, and ensuring the development of appropriate organoleptic qualities in the manufacturing of fermented meat products [148–150]. The fermentation process makes use of many types of bacteria and yeast [151]. *Listeria monocytogenes* levels are reduced, and the food safety and shelf life of fermented meat products are improved as a consequence of the bacteria of lactic acid in meats [152]. *Nham* is a fermented sausage that is only found in Thailand. The bacteria of lactic acid are utilized in this sausage type. Foods have antibacterial properties thanks to the bacteriocins and organic acids produced during fermentation [153]. Gram-positive *cocci* (*Staphylococcus carnosus* and *Staphylococcus xylosus*), yeast (*Debaryomyces hansenii* and *Candida famata*), and mold (*Penicillium nalgiovense* and *Penicillium camambertii*) are also utilized in fermentation in addition to lactic acid bacteria [147]. *Latilactobacillus sakei*, *Weissella*, *Staphylococcus equorum*, *Debaryomyces hansenii*, *Kurtzmaniella zeylanoides*, *Wickerhamomyces subpelliculosus*, and *Zygosaccharomyces rouxii* are the predominant bacteria found in Portuguese fermented sausages. Nitrogen compounds, acids, alcohols, aliphatic hydrocarbons, aldehydes, lactones, pyrans, ketones, terpenoids, esters, sulfur compounds, aromatic hydrocarbons, phenols, and furans are formed as volatile organic compounds as a result of microbiological reactions in these fermented sausages [154]. The most often isolated bacterial species in salami are *Lactobacillus* and *Staphylococcus*, but the *Gammaproteobacteria phylum*, *Moraxellaceae family*, *Acinetobacter*, *Pseudomonas*, *Carnobacterium*, and *Enterococcus* are also present [155].

The enzymatic hydrolysis and fermentation of starting cultures produce bioactive peptides. Both meat products and the gastrointestinal system after intake contain these peptides [156]. In microbial activities that take place in fermented meat products, biogenic amines are produced that are important for food safety and quality. The biogenic amines putrescine, histamine, cadaverine, and tyramine, as well as tryptamine and bphenylethylamine, were found in a study on fermented sausages [157,158]. Although the *Bifidobacterium longum* species, which participates in the fermentation process and has probiotic properties as well [159], inhibits the creation of cadaverine from biogenic amines, and an increase in these amine species also leads to toxicity and the formation of N-nitrosa compounds [160,161]. When nitrites are present, biogenic amines can be transformed into nitrosamines. Secondary amines and NO can combine to generate far more durable carcinogenic nitrosamines than primary amines. Salami samples contain N-Nitrosodimethylamine, N-Nitrosopyrrolidine, N-Nitrosodipropylamine, and N-Nitrosomethylethylamine kinds [162]. N-nitrosoethylmethylamine, N-nitrosodimethylamine, N-nitrosopiperidine, N-nitrosopyrrolidine, N-nitrosodiethylamine, N-nitrosodi-n-propylamine, and N-nitrosomorpholine are the principal nitrosamines found within the majority of products of fermented meat [161,163]. Figure 1 shows the changes throughout the meat fermentation.

In the ripening of fermented sausages, *Lactobacillus rhamnosus* CTC1679 predominates, and it briefly colonizes the gastrointestinal system [164]. The lactic acid bacteria *Pediococcus pentosaceus* KL14, KL10, KL11, and KL14 that are isolated from fermented pork flesh have high radical scavenging abilities. The ouperoxide dismutase activity is also strong in some lactic acid species [165]. Strong proteolysis that occurs during fermentation may eventuate in the occurrence of peptides that have ACE inhibitor and antioxidant properties. Belgian samples have stronger radical scavenging activity and a ferric reducing impression, while Belgian and Spanish dry fermented sausages exhibit an ACE inhibitory effect [166]. Carcinogenic, teratogenic, and mutagenic effects can be caused by N-nitrosamines that are produced during the fermentation of meat products [167]. Table 2 lists the effects of fermented meat and certain bioactive compounds on health.

As for fermented fish products, there are more studies examining the health effects of fish rather than fermented fish. However, studies examining the effects of fermented fish products on health are not sufficient. In a study conducted this year (2023), it was suggested that novel dipeptidyl peptidase-IV inhibitory peptides (D4IPs) discovered in fermented mandarin fish may alleviate the active amino acid sequences of type 2 diabetes mellitus [168]. And it is stated that *Lactiplantibacillus plantarum*, *Pediococcus pentosaceus*, *Pediococcus acidilactici*, *Pediococcus lolii*, *Enterococcus hirae*, and *Enterococcus lactis* among the lactic acid bacteria isolated from *Shindal*, a traditional fermented fish food, have probiotic properties [169].

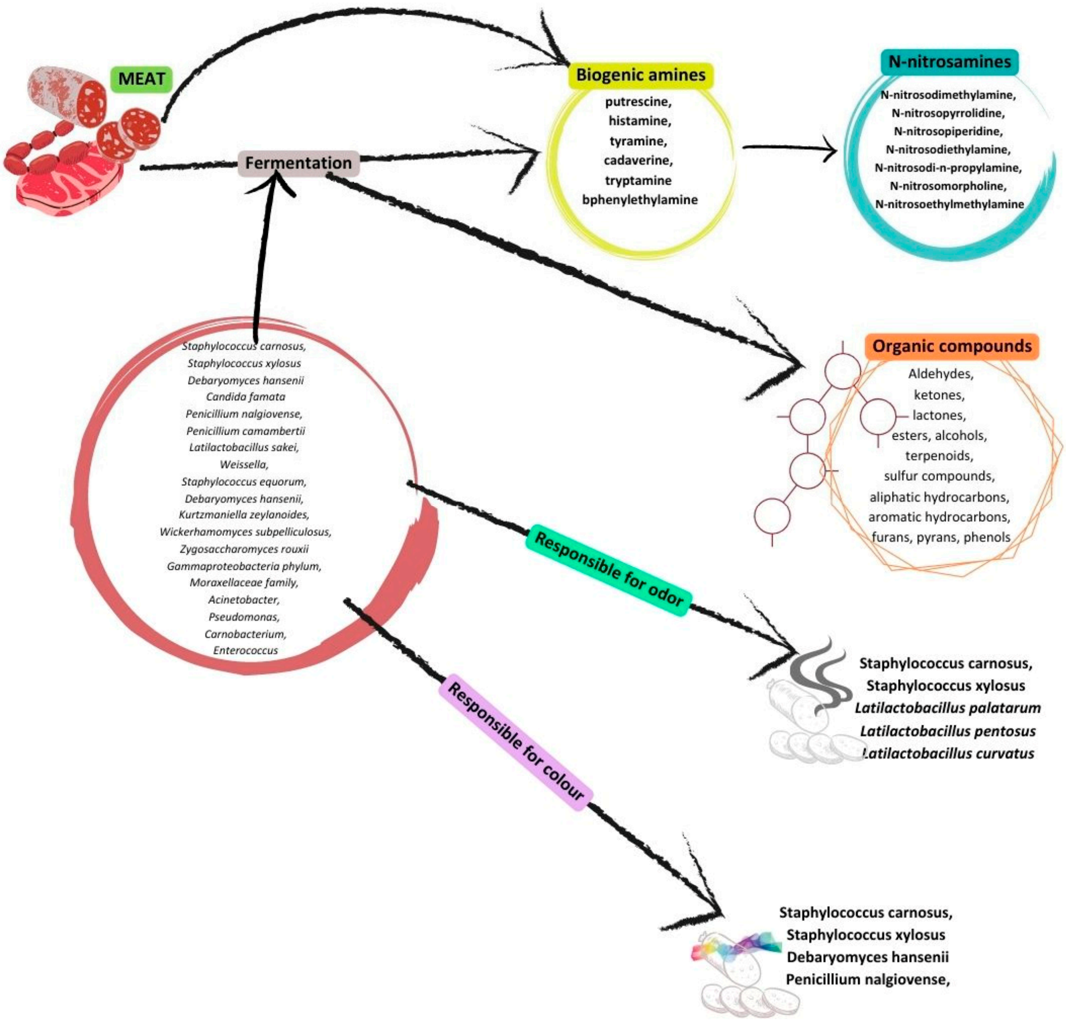

Figure 1. Schematic summary of changes throughout meat fermentation.

Table 2. Effects of fermented meat and certain bioactive compounds on health.

Fermented Foods		**Certain Bioactive Compounds**	**Effects on Health**	**References**
Intestine				
	Fermented mutton jerky	x3-2b *Lactiplantibacillus plantarum* and composite bacteria	Purine content of fermented mutton jerky by x3-2b *Lactobacillus plantarum* and composite bacteria ↓ *In vitro* digestion, decreasing purine content by 37x-3 *Pediococcus pentosaceus* ↑	[170]
	Cured beef	-	Gastric protein carbonylation ↑ Colonic *Ruminococcaceae* ↑ Cecal propionate ↑ TBARs and diacetyl in feces ↑ Levels of cecal butyrate, fecal phenol, dimethyl disulfide ↓ Level of fecal carbon disulfide ↑ Colonic *Ruminococcaceae* ↑	[171]

Table 2. *Cont.*

Fermented Foods		Certain Bioactive Compounds	Effects on Health	References
	Fermented sausage	*Enterococcus faecium* CRL 183	*Lactobacillus* spp. in ascending colon, transverse colon, and descending colon ↓ *Bacteroides* spp. in descending colon ↓ *Enterobacteriaceae* in transverse colon and descending colon ↓ Colonic ammonium ions ↑ Butyric acid concentration in transverse colon, ascending colon, and descending colon ↑ Concentration of propionic acids in ascending colon and transverse colon ↑ Concentration of acetic acid in ascending colon, transverse colon, and descending colon ↓	[172]
	Fermented sausage	-	Release of free iron in digestive system ↑ Concentration of gastric N-nitrosamine ↑	[173]
	Fermented sausage	*Enterococcus faecium* S27	Transfer of tetracycline resistance determinant (tet(M)) to *E. faecium* and *Enterococcus faecalis* ↑ Transfer of *Enterococcus faecium*'s streptomycin resistance ↑	[174]
	Fermented sausage	Bologna sausage (a) Dry fermented sausage (b)	Calcium transporter in Caco-2 cells: in (a) ↑, in (b) ↓	[175]
	Fermented salami	Plant extracts	Phenol and p-cresol in colon ↓ Acetate, propionate, butyrate in colon ↑ *Enterobacteriaceae* ↓ Bifidobacteriaceae ↑	[176]
	Fermented fish	*Staphylococcus* sp. DBOCP6	Non-hemolytic and non-pathogenic effects against broad and narrow spectrum antibiotics Ability to adhere to the intestinal wall	[177]
Cardiovascular diseases and ACE-I inhibitory effects				
	-	-	Cardiovascular disease risk, stroke risk ↑ Total mortality risk ↑	[178]
	Salami Sausage		Cardiovascular disease risk ↑	[179]
		-	Cardiovascular disease risk ↑	[180]
		-	Total stroke incidence ↑ No association between ischemic stroke and coronary heart disease mortality	[181]
	Bacon Sausage	-	Cardiovascular death risk ↑ Ischemic heart disease risk ↑	[182]
	Dry-cured pork ham	-	Levels of total cholesterol, LDL, basal glucose ↓	[183]

Table 2. *Cont.*

Fermented Foods		**Certain Bioactive Compounds**	**Effects on Health**	**References**
	Semi-dry fermented camel sausage	*Lactiplantibacillus plantarum* KX881772	Inhibition of ACE ↑ Cytotoxicity activity towards Caco-2 cell line ↑ α-amylase inhibition ↑ α-glucosidase inhibition ↑	[184]
	Fermented pork sausage	*Staphylococcus simulans* NJ201 *Lactiplantibacillus plantarum* CD101	ACE inhibition ↑ Superoxide anion scavenging activities ↑ Ferric-reducing antioxidant activity ↑	[185]
	Dry fermented camel sausage	*Staphylococcus xylosus* and *Lactiplantibacillus plantarum* *Staphylococcus caarnosus* and *Latilactobacillus sakei* *Staphylococcus xylosus* and *Lactobacillus pentosus*	Antioxidant capacity by <3 kDa peptides ↑ Maximum ACE inhibition by <3 kDa peptides Maximum ACE inhibition in sausages with *S. xylosus* and *L. plantarum*	[186]
	Dry-cured ham	-	ACE inhibition ↑ Radical scavenging activity ↑ PAF-AH inhibitory effect ↑	[187]
	Fermented meat	-	Antioxidant activity against OH-radical by GlnTyr-Pro ↑	[188]
	Dry-fermented sausage	Starter culture (P200S34) and protease (EPg222)	ACE inhibition ↑ Antioxidant activity ↑	[189]
		-	Risk of cardiovascular mortality, stroke, myocardial infarction via reduction in processed meat ↓	[190]
		-	Risk of all-mortality cause and cardiometabolic disease via lower consumption ↓	[191]
		-	Risk of heart failure ↑	[192]
Cancer				
		-	Risk of colon cancer, rectal cancer, breast cancer, lung cancer, and colorectal cancer ↑	[193]
	Ham Sausage Bacon	-	Breast cancer risk ↑	[194]
		-	Weak positive association with breast cancer	[195]
		-	Breast cancer risk with diet rich in processed meat ↑	[196]
	Ham Sausage Bacon	-	Gastric cancer risk ↑	[197]
	Ham Sausage Bacon	-	Colorectal cancer risk ↑	[198]

Table 2. *Cont.*

Fermented Foods	Certain Bioactive Compounds	Effects on Health	References
	-	Colorectal cancer risk with lower consumption ↓	[199]
	-	Colorectal cancer risk with lower consumption ↓	[200]
	-	Colorectal cancer risk ↑	[201]
Ham Sausage Bacon	-	Colorectal cancer risk ↑	[202]
Ham Sausage Bacon	-	Colorectal cancer risk ↑	[203]
	-	Colorectal adenoma risk ↑	[204]
Ham	-	Risk of renal cell carcinoma ↑ Risk of bladder cancer ↑	[205]
Ham Sausage Bacon	-	Bladder cancer risk ↑	[206]
Ham Sausage Bacon	-	Minimal connection to kidney cancer risk	[207]
Ham Salami Sausage Bacon	-	No association with gliomas	[208]
		Risk of hepatocellular carcinoma ↑	[209]
Other diseases			
	-	Risk of type 2 diabetes ↑	[210]
Bacon Salami Sausages	-	Risk of diabetes as well as stroke and coronary heart disease ↑	[211]
	-	Risk of type 2 diabetes ↑	[212]
	-	Type 2 diabetes risk ↑	[213]
	-	Gestational diabetes mellitus risk ↑	[214]
	-	No change in Crohn's disease flares	[215]
	-	Risk of mortality via increase in consumption ↑	[216]
	-	Mortality risk of all causes (except cancer) and cardiovascular-caused mortality ↑	[217]
	-	Depression risk ↑	[218]
	N-Nitrosodimethylamine	No change in glioma	[219]
	Diethylnitrosamine	Probability of hepatocarcinogenesis	[220]

↑: increased, ↓: decreased, LDL: low-density lipoprotein, ACE: angiotensin-converting enzyme, kDa: kilodalton, PAF-AH: platelet-activating factor acetulhydrolase, Gln Tyr-Pro: Glycine Tyrosine-Proline.

4. Fermented Vegetables and Fruits

Fruits and vegetables have important health effects due to their contents of fiber, vitamins, minerals, phenolic compounds (flavonoids, sulfur compounds, phytoestrogens, and monoterpenes), and bioactive peptides [221]. Their consumption can contribute to the prevention of many chronic diseases such as diabetes, cardiovascular diseases, and cancer [222,223]. It has been reported that the daily consumption of five servings of vegetables and fruits can reduce mortality in diseases [224]. Another way of consuming vegetables and fruits is in their fermented form. Resulting from the lactic acid fermentation of vegetables such as cucumbers, cabbages, capers, carrots, and tomatoes, different products such as kimchi, pickles, turnips, Pak-Gard-Dong, and Dhamuoi are obtained [31,225]. In addition, fermentation has recently been emphasized for the utilization of waste and by-products of vegetables and fruits (pineapple peel, orange peel, mango seed, etc.) [226].

As a result of fermentation, the riddance of anti-nutritional factors; the formation of metabolites with positive effects (bioactive peptides and exopolysaccharides); the improvement in bioavailability through the hydrolysis of polymers (esters of phenolic compounds); increased vitamins, minerals, and phenolic compounds; and the presence of bacteria with probiotic properties and prebiotic effects lead to positive effects on health [221].

4.1. Fermented Vegetables

Vegetables are a significant part of a healthy diet. Low vegetable consumption leads to negative health effects [227]. One of the ways vegetables are consumed is in their fermented form. Mostly lactic acid and alkaline fermentation occurs when vegetables are fermented [228]. Lactic acid fermentation can occur in vegetables when conditions are suitable (anaerobic conditions, suitable temperature, and humidity and salt concentrations). The products created as a result of vegetable fermentation vary between nations. For example, in Europe, sauerkraut is formed based on fermentation of cabbage, while in Korea, kimchi is formed as a result of fermentation of cabbage, green onions, etc. [229]. This section focuses on kimchi and sauerkraut, which have more scientific data on bioactive components and health effects.

A traditional Korean vegetable dish, kimchi (kimchi cabbage), is produced through the fermentation of radish, cucumber, and other vegetables by lactic acid bacteria [230]. Kimchi contains fiber, vitamins (ascorbic acid, etc.), minerals, 3-(4′-Hydroxyl-3′,5′-dimethoxyphenyl) propionic acid (HDMPPA), capsaicin, allyl compounds, isothiocyanate, indole compounds, and thiocyanate [231,232]. In another study using kimchi methanol extract (HDMPPA, quercetin, ascorbic acid, and capsaicin) and kimchi bioactive components, antioxidative (nuclear factor (erythroid-derived 2)-like 2 (Nrf2), SOD1, and GPx increased) and anti-inflammatory (NF-κB, inducible nitric oxide synthase (iNOS), and cyclooxygenase 2 (COX-2) decreased) activities were found to improve cognitive function in mice with amyloid beta (Aβ)25-35-induced Alzheimer's [233]. The active ingredient of kimchi, HDMPPA, has shown antioxidant, anti-inflammatory, and anti-atherosclerotic effects by lowering cholesterol; reducing cyclooxygenase-2 and ROS levels, lipid peroxidation, and lipid accumulation; and suppressing NF-κB, mitogen-activated protein kinase (MAPK), and phosphatidylinositol 3-kinase/protein kinase B (PI3K/Akt) signaling pathways and oxidative stress [234–237].

Bacteria isolated from kimchi have probiotic, anti-inflammatory, antioxidant, anti-obesity, antidiabetic, antimicrobial, and immune system effects [238–246] (Table 3). Not only the bacteria and metabolites derived from kimchi, but also the dietary consumption of kimchi have been shown to have positive effects [247]. Dietary kimchi consumption had a positive effect on C26 adenocarcinoma-induced cancer cachexia by inhibiting IL-6, inhibiting lipolysis, and increasing lipogenesis. It has also been shown to improve cachexia-induced muscle atrophy and reduce NF-κB, extracellular signal-regulated kinase $\frac{1}{2}$ (ERK $\frac{1}{2}$) activation, AKT, mammalian target of rapamycin (mTOR), and PI3K catabolism levels. It also decreased tumor size and tumor mass [247].

Table 3. Possible health effects of microorganisms isolated from some fermented vegetables.

Fermented Vegetables	Microorganism	Health Effects	Specific Effects	References
Kimchi				
	Weissella cibaria JW15	Anti-inflammatory	Proinflammatory cytokines (IL-1β, IL-6, TNF-α) ↓ Nitric oxide, prostaglandin E2, COX-2 ↓ IκB-α degradation and MAPKs, NF-κB activation ↓	[239]
	Lactiplantibacillus plantarum LB5 (LPLB5)	Antioxidant Anti-inflammatory Antibacterial	Proinflammatory cytokines (IL-1β, IL-6, TNF-α) ↓ Anti-inflammatory cytokines (IL-4, IL-10, IFN-γ) ↑ *Escherichia coli* O157:H7 *Pseudomonas aeruginosa*, *Listeria monocytogenes*, and *Staphylococcus aureus* ↓ ABTS radical scavenging activity ↑	[240]
	Lactiplantibacillus plantarum LRCC5314	Anti-inflammatory Anti-stress	TNF-α, IL-1β, IFN-γ, NO ↓ Cortisol concentration ↓ Adipocytes: TG concentration ↓ Adipogenesis-related genes, adiponectin, FAS, PPAR/γ, and C/EBPα, TNF-α, IL-6↓	[241]
	Lactiplantibacillus plantarum 200655	Neuroprotective	BDNF expression and concentration ↑ BDNF and tyrosine hydroxylase mRNA expression ↑ Apoptosis-related Bax/Bcl-2 ratio ↓ Caspase-3 activity ↓	[242]
	Lactobacillus sakei	Anti-obesity	Body fat mass ↓ Abdominal visceral fat↓ Waist circumference ↓	[243]
	Levilactobacillus brevis KU15153	Antioxidant Antimicrobial	*Escherichia coli* ATCC 25922, *L. monocytogenes* ATCC 15313, *S. Typhimurium* P99, and *S. aureus* KCCM 11335 ↓ DPPH radical scavenging activity ↑	[244]
	Levilactobacillus brevis KU15147	Antioxidant Immune enhancing	NO production, iNOS, TNF-α ↓ Radical scavenging activity of DPPH 38.56% Radical scavenging activity of ABTS 22.30% β-carotene bleaching inhibitory activity 23.82%	[245]
	Lactiplantibacillus plantarum LRCC5310 *Lactiplantibacillus plantarum* LRCC5314	Antidiabetic Anti-inflammatory	Serum insulin ↑ Fasting blood glucose ↓ Upregulating expression of GLUT 4 and adiponectin TNF-α, IL-6 ↓ Downregulation of Ccl2 and leptin expression Serum corticosterone ↓ mRNA levels of stress-related genes (Npy, Y2r) ↓	[246]

Table 3. *Cont.*

Fermented Vegetables	Microorganism	Health Effects	Specific Effects	References
Sauerkraut				
	Exopolysaccharides from *Lacticaseibacillus paracasei*	Antioxidant	Total antioxidant capacity 76.34% Hydrogen peroxide scavenging activity 68.65% DPPH free radical scavenging activity 60.31%	[248]
	Exopolysaccharides from *Lacticaseibacillus Casei*	Antioxidant Immunomodulatory	Showed dose-dependent effects: Hydrogen peroxide scavenging activity, DPPH free radical scavenging activity, superoxide radicals scavenging activity In macrophages: TNF-α, ROS production ↑ NF-κB p65 expression ↑ Expression of the c-jun protein ↑	[249]
	Lacticaseibacillus casei NA-2	Antibacterial	Inhibit the growth of *Bacillus cereus*, *Staphylococcus aureus*, *Escherichia coli* O157:H7, and *Salmonella typhimurium*	[250]
	Lactiplantibacillus plantarum	Antimicrobial	*Escherichia coli* O157 and *Shigella flexneri* CMCC(B) ↓	[251]

↑: increased, ↓: decreased, IL: interleukin, COX-2: cyclooxygenase 2, IFN: interferon, TNF-α: tumor necrosis factor alpha, MAPK: mitogen-activated protein kinases, ABTS: 2,2′-azino-bis(3-ehtylbenzothiazoline-6-sulfonate), NO: nitric oxide, NF-kB-: nuclear factor kappa B, IκB-α: IkappaB-alpha, iNOS: inducible nitric oxide synthase, BDNF: brain-derived neurotrophic factor, DPPH: 2,2-diphenyl-1-picrylhydrazyl, ROS: reactive oxygen species, GLUT-4: glucose transporter-4, PPAR/γ: peroxisome proliferator-activated receptor gamma, FAS: fatty acid synthase (lipogenic marker), NPY: neuropeptide Y, Y2R: neuropeptide Y receptor 2, CCL-2: C-C motif chemokine ligand 2, C/EBPα: CCAAT/enhancer binding protein alpha.

Kim et al. [252] showed that by altering the gut–brain axis, kimchi lowered obesity-related neuroinflammation. Kimchi reduced adipose tissue gain, serum free fatty acids, monocyte chemoattractant protein-1 (MCP-1), and TNF-α levels. It also reduced hypothalamic neuroinflammation and hypothalamic apoptotic protein expression. It was effective in the improvement of gout dysbiosis. Claudin-5, occludin, total short-chain fatty acids, acetate levels, and Akkermansia muciniphila colonization increased [252]. There are studies suggesting that kimchi may have a positive effect on colon adenoma, irritable bowel syndrome (IBS), and obesity through its effect on the microbiota composition [253–255]. In the case of IBS, kimchi consumption was reported to improve IBS symptoms by increasing fiber intake, controlling immunity, and inhibiting harmful intestinal enzyme activity (β-glucosidase and β-glucuronidase) [253]. Kimchi consumption may also affect diabetes by reducing insulin resistance and HbA1c; increasing insulin sensitivity, QUICKI, and β-cell function; and improving glucose tolerance [256,257]. According to all of this research, kimchi may benefit health due to its bioactive ingredients and probiotic microorganisms.

Sauerkraut is another fermented vegetable product that has been studied. Similar to kimchi, the bacteria isolated from sauerkraut, exopolysaccharides, and the bioactive compounds formed as a result of fermentation have shown antioxidant, antibacterial, and immunomodulatory effects [248]. It was also revealed that the *Lactiplantibacillus plantarum* strain isolated from sauerkraut may have a probiotic effect. *Lactiplantibacillus plantarum* S4-1 decreased the total cholesterol, triglyceride, and LDL-C contents [251]. The fermentation of sauerkraut resulted in the formation of ascorbigen, indole-3-carbinol, and the degradation of glucosinolates [258]. Ascorbigen may show antioxidant properties [259], while indole-3-carbinol can show antioxidant, anti-inflammatory, anti-obesity, antidiabetic, anti-atherosclerotic, anticancer, antihypertensive, and neuroprotective effects [260].

In adolescents and adults, high servings of raw/cooked cabbage/sauerkraut (>3 servings/week) were associated with a lower risk of breast cancer than low servings (≤1.5 servings per week) [261]. The consumption of pasteurized and unpasteurized sauerkraut improved the irritable bowel syndrome symptom severity score in individuals with irritable bowel syndrome, and the consumption of unfermented sauerkraut increased sauerkraut-associated LAB (*Lactiplantibacillus plantarum* and *Levilactobacillus brevis*) in feces [262].

Similar studies were carried out in fermented cucumber products with kimchi and sauerkraut. It was revealed that the bioactive peptides formed in lactic acid-fermented cucumber showed an ACE inhibitory effect [263]. When the change in the free amino acid profile of cucumbers as a result of fermentation was analyzed, the highest amino acids in fresh cucumbers were glutamine, GABA, arginine, citrulline, and asparagine. As a result of fermentation, the concentrations of leucine, isoleucine, methionine, lysine, phenylalanine, histidine, tyrosine, proline, and ornithine amino acids increased, while the glutamine, GABA, and aminoadipic acid concentrations decreased. Increasing the salt concentration (6%) increased the arginine concentration [264].

Plant-based foods contain micronutrients, macronutrients, and bioactive components as well as anti-nutrient components. These alleged anti-nutrients, which also include tannins, phytoestrogens, lectins, oxalates, and phytates, are thought to limit the absorption of important nutrients. However, it has also been suggested that it may have health-promoting effects [265]. It has been shown that lectin, phytate, tannin, and oxalate levels decrease as a result of fermentation compared to fresh produce [266–268]. As a result of lactic acid fermentation in the African nightshade plant, the tannin level decreased by 76.27–92.88%, and the oxalate level decreased by 77.33–90% [267]. Similarly, as a result of the lactic acid fermentation of white cabbage sprouts, the amounts of phytate, tannin, and oxalate decreased by 42, 66, and 53%, respectively [269].

4.2. Fermented Fruits

Fruits show positive effects on health due to their fiber, low energy density, vitamin/mineral (potassium, vitamin C, etc.), and phytochemical (polyphenols and carotenoids) contents [270]. There are studies evaluating the health effects of the fermentation of many fruits. Studies on fermentation in fruits such as apples, mangoes, papayas, lemons, and citrus have been carried out [271–275]. Fermented fruits can be made from fruits mainly based on lactic acid and acetic acid fermentation [276,277]. The use of lemon-fermented products resulting from the fermentation of lemon with *Lactobacillus* OPC1 decreased the total triglycerides and total cholesterol in the liver and regulated the lipid metabolism and gut microbiota in rats [275]. It was revealed that fermented papaya products may exhibit immunomodulatory, antioxidant, anticancer, anti-inflammatory, antidiabetic, and antidyslipidemic properties. Fermented papaya decreased pro-inflammatory cytokines and pro-oxidant components [271]. *Lactobacillus acidophilus* (BCRC14079)-fermented mango peel decreased Aβ accumulation, a neuronal protective product, by inhibiting oxidative stress and increasing BDNF expression in neural cells [273].

The fermentation of fruits using selected probiotic strains resulted in beneficial sensory and health effects. Yang et al. [276] found that the fermentation of apple juice with *Lactobacillus acidophilus*, *Lacticaseibacillus casei*, and *Lactiplantibacillus plantarum* bacteria increased the antioxidant and antibacterial capacities of apple juice. The total amino acid content and lactic acid content increased, while the total phenolic acid content decreased. The gallic acid, protocatechuic acid, and catechin concentrations increased with fermentation, but the total phenolic acid content decreased with the effect of storage [276]. As a result of the fermentation of cherry juice using nine *Lactobacillus* strains, *Lactobacillus acidophilus* 150 and *Limosilactobacillus fermentum* DT41 fermentations increased the polyphenol contents compared to the baseline [278]. Dragon fruit fermentation (*Lactiplantibacillus plantarum* FBS05) increased antibacterial and antioxidant activities [279]. Cirlini et al. [280] evaluated the organic acid content in elderberry fruit and found lactic acid as the main organic acid. Malic acid found in the fruit before fermentation decreased with fermentation, the amount of citric acid varied according to the bacteria, and tartaric acid was also found in fermented juices [280]. Kiwifruit juice fermentation (*Lactobacillus acidophilus* 85 (La85), *Lactobacillus helveticus* 76 (Lh76), and *Lactiplantibacillus plantarum* 90 (Lp90)) resulted in the formation of protocatechuic acid and catechins. Protocatechuic acid was the highest in Lh76 fermentation. These compounds have antioxidant effects. Caffeic acid was not detected as a result of fermentation [281]. Wu et al. [282] showed that the fermentation of blueberry and blackberry juices with *Lactiplantibacillus plantarum*, *Bifidobacterium bifidum*, and *Streptococcus thermophilus* resulted in a decrease in the anthocyanin levels. *Lactiplantibacillus plantarum* has a higher capacity to metabolize phenolic acids and organic acids. The highest lactic acid, syringic acid, and antioxidant capacity were exhibited as a result of fermentation with this microorganism [282]. The pH, acidity, total and reducing sugars, organic acid, and total phenolic contents of blueberry juice were significantly altered via probiotic fermentation, which had an effect on the juice's physicochemical, anti-inflammatory, antibacterial, and antidiabetic qualities [283].

Fruit vinegars are among other fermented products obtained from fruits. Two different fermentations can occur in vinegar: alcoholic and acetic acid fermentation. The microbiota leading to vinegar production varies. Acetic acid can be produced in large quantities by the *Acetobacter* and *Komagataeibacter* species [277]. Vinegar is obtained from many fruits such as grapes, apples, pomegranates, and blueberries. Polyphenols and organic acids, especially acetic acid, can show beneficial effects in fruit vinegar [284]. Bioactive components such as catechins, p-hydroxybenzoic acid, gallic acid, syringic acid, caffeic acid, p-coumaric acid, and chlorogenic acid have been provided in different kinds of vinegar [285,286]. Apple cider vinegar has been found to have hypocholesterolemic, antidiabetic [287–289], antioxidant [288,290], antimicrobial, anti-inflammatory [291], and anti-obesity effects [290] and improve cognitive function [292] reproductive function, and liver function [293]. Apple cider vinegar may exert antidiabetic effects by decreasing HOMA-IR, fasting blood glucose, HOMAβ, and OUICKI levels [287–289,293]. It may be effective in hypercholesterolemia by improving the total cholesterol, triglyceride, LDL cholesterol, total cholesterol/HDL-C, and LDL-C/HDL-C levels [287,289,290,293], and in non-alcoholic fatty liver disease by improving hepatic enzymes and reducing steatosis and inflammation in the liver [289,293]. It also has effects on neurodegeneration, ovulation, and obesity. The impact of apple cider vinegar on neurodegeneration was studied by Tripathi et al. [292]. As a result of vinegar consumption in mice, a decrease in the Morris water maze escape time, an increase in the time spent in the target quadrant, a decrease in acetylcholinesterase (AChE) and Malondialdehyde (MDA) levels, and an increase in glutathione (GSH) and SOD levels were found. Thanks to these effects, it was emphasized that it may be effective in dementia and Alzheimer's, and that this effect in apple cider vinegar would be related to its polyphenol, flavonoid, and organic acid contents [292]. Shams et al. [293] found that apple cider vinegar increases estradiol levels and may have a positive effect on ovarian reserve by increasing the number of primordial and primary follicles [293]. Vinegar may work in obesity by reducing body weight and food intake and delaying gastric emptying [290,294]. Intervention with different vinegars (pomegranate, prickly pear, or apple) decreased body weight; body weight gain; total visceral adipose tissue; mesenteric, epididymal, and perirenal fat; total cholesterol; plasma cardiac biomarkers (creatine kinase-MB isoenzyme (CK-MB), lactate dehydrogenase (LDH), alanine aminotransferase (ALT), and aspartate aminotransferase (AST)); plasma inflammatory markers (CRP, homocysteine, and fibrinogen); plasma and visceral adipose tissue leptin; and TNF-α levels and increased adiponectin levels in obese rats. All of these results suggest that obesity may affect cardiometabolic symptoms [295].

Another fermented fruit product is wine. The fermentation of grape in wine is a process that involves yeast and LAB acting together. Two common fermentation processes are emphasized: Alcoholic fermentation with yeasts, and malolactic fermentation occurs as a result of bacteria [296]. In the analysis of wine, catechins, p-coumaric acid, resveratrol, rutin, quercetin, myricetin, anthocyanin, tannins, flavan-3-ol, and phenolic acids (caffeic acid, ellagic acid, syringic acids, 2.5-dihydroxybenzoic acid, vanillic acid, and ferulic acid) are found [297–299]. There is a significant relationship between the polyphenol content and antioxidant activity in wines [297]. Other compounds formed as a result of fermentation in red wine are melatonin [300,301] and hydroxytyrosol [297,302]. Red wine polyphenols have antioxidant [303–305], antibacterial [306], anti-inflammation, anticancer [307–313], antidiabetic [308], antithrombotic, antidepressant [314,315], and neuroprotective effects [309]; are involved in the regulation of bone mineral density [316], microbiota modulation [305,310,317], and micro RNA regulation [308]; effect adipose tissue, hypocholesterolemia [318], and the regulation of endothelial function [319]; and have anti-obesity effects [320–322] (Figure 2). In addition, polyphenols have also shown positive effects on ulcerative colitis through microbiota modulation (*Akkermansia* increase), anti-inflammatory effects, the inhibition of the PI3K/Akt pathway and the hypoxia-inducible factor-1 (HIF-1α)- T helper 17 (Th17) pathway, and the reduction in vascular endothelial growth factor A (VEGFA) [323–325].

Melatonin, one of the other molecules in red wine, has anti-inflammatory, anti-inflammation, immunomodulatory, antioxidant, antiapoptotic, maternal/fetal health, cardiovascular, neuroinflammation, and respiratory health effects [326–329]. Hydroxytyrosol may be effective in cardiovascular disease (CVD), Parkinson's disease, Alzheimer's disease, diabetes, metabolic syndrome, cancer, and osteoporosis with the enhancement of AMP-activated protein kinase (AMPK), Sirtuin 1 (SIRT-1) signaling pathways, antioxidant and anti-inflammatory effects, decreased mitochondrial dysfunction, increased epigenetic regulation, and anticancer and anti-hypocholesterolemic effects [330–333].

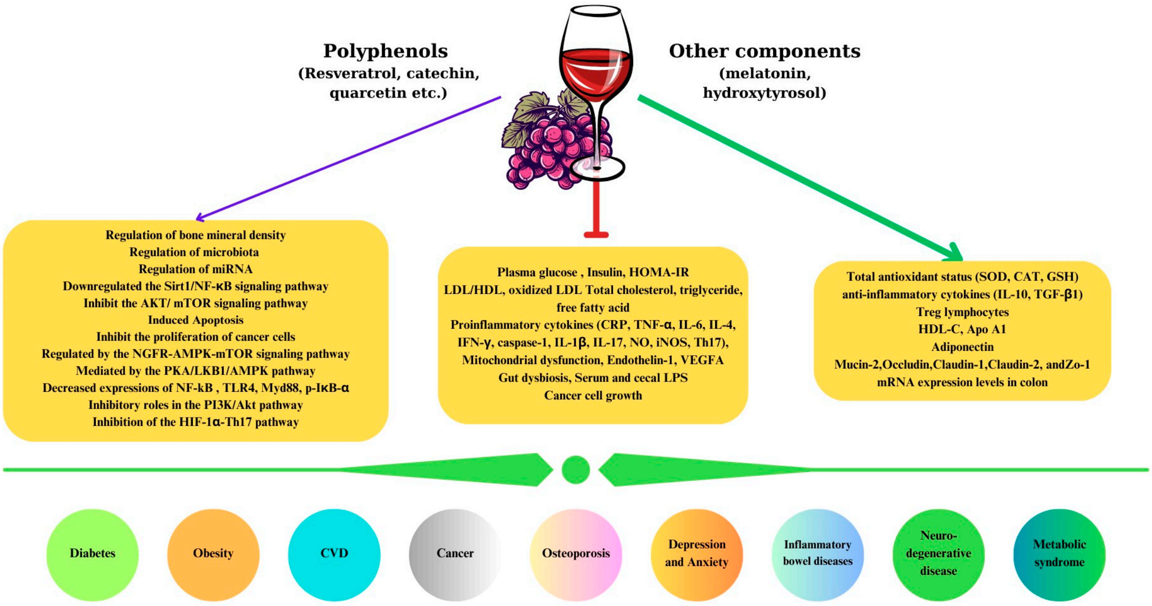

Figure 2. Health effects of red wine components. Red line: suppressive effect, green line: increase, purple line: another effect, miRNA: micro RNA, Sirt 1: Sirtuin 1, NF-kB: nuclear factor kappa B, NGFR: nerve growth factor receptor, AMPK: AMP-activated protein kinase, mTOR: mammalian target of rapamycin, PKA: protein kinase A, LKB1: liver kinase B1, MyD88: myeloid differentiation protein 88, TLR4: Toll-like receptor 4, p-IkB-α: phospho-IkappaB-alpha, PI3K/Akt: phosphatidylinositol 3-kinase/protein kinase B, HIF-1α: hypoxia-inducible factor-1, Th17: T helper 17, HOMA-IR: homeostasis model assessment of insulin resistance, iNOS: inducible nitric oxide synthase, IFN-γ: interferon gamma, TNF-α: tumor necrosis factor alpha, IL: interleukin, CRP: C-reactive protein, NO: nitric oxide, LDL: low-density lipoprotein, HDL-C: high-density lipoprotein cholesterol, VEGFA: vascular endothelial growth factor A, LPS: lipopolysaccharides, GSH: glutathione, SOD: superoxide dismutase, CAT: catalase, TGF-β1: transforming growth factor beta, Apo A1: apoprotein A1, CVD: cardiovascular disease.

5. Fermented Legumes

Plants of the Leguminosae family make up legumes. Peas, chickpeas, lentils, soybeans, and peas are examples of edible legumes [334]. Because of the important and nourishing bioactive compounds that legumes contain, they are essential for human nutrition [335]. They are all rich in protein, fat, carbohydrate, and minerals [334,336]. Additionally, they have a lot of fiber, vitamins from the B group, and useful phytochemicals with biological effects [335]. Galactooligosaccharides, lectins, saponins, and tannins are examples of readily accessible non-nutrient molecules that are common sources of protease inhibitors [337]. They are significant sources of isoflavones with estrogen-like properties and effects on calcium [338].

Due to the inclusion of non-nutrient components, legumes have a limited potential to be digested and bioavailable. It is suggested to use soaking, boiling, or fermentation to improve digestion and bioavailability. Thus, especially with fermentation, non-nutritious foods are changed into substances with nutritional value [339]. Antioxidant chemicals produced by the fermentation of soybeans include furanones, peptides, 3-hydroxyanthranilic acid, and melanoidins. Additionally, bioactive substances with anti-inflammatory effects include isoflavone, butyric acid, 2S albumin, α-linolenic acid, soy sauce polysaccharides, and glycones [340]. The fermentation process uses microorganisms to catalyze metabolic reactions and produce bioactive chemicals [341]. A traditional Korean dish, *cheonggukjang*, is produced in the wake of the fermentation of soybeans. Bioactive compounds not found in raw soybeans are produced during fermentation as a result of isoflavones such as phenolic acids, genistein, phytic acids, saponins, daidzein, and trypsin inhibitors [342,343].

Legumes are fermented using starter cultures composed of lactic acid bacteria. Examples of lactic acid bacteria include *Lactiplantibacillus plantarum* subsp. *Plantarum*, *Streptococcus thermophilus*, *Leuconostoc mesenteroides Lactobacillus acidophilus*, and *Lactobacillus delbrueckii* ssp. *bulgaricus Lacticaseibacillus casei*. In fermented legumes, these bacteria both perform fermentation and provide a source of probiotics [344]. The most significant fermented legumes employed in soy products are the bacteria of lactic acid, which are the starting bacteria used for the occurrence of soy milk and tofu [345]. Fermented soybeans contain *Bacillus* species as well the bacteria of lactic acid, and *Bacillus* genome sequences have been discovered in these foods [346].

There are many products made from fermented legumes. *Natto*, fermented soy milk, and *tempeh* have been a part of traditional Asian meals for generations, but they are now available for consumption all over the world [347]. *Miso*, a Japanese fermented delicacy made from the *Aspergillus oryza* mold of soybeans, is one of these fermented legume foods [348]. Another fermented soy substance called *jang* is a common Korean food. Numerous common yeast species, including *Debaryomyces hansenii*, *Hyphopichia burtonii*, and *Jang Saccharomycopsis fibuligera*, are abundant there [349]. *Bacillus* spp. species are discovered. The following kinds of bacteria are involved in the fermentation process: *Bacillus fusiformis Bacillus sphaericus*, *Bacillus amyloliquefaciens*, *Bacillus megaterium*, *Bacillus licheniformis Bacillus cereus*, *Bacillus badius*, and *Bacillus pumilus* [350]. *Ugba*, a traditional food made at home in Africa, can be counted among the fermented legumes [351]. *Pediococcus pentosaceus* and *Pichia kudriavzevii* TY1322 are isolated in Swedish fermented legume beverages. While the TY1322 of these species is effective in reducing phytates, it is predicted that it can be put to use as a starter culture in various legume fermentations [352].

Fermentation improves digestibility and produces new bioactive chemicals that are helpful to health. It has links to cancer, diabetes, inflammation, antioxidants, and diabetes [353]. The health-protective molecule, GABA, which rises with fermentation, is a substance [354]. It has an impact on enhancing cell viability and preventing oxidative damage [355]. One of the legumes that receives a lot of attention globally is soybean, which, along with its fermentation, has a regulating effect on the stool microbiota [356]. Increases in the catalase, superoxide dismutase, and glutathione peroxidase levels, along with a decrease in reactive oxygen species and pro-inflammatory cytokines (NF-κB, IL-β, COX-2, and TNF-α), give fermented soy products anti-inflammatory effects [357]. Additionally, it affects vital enzymes that are part of the hypoglycemic processes, including α-amylase and α-glucosidase [358]. The primary bioactive ingredient in fermented soybeans, daizein, has been linked to diseases such insulin resistance, obesity, and dyslipidemia [359]. Table 4 provides an overview of the health benefits of fermented legumes.

Table 4. Effects of fermented legumes and certain bioactive compounds on health.

Fermented Foods	Specific Foods	Certain Bioactive Compounds	Effects of Health	References
Kidney beans	White and dark kidney beans	-	Cecal short-chain fatty acid levels (acetate, butyrate, and propionate), colon crypt height, and MUC1 and Relmβ mRNA expression ↑ Genes of TLR4, MUC1-3, Relmβ ↑ Expressions of IL-6, IFNγ, IL-1β, MCP-1, and TNFα ↓ Levels of serum for IL-17A, TNFα, IL-6, IL-1β, and IFNγ ↓	[360]
	Kidney bean fermented broth	-	With this diet, level of blood lipids (ALT, AST, TG) in hyperlipidemia ↓ With this diet, serum HDL in hyperlipidemia ↑ *Firmicutes*/*Bacterioidetes* ratio and pathogenic bacteria ↓ Beneficial bacteria ↑	[361]
Soybean	Fermented soybean dried extracts	Isoflavin β	12-O-tetradecanoylphorbol-13-acetate (TPA-)-induced biochemical alterations in skin ↓ GSH depletion ↓	[362]
	Fermented soybean paste	Histamine Tyramine	Increased hepatic expression of IL-1β and PARP-1 ↓ Elevated blood plasma levels of MAO-A, AST/ALT, and CRP ↓	[363]
	Fermented soybean products	-	IgE immunoreactivity ↓	[364]
	Fermented mung bean Fermented soybean	-	Having cytotoxicity activities opposite to breast cancer MCF-7 cells by arresting the G0/G1 phase, followed by apoptosis Vaibility and the proliferation of splenocyte ↑ Levels of serum for IL-2 and IFN-γ ↑	[365]
	Fermented soybean	Aqueous extract of Hawaijar	Glucose uptake, G6P production, and expressions of pPI3K, pAKT, pAMPK, and GLUT4 ↑	[366]
	Fermented soybean	Isoflavone (genistein and daidzein)	Level of progesterone ↑	[367]
	Alcohol-fermented soybean	-	p38, iNOS mRNA, JNK, and TNF-α in mouse peritoneal macrophages ↑	[368]

Table 4. *Cont.*

Fermented Foods	Specific Foods	Certain Bioactive Compounds	Effects of Health	References
	Soybean fermented by *Lacticaseibacillus paracasei* TK1501	Lipoteichoic acid (LTA) Peptidoglycan (PGN)	Via lipoteichoic acid (LTA): Serum IL-4 and colonic TGF-β1 expression ↑, serum IL-1β and colonic IFN-γ expression ↓, intestinal inflammation ↓, mRNA levels of MUC2 ↑ Via peptidoglycan (PGN): Serum TNF-α and colonic IFN-γ ↓, colonic TGF-β1 expression ↑, mRNA levels of MUC2 ↑	[369]
	Soybean fermented by *Bacillus subtilis*	Menaquinone-7, daidzin, genistein, glycitin, and nattokinase	AChE activity within hippocampus ↑ Protein carbonyl contents in hippocampus ↓ Activity of reduced glutathione, catalase, superoxide dismutase in hippocampus ↑	[370]
	Black soybean fermented by *Bacillus subtilis*	-	Expression of aging biomarkers (hepatic p16INK4A and GLB1) ↓ Hepatic 8-hydoxy-2′-deoxyguanosine (8-oxodG) ↓ Hepatic levels of IL-6, MCP-1, and IL-10 levels in elder mice ↓ Beneficial microbiomes (*Alistipes*, *Anaeroplasma*, *Coriobacteriaceae* UCG002, and *Parvibacter* spp.) ↑	[371]
	Black soybean and fermented black soybean broth	-	Antioxidative effect by inhibiting power and ferrous ion chelating ↑ Detroit 551 cell viability ↑	[372]
	Fermented soy permeate	Isoflavones and α-galactooligosaccharides	Muscle glycogen content ↑	[373]
	Chungkookjang	Genistin Daidzein	DNA fragmentation ↓ Viability of splenocytes and thymocytes ↑ Apoptosis of splenocytes and thymocytes ↓	[374]
	Cheonggukjang	Intact isoflavones (genistein, daidzein, and glycitein) Equol 7-glucuronide Genistein, 3-hydroxygenistein, and 4′-sulfate	Intact isoflavones (genistein, daidzein, glycitein), 3-hydroxygenistein, genistein 4′-sulfate, and equol 7-glucuronide promote osteoblastogenesis via increased ALP activity, 3-hydroxygenistein inhibits osteoclast formation via decreased bone resorption activity	[375]
	Cheonggukjang	-	NF-kB and MAPK activation, IL-4 mRNA expression, IgE expression, and IL-31 mRNA expression in atopic dermatitis ↓	[376]
	Doenjang *Cheonggukjang*	-	Activation of redox-sensitive NF-kB ↓ iNOs levels, COX-2 ↓	[377]

Table 4. *Cont.*

Fermented Foods	Specific Foods	Certain Bioactive Compounds	Effects of Health	References
	Doenjang *Cheonggukjang*	-	Th1-mediated immune responses ↑ Level of IFN-γ ↑ Level of IL-4 ↓ Resistance to *Listeria monocytogenes* infection ↑	[378]
	Doenjang	-	Fecal lipopolysaccharide levels ↓ The amount of *Ruminococcaceae*, *Bifidobacteria*, *Lachnospiraceae*, and *Firmicutes* ↓ The amount of *Odoribacter_f* and *Bacterioidetes* ↑ β-glucuronidase and NF-kB activity ↓ TNF- α expression ↓ IL-10 expression ↑ Occludin ↑	[379]
	Cheonggukjang (*natto*)	Nattokinase	Digestion of fibrin ↑ Digestion of plasmin substrate (H-D-Val-Leu-Lys-Pna (s-2251)) ↑	[380]
	Natto	Natto extract (Heated-natto extract or Unheated-natto extract)	Heated-natto extract, degradation of Glycoprotein D of BHV-1 Degradation of SARS-CoV-2 receptor-binding domain Unheated-natto extract, inhibition of anti-BHV-1 activity by serine protease inhibitor	[381]
	Natto	Vitamin K Phytoestrogens	Vitamin K, bone health ↑ Phytoestrogens, menopausal disorder, osteoporosis, breast cancer risk ↓	[382]
	Natto	Vitamin K2	Maintaining bone stiffness	[383]
	Natto	-	In women aged under 60 years, dementia risk ↓	[384]
	Miso	Lipopolysaccharide- neutralizing protein	PGD2 production via macrophage cells ↓	[385]
	Fermented soybeans	C-miso (a) S_{10}-miso (b) S_9O_1-miso (c)	Antioxidant effects: For unheated forms: a > b > c For heated forms: a > b > c Antimutagenicity effects: For unheated forms: a = b > c For heated forms: a > b > c	[386]
	Miso soup, fermented soybeans, *houba-miso*	Isoflavone	Hot flush severity↓	[387]
	Miso soup, *natto*, and soybeans	-	Attenuated arterial stiffness via brachial–ankle pulse wave velocity ↓	[388]
	Miso and *natto*	Isoflavones	Blood pressure ↓	[389]
	Low-salt O-miso	-	Serum cholesterol ↓ Serum and liver TBARS value ↓ Serum GSH-Px and hepatic catalase ↑	[390]

Table 4. *Cont.*

Fermented Foods	Specific Foods	Certain Bioactive Compounds	Effects of Health	References
	Soybean *koji*	-	Increase in mRNA expression incident to lipogenic genes and weightiness of white adipose tissue ↓ Serum levels of triglyceride, low-density lipoprotein cholesterol, and total cholesterol ↓ Serum levels of high-density lipoprotein cholesterol ↑ Lipid accumulation in the white adipose tissue and liver ↓	[391]
	Soy *Meju*	*Tetragenococcus halophilus* EFEL7002	May adhere to Caco-2 cells Protective effect against H_2O_2-induced epithelial damage Antioxidant activity in human intestine Anti-inflammatory effects by inhibiting NO synthase within RAW 264.7 cells mRNA expressions of IL-6, IL-10, and IL-1β ↑	[392]
	Thua-Nao	Daidzein Genistein	MCF-7 and HEK293 cancer cell growth ↓ Amount of viable HepG2 cells ↓	[393]
	Fermented soy beverage	-	Levels of LDL cholesterol and total cholesterol ↓	[394]
Soy milk	Soy milk powder	Isoflavones 3-HAA	TG accumulation and total cholesterol within liver under oxidative stress ↓	[395]
	Fermented soy milk via *Enterococcus faecalis* VB43	Reduction in conglycinin (7S) and glycinin (11S)	*Enterococcus faecalis* VB43-fermented soy milk may cause less severe allergy reactions in susceptible people	[396]
Red bean	Tempeh (fermented red bean via *Rhizopus* and *Lactobacillus*)	Anthocyanin and GABA	ROS, pCREB, and iNOS expressions ↓ BDNF expression ↑	[397]

↑: increased, ↓: decreased, MUC1: colonic mucin 1, MUC2: colonic mucin 2, CREB: cAMP response element binding protein, MUC3: colonic mucin 3, Relmβ: resistin-like molecule beta, TLR4: Toll-like receptor 4, IFN-γ: interferon-γ, AST: aspartate aminotransferase, TG: triglyceride, NF- kB: nuclear factor kB, HDL: high-density lipoprotein, GSH: glutathione, PARP-1: poly (ADP-ribose) polymerase 1, MAO-A: monoamine oxidase A, CRP: C-reactive protein, IL-: interleukin-, TGF-β1: transforming growth factor beta 1, AChE: acetylcholinesterase, SOD: superoxide dismutase, GLB1: galactosidase beta-1, ALP: alkaline phosphatase, MAPK: mitogen-activated protein kinase, MCP-1: monocyte chemoattractant protein-1, Th1: T helper type 1, iNOS: inducible nitric oxide synthase, PGD2: prostaglandin D2, TBARS: thiobarbituric acid reactive substances, H_2O_2: hydrogen peroxide, LDL: low-density lipoprotein, ROS: reactive oxygen species, NO: nitric oxide, cAMP: cyclic adenosine monophosphate, BDNF: brain-derived neurotrophic factor, 3-HAA: 3-hydroxyanthranilic acid, JNK: c-Jun N-terminal kinase, TNF-α: tumor necrosis factor-α, ALT: alanine aminotransferase.

6. Fermented Cereals

Cereals are edible grains or seeds from the Gramineae family. The group of grains includes rye, oats, barley, maize, triticale, millet, and sorghum. The two most significant cereal crops worldwide are wheat and rice [398]. Many people consume rice as a fundamental food, especially in portions of Asia, Latin America, and Africa [399]. Rice is one of the most widely consumed grains. With regard to minerals, dietary fiber, zinc, protein, lipids, complex vitamins of vitamin B, and vitamin E, cereals play significant roles in our nutrition. However, beneficial phytochemicals such phytic acid, phenolic compounds, and gamma-oryzanol have significant roles [400].

Cereals are also best processed through fermentation, a time-honored technique [401]. The fermenting method is becoming more and more popular due to the growing interest in dietary consumption and nutrition [402]. In Africa, foods made from fermented grains are used as staple foods [403]. Among the most common grains utilized in fermentation are wheat, corn, teff, sorghum, and millet [404]. It is possible to give examples of regionally fermented grain-based dishes like *Mawè* and *Ogi* [405]. Utilizing *Streptococcus thermophilus* during fermentation enhances texture and flavor while also increasing volatile chemicals (diacetyl and acetoin) [406]. The fermentation process decreases the moisture and carbohydrate contents while increasing the total protein and ash contents in corn beverages fermented with *Lactobacillus bulgaricus* and *Streptococcus thermophilus* [407]. The traditional Peruvian drink, "*Chicha de siete semillas*", is fermented using *Streptococcus macedonicus* and *Leuconoctoc lactis*. This fermented cuisine contains a lot of GABAs and is made from grains, pseudograins, and legumes. *Streptococcus macedonicus* is typically chosen for maize preparation if corn is to be used as a grain source [408]. *Amahewu* is another type of fermented grain. *Amahewu* is a fermented oatmeal or beverage made from corn that is mostly enjoyed in South Africa. Depending on the graft type, the type of maize, and the present fermentation circumstances, *Amahewu*'s nutritional and sensory qualities may change [409]. *Bacillus*, *Arthrobacter*, *Lactobacillus*, *Ilyobacter*, *Clostridium*, and *Lactococcus* are only a few of the numerous and distinct microbial species that are abundant in the fermented rice-based beverage, *Chokot*, made in India [410]. A popular fermented beverage made from grains called *boza* is enjoyed in many Balkan nations. *Boza* is rich in *lactic acid bacteria*, including *Pediococcus parvulus*, *Lactobacillus parabuchneri*, *Limosilolactobacillus fermentum*, *Lactobacillus coryniformis*, and *Lactobacillus buchneri*. Other types of microbiota found in *boza*, however, include yeasts such *Pichia fermentans*, *Pichia norvegensis*, *Pichia guilliermondii*, and *Torulaspora* spp. [411]. *Boza*, a grain-based food, is likewise high in putrescine, spermidine, and tyramine [412]. It has health impacts in addition to enhancing the functional and nutritive value of fermented grain products and satisfying the demands of contemporary consumers for health-promoting products [413]. Table 5 contains a list of the consequences of fermented cereals on health.

Table 5. Effects of fermented cereals and certain bioactive compounds on health.

Fermented Foods	Certain Bioactive Compounds	Effects of Health	References
Jalebi	*Lapidilactobacillus bayanensis* *Bacillota* *Candida glabrata* *Lapidilactobacillus dextrinicus* *Pichia kudriavzevii* *Pediococcus stilesii* *Wickerhamomyces anomalus* *Gluconobacter japonicus*	Probiotic functions	[414]
Ogi	Combination with tigernuts and sesame seeds	Antioxidant activity ↑ α-glucosidase enzyme inhibitory activity ↑	[415]
Borde	Lactic acid bacteria strains (WS07, AM15, and AM20) Yeast strains (WS15, AA19, AM18, and AM23)	Cholesterol lowering ability ↑	[416]
Kunu-zaki	*Limosilactobacillus fermentum* *Leuconostoc citreum* *Weissella confusa*	Anti-fungal activity	[417]
Kounou	Flavonoids Polyphenols	Antioxidant activity	[418]

Table 5. *Cont.*

Fermented Foods	Certain Bioactive Compounds	Effects of Health	References
Bozai (*Boza*)	Bacteriocin LF-BZ532	Antimicrobial spectrum opposite to both Gram-positive and Gram-negative bacteria	[419]
Fermented cereal pastes	*Lactobacillus*	Serum and hepatic cholesterol levels ↓ Ratio of LDL-C to HDL-C ↓ Hepatic LDL receptor and CYP7A1 gene expressions ↑ Activity of superoxide dismutase ↑ Count of coliform and *Clostridium perfringens* in feces ↓	[420]
Kunu-zaki *Ogi*	*Lactiplantibacillus plantarum* ULAG11 *Lactiplantibacillus plantarum* ULAG24	Exclusion of *Salmonella enterica* LT2 via adherence of *L. plantarum* ULAG24 to HT29 cell line ↑ Stimulation of IFNγ and IL-10 via *L. plantarum* ULAG24 ↑ Expression of amylase via *L. plantarum* ULAG11 ↑	[421]
Fermented quinoa and wheat	*Bifidobacterium breve* *Bifidobacterium longum*	ACE-inhibition activities ↑ Antioxidant activities ↑ Cytotoxicity activities against Caco-2 cell line ↑	[422]
Fermented barley	*Lactobacillus*	Hepatic superoxide dismutase activity ↑ Improvement in intestinal microbiota dysbiosis ↑ Bacteroidetes ↑ Firmicutes/Bacteroidetes ratio ↓	[423]
Fermented quinoa flour	*Pleurotus ostreatus*	ACE-I inhibitory ↑	[424]
Togwa	*Lactic acid*	*Campylobacter* spp., *Salmonella* spp., *ETEC* and *Shigella* spp. ↓	[425]
Fermented rye	-	*Romboutsia*↑ *Bilophila*↓ Fecal acetic acid ↑	[426]
Fermented Tartary buckwheat	*Monascus purpureus*	Liver glycogen content ↑ SOD activity ↑ CAT activity ↑	[427]
Fermented pearl millet flour	*Aspergillus sojae*	Antioxidant activity ↑ DNA damage protection activity ↑	[428]
Fermented sorghum	*Pediococcus acidilactici* OHFR1	*Muribaculum*, *Parabacteroides*, and *Phocaeicola* ↑ *Oscillibcater*, *Acetatifactor*, and *Acetivibrio*↓	[429]
Bhaati Jaanr	-	Proliferation of colon adenocarcinoma cell lines (HT29 and SW480) ↓ Expression of IL-1β, COX-2, IL-6, and TNF-α ↓	[13]

↑: increased, ↓: decreased, LDL-C: low-density lipoprotein cholesterol, HDL-C: high-density lipoprotein cholesterol, CYP7A1: cholesterol-7α-hydroxylase, IL-: interleukin-, ACE: angiotensin-converting enzyme, ETEC: enterotoxigenic Esherichia coli, SOD: superoxide dismutase, CAT: catalase, DNA: deoxyribose nucleic acid, IFN-γ: interferon-γ, TNF-α: tumor necrosis factor-α.

7. The Other Side of Fermented Foods

Dairy products, vegetables and fruits, legumes, meats, and grains are among the fermentable food groups. Microorganisms that play roles in fermentation and the bioactive compounds released during fermentation have antioxidant, anti-fungal, and antidiabetes effects; are involved in the protection of cognitive function and the regulation of intestinal microbiota; and have anti-inflammatory, antihypertension, anticancer, and anti-obesity effects (Figure 3).

Although fermentation has positive impacts on health, another aspect of it needs to be examined. One of the aspects that should be emphasized is the biogenic amines contained in some fermented products. Biogenic amines are compounds that exist especially in fermented meat products and increase with fermentation [430]. Biogenic amines such as spermidine and cadaverine cause an increase in N-nitrosodimethylamine and N-nitrosopiperidine levels [431]. The nitrosamines belong to the carcinogen group. While the most prevalent forms of nitrosamines in meat are N-nitrosodimethylamine and N-nitrosopiperidine [432], the International Agency for Research on Cancer categorizes N-nitrosopiperidine as group 2B, while N-nitrosodimethylamine is classified as group 2A [433].

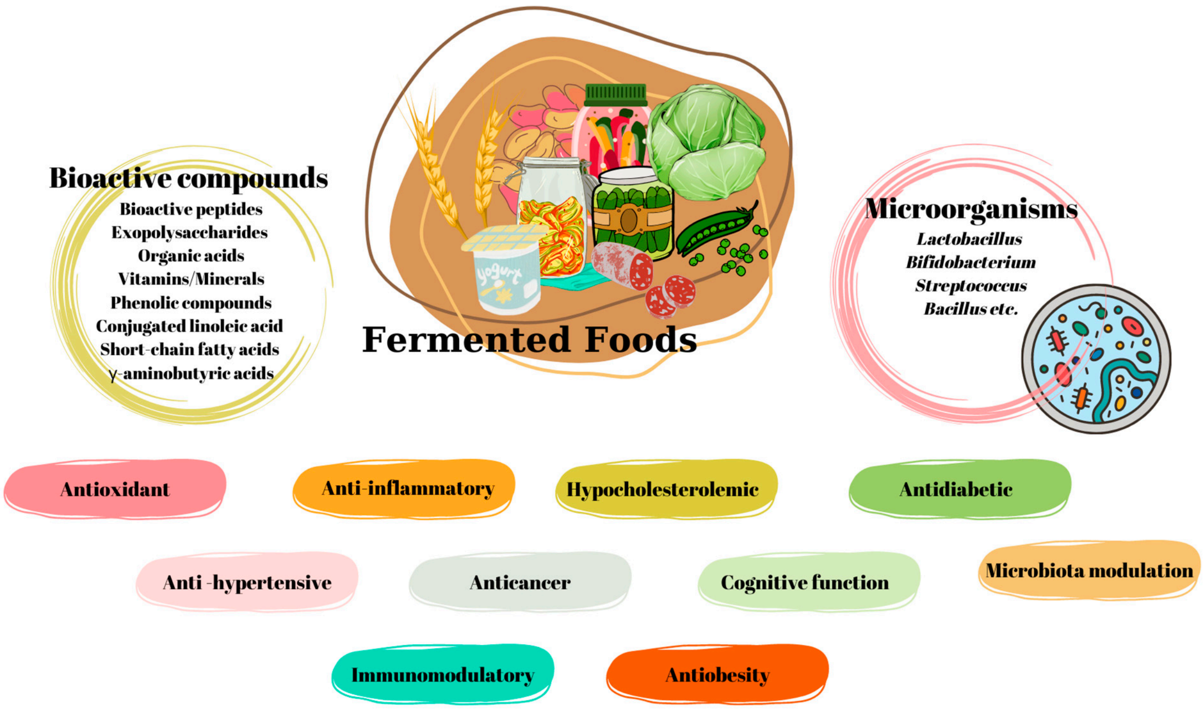

Figure 3. Schematic summary of the effects of fermented foods on health.

Another component found in fermented foods that has been linked to health is biogenic amines. Histamine, tyramine, putrescine, and cadaverine are the biogenic amines that are most frequently observed [434]. The bacterial decarboxylation of the appropriate amino acids using substrate-specific decarboxylase enzymes is the primary method used to create biogenic amines in food. For example, histamine is formed from the amino acid histidine via histidine decarboxylase, while cadaverine is formed from lysine [435]. They can occur in many fermented foods such as cheese, sauerkraut and another vegetables, soybean, meat, fish, beer, wine, etc. [434,435]. Biogenic amines have many roles in the body such as protein, hormone, and nucleic acid syntheses, blood pressure control, and the promotion of cell growth. However, excessive intake may have toxic effects. Many symptoms such as food poisoning, headache, and sweating can be seen [436]. Biogenic amine formation and an increase in the amount can be prevented by paying attention to the storage temperature of foods, packaging processes, natural components, and appropriate starter culture selection [437]. There are studies on starter cultures, especially in fermented foods. The use of *Bacillus polymyxa* as a starter culture during salted fish fermentation and *Lactobacillus plantarum* as a starter culture during miso fermentation reduced biogenic amines [438,439].

Another unhealthy compound that can be found in some fermented foods is salt. High salt consumption has negative health effects. It is therefore important to reduce salt consumption. However, reducing salt in fermented foods may pose a problem with regard to food safety, texture, and flavor [440]. While ensuring that this reduces salt intake, it may cause the development of pathogenic microorganisms. Reducing the salts used may result in increased yeast, *Enterobacteriaceae*, and microbial growths [441]. Microbial growth can occur due to the decrease in water activity. As a result of the increase in some microorganisms, the formation of biogenic amines and nitrosamines may increase [430,442–446]. In addition, there is an increase, especially in the NDMA type, due to the replacement of sodium salt with potassium salt [447]. There are different practices for reducing sodium salt in some traditional fermented foods to change the diffusion and dissolution state by improving the physical form of the sodium salt used. Vacuum curing technology, ultrasound technology, high pressure technology, and microwave technology are used to obtain low-sodium products [440].

The future growth of the fermented food sector is made possible by the lowering of sodium and nitrosamines in traditional fermented foods. Studies on fermented foods show heterogeneous characteristics. This makes it difficult to compile the studies on a fermented food and to make a general evaluation of the positive and negative properties of that fermented food. In addition, studies on the amounts of fermented foods consumed by people need to be increased. In this way, responses to the effects of the amounts of fermented foods consumed on humans can be evaluated.

The regulatory effects of many fermented foods on health are explained in this article. These foods have a large place in our daily diets. However, their "consumption amount" is not determined by legal regulations. However, the lack of production standards (industrial type, homemade type, etc.) of fermented foods will cause both difficulty and inability in achieving homogenization, especially in surveillance and determining microorganism species differences and by-products due to such microorganisms.

8. Conclusions

The earliest food processing technique to have developed alongside human civilization is fermentation. The foods not only stayed fresh for a very long time, but they also developed new sensory qualities like flavors and smells. With the development of the food sector, fermented goods are becoming more and more popular. Fermented foods fall into significant food groups in human nutrition. Food groups that can be fermented include dairy products, cereals, legumes, fruits and vegetables, meats, and grains. In addition to internationally popular fermented foods like kefir, yogurt, cheese, fruit vinegar, and wine, traditional fermented pickles like kimchi and sauerkraut are also referred to as "pickles". In addition, there are more regionally specific traditional fermented foods that can be pointed out including the following: meats such as *nham*; cereals such as *mawè*, *jalebi*, *borde*, *kunu-zaki*, *kounou*, *togwa*, *bhaati jaanr*, *ogi*, *chicha de siete semillas*, *amahewu*, *chokot*, and *boza*; and legumes such as *cheonggukjang*, *natto*, *miso*, *jang*, *ugba*, *doenjang*, *koji*, and *meju*. In the fermentation of foods, two significant components can be identified: (i) bioactive substances generated during fermentation and (ii) microorganisms involved during fermentation. Among the bioactive substances are organic acids, bioactive peptides, exopolysaccharides, conjugated linoleic acid, biogenic amines, isoflavones, phytoestrogens, nattokinase, and N-nitrosamines. Microorganisms, which are another factor in the realization of fermentation, come to the fore in different ways in different foods. Microorganisms such as *Lactobacillus*, *Bifidobacterium*, *Streptococcus*, and *Bacillus* species are regarded as probiotics in the fermentation process. Microorganisms that are efficient in the fermentation process and the bioactive substances they produce have impacts on health. Antidiabetes, anticancer, antioxidant, anti-inflammatory, antihypertension, and anti-fungal effects; the regulation of intestinal microbiota; the protection of cognitive function; and anti-obesity activities are just a few of fermented foods' effects. Along with the positive effects of microorganisms and bioactive compounds in fermented foods on health, studies should be increased to elucidate the mechanisms for the effects of these foods on health. Studies have generally been carried out on isolated bioactive compounds and/or microorganisms. However, it is substantial to increase studies that evaluate the intake of fermented foods as a complex, rather than as a single component in human nutrition, and their interactions with each other. In future studies, the amount and duration of fermented foods in human nutrition should be evaluated.

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