microorganisms

MDPI

Review

The Survival of Psychobiotics in Fermented Food and the Gastrointestinal Tract: A Review

Patrycja Cichońska *, Ewa Kowalska and Małgorzata Ziarno

Department of Food Technology and Assessment, Institute of Food Science, Warsaw University of Life Sciences-SGGW (WULS-SGGW), Nowoursynowska 159c St., 02-776 Warsaw, Poland; ewa_kowalska@sggw.edu.pl (E.K.); malgorzata_ziarno@sggw.edu.pl (M.Z.)
* Correspondence: patrycja_cichonska@sggw.edu.pl

Abstract: In recent years, scientists have been particularly interested in the gut–brain axis, as well as the impact of probiotics on the nervous system. This has led to the creation of the concept of psychobiotics. The present review describes the mechanisms of action of psychobiotics, their use in food products, and their viability and survival during gastrointestinal passage. Fermented foods have a high potential of delivering probiotic strains, including psychobiotic ones. However, it is important that the micro-organisms remain viable in concentrations ranging from about 10^6 to 10^9 CFU/mL during processing, storage, and digestion. Reports indicate that a wide variety of dairy and plant-based products can be effective carriers for psychobiotics. Nonetheless, bacterial viability is closely related to the type of food matrix and the micro-organism strain. Studies conducted in laboratory conditions have shown promising results in terms of the therapeutic properties and viability of probiotics. Because human research in this field is still limited, it is necessary to broaden our understanding of the survival of probiotic strains in the human digestive tract, their resistance to gastric and pancreatic enzymes, and their ability to colonize the microbiota.

Keywords: psychobiotics; probiotics; bacterial viability; fermentation; gastrointestinal passage; brain health; neurological disorders; gut–brain axis

Citation: Cichońska, P.; Kowalska, E.; Ziarno, M. The Survival of Psychobiotics in Fermented Food and the Gastrointestinal Tract: A Review. *Microorganisms* **2023**, *11*, 996. https://doi.org/10.3390/microorganisms11040996

Academic Editor: Flavia Indrio

Received: 25 March 2023
Revised: 4 April 2023
Accepted: 10 April 2023
Published: 11 April 2023

1. Introduction

In the modern era, maintaining physical as well as emotional well-being is a constant struggle that many people tend to overlook. We are currently confronted with a plethora of information on mental illness that results in tragedies and rising suicide rates. Mental health and physical health are closely inter-related. The most important aspect that has piqued scientists' interest in recent years is the gut–brain axis and, more specifically, the microbiota–gut–brain axis, because microbiota is the key element here [1]. The role of probiotic strains in alleviating mood disorders was first highlighted by an article published in the British Journal of Psychiatry in 1910. However, it was not until 1970 that scientific evidence became available when Bahr and his colleagues, based on their observation of piglets lacking microbiota, showed that the intestinal microbiota is in close communication with the brain, a distant topographic organ [2].

Probiotics allow for the modification of the function of intestinal microbiota. According to the latest FAO/WHO definition, probiotics are live microorganisms that, when administered in the right amount, have a beneficial effect on the health of the host [3]. The positive effect of probiotics on various types of digestive disorders was proven a long time ago, while recent data indicate that they also have an influence on the nervous system, immune system, hypothalamus, adrenal glands, or pituitary gland. Dinan et al. [4] proposed a definition of a psychobiotic that is merely a modification of the definition of a probiotic. According to this definition, psychobiotics are living organisms that, when administered in the right amount, have a beneficial effect in patients with mental or neurological diseases.

The central nervous system (CNS) is connected to the digestive system through the vagus nerve, the dorsal root ganglia of the spinal cord, and the autonomic nervous system of the intestines. The microbiota–gut–brain axis can act bidirectionally through hormones, cytokines, and bacterial metabolites secreted in the intestinal lumen. It has also been shown that the immunocompetence and neuroactivity of microbiota metabolites affect the structure and function of certain areas of the brain, such as the limbic system, which is responsible for emotions [5]. Studies that have been conducted so far clearly confirm the role of the vagus nerve, as well as the entire enteral nervous system, in the process of mood regulation. They have also revealed the relationship between intestinal dysbiosis and mental health deterioration. Dysbiosis, which refers to the imbalance between beneficial and pathogenic bacterial strains, affects the conversion of tryptophan to 5-hydroxytryptamine (serotonin), a neurotransmitter responsible for mood modulation and mental state. Insufficient serotonin synthesis may be one of the causes of mental disorders [6].

This paper describes the mechanisms of action of psychobiotics, their use in food products, and their viability and survival during gastrointestinal passage.

2. Characteristics of Psychobiotics and Their Impact on Human Health

Intestinal micro-organisms indirectly affect the processes controlled by the CNS. This is achieved by modulating the immune system, the hypothalamic–pituitary–adrenal axis, neurotransmitters, and the synthesis of metabolites such as short-chain fatty acids (SCFAs), i.e., butyrate, acetate, and propionate. Data indicate that SCFAs greatly influence the microbiota–gut–brain axis and the physiology of the brain itself, due to their ability to penetrate the blood–brain barrier. They are also critical for the proper functioning of the intestinal barrier and maintaining its integrity [7]. The graphical presentation of the bidirectionality of the gut–brain axis is shown in Figure 1.

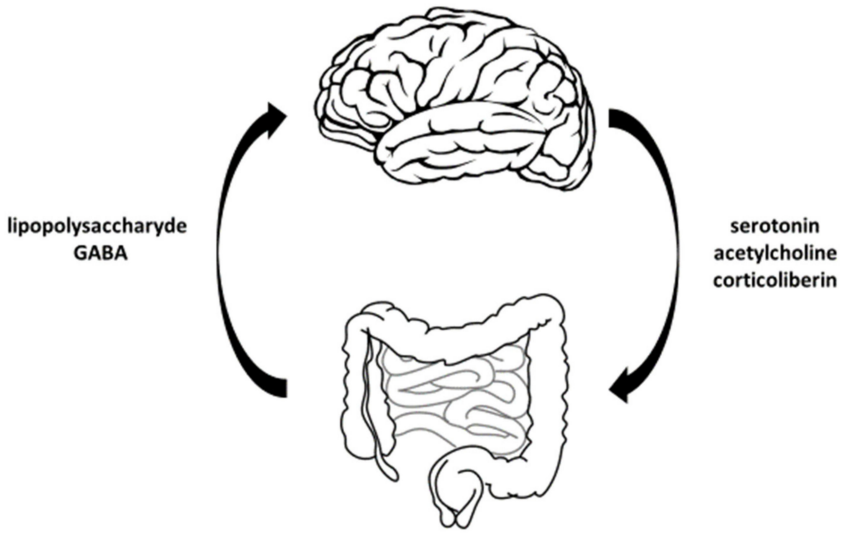

Figure 1. Graphical presentation of the bidirectionality of the gut–brain axis.

The current circumstances are not unfavorable and do not support maintaining good health. Some of the factors worsening the health of society are processed foods with large amounts of sugar, air pollution, the availability of stimulants, and a sedentary lifestyle. This article, however, focuses on another important factor—rapid deterioration of intestinal health and functioning. Intestines are home to superorganisms, i.e., the intestinal microbiota, which is a collection of micro-organisms, including bacteria, archaea, viruses, and eukaryotic organisms. The composition and functions of the intestinal microbiota affect the whole body as well as the work of each system [8]. For instance, these organisms play a key role in the process of digestion and deriving energy from food, as well as fermenting undigested food residues. The main source of energy for the intestinal microbiota is plant fiber, thanks to which the bacteria can produce metabolites, as well as mucus necessary

for the intestinal epithelium [9,10]. The intestinal microbiota is also responsible for the synthesis of vitamins, including those from group B and vitamin K [11]. Therefore, when the homeostasis of the intestinal microbiota is disturbed, a state of intestinal dysbiosis is established. This has been shown to be associated with inflammatory bowel diseases (IBDs), irritable bowel syndrome (IBS), and the over-growth of bacteria in the small intestine, as well as civilization diseases, including obesity, diabetes, and cancer [12,13]. Furthermore, research in the last decade clearly indicates a link between mental illnesses such as depression and the intestinal microbiota [14].

Psychobiotics not only modulate the neuroimmune axes but also affect cognitive processes such as memory, learning, and general behavior. This discovery has led to changes in the current paradigm of symbiosis between bacteria and the human body. According to recent reports, this relationship resembles commensalism rather than pure symbiosis [15].

A crucial aspect that should be mentioned when describing the mechanisms of action of psychobiotics is the structure of the nervous system. Microglia are a collection of non-neuronal cells belonging to the CNS, which constitute 5–20% of glial cells. A particularly important fact in the context of the influence of the intestinal microbiota on mental health is that microglial cells release cytokines and, to some extent, are responsible for activating the inflammatory response [16]. The intestinal microbiota plays a role here, as it affects the maturation and function of the microglia. Studies on "germ-free" animals have revealed a longer microglial development process. This proves the existence of a mutual relationship between the microbiota and microglia, depending on the stage of development and the time of colonization by micro-organisms. Unfortunately, it is still unclear which specific mechanisms mediate the influence of the intestinal microbiota on microglia [17]. It is presumed that the specific modulation of microglia may be achieved only with the help of certain intestinal bacterial strains. These are mostly strains that have been recognized so far as psychobiotic. The psychobiotic effects of some probiotic strains have been demonstrated in both animal and human studies. Table 1 summarizes the most recent scientific reports on the possible uses of psychobiotics.

Table 1. Potential psychobiotic effect of probiotic bacterial strains.

Bacterial Strain	Study Model	Potential Psychobiotic Effects	References
Lactiplantibacillus plantarum C29	humans with mild cognitive impairment	• improved combined cognitive functions	[18]
L. plantarum DR7	stressed adults	• improved cognitive and memory functions and enhanced the serotonin pathway	[19]
L. plantarum P8	stressed adults	• reduced scores of stress and anxiety; enhanced memory and cognitive traits	[20]
	stressed adults	• enhanced the diversity of neurotransmitter-synthesizing/consuming species-level genome bins and the levels of some predicted microbial neuroactive metabolites • reduced stress	[21]
L. plantarum PS128	mouse with 1-methyl-4-phenyl-1,2,3,6-tetrathydropyridine-induced Parkinson's disease	• inhibited neurodegenerative processes	[22]
	male children with autism spectrum disorder	• ameliorated opposition/defiance behaviors and improved the total score of The Swanson, Nolan, and Pelham-IV	[23]
	adult IT specialists	• improved self-perceived stress, overall job stress, job burden, cortisol level, general or psychological health, anxiety, depression, sleep disturbances, quality of life, and both positive and negative emotions	[24]
	patients with self-reported insomnia	• decreases in Beck Depression Inventory-II scores, fatigue levels, brainwave activity, and awakenings during the deep sleep stage	[25]

Table 1. *Cont.*

Bacterial Strain	Study Model	Potential Psychobiotic Effects	References
L. plantarum ATCC 8014™	Wistar rats	• reduced the number of dead cells and increased acetylcholine in the brains of rats with Alzheimer disease (AD)	[26]
	male Wistar rats	• ameliorated depression and anxiety-like behavior and cognitive performance • improved serum and brain oxidative stress markers • decreased oxidative stress in the hippocampus and amygdala	[27]
L. plantarum 299v	young adults under examination stress	• prohibited increased levels of the stress marker cortisol during the examination period	[28]
	patients with major depressive disorder (MDD)	• improvement in Attention and Perceptivity Test and in California Verbal Learning Test • decrease in kynurenine concentration	[29]
Limosilactobacillus reuteri DSM 17938	mice	• changed gut microbiota to modulate immune responses in murine experimental autoimmune encephalomyelitis	[30]
Lactobacillus helveticus CCFM1076	rats withvalproic acid-induced autism	• restored neurotransmitter homeostasis by improving the balance of the 5-hydroxytryptamine system in the peripheral and central nervous systems, thereby ameliorating autistic-like behaviors	[31]
L helveticus NS8	chronic stress rats	• improved chronic restraint stress-induced behavioral (anxiety and depression) and cognitive dysfunction	[32]
	rats with hyperammonemia	• reduced the level of inflammatory markers, decreased serotonin metabolism, restored cognitive function, and improved anxiety-like behavior	[33]
Lacticaseibacillus rhamnosus JB-1	mice	• reduced stress-induced corticosterone and anxiety- and depression-related behavior	[34]
	Wistar rats subjected to chronic unpredictable mild stress protocol	• mitigated anxiety • the level of brain metabolites was stable, with only the taurine level decreasing	[35]
L. rhamnosus GG	mice with induced obsessive-compulsive disorder (OCD)-like behavior	• attenuating OCD-like behaviors	[36]
	middle-aged and older adults	• improved cognitive performance because of improved total cognition score	[37]
	female mice	• protective effect on gut microbiota • relief of anxiety-like behavior in adult *L. rhamnosus* GG-colonized offspring	[38]
	drug-naive children and adolescents with a diagnosis of attention-deficit/hyperactivity disorder (ADHD)	• improvement in the PedsQL Child Self-Report Total Score	[39]
Lactobacillus gasseri CP2305	male university Ekiden runners	• prevented the stress-induced changes in the expression of genes related to mitochondrial functions	[40]
	young adults exposed to chronic stress	• reduced anxiety and sleep disturbance	[41]
	Japanese medical students	• improved sleep quality • prevented increases in basal salivary cortisol release and expression of stress-responsive microRNAs • normalized bowel habits under the stressful conditions	[42]

Table 1. *Cont.*

Bacterial Strain	Study Model	Potential Psychobiotic Effects	References
Lacticaseibacillus casei Shirota	male football players	• decreased cognitive state anxiety scores, somatic state anxiety, and perceived stress scores	[43]
	healthy medical students under academic examination stress and rats with water avoidance stress	• suppressed salivary cortisol levels and the incidence rate of physical symptoms in students • suppressed water avoidance stress in rats	[44]
	patients with MDD or bipolar disorder (BD)	• alleviated depression symptoms	[45]
Bifidobacterium breve A1	AD mice	• prevented cognitive disorders	[46]
	elderly with mild cognitive impairment	• improved cognitive function	[47]
	patients with schizophrenia	• improved anxiety and depressive symptoms	[48]
B. breve CCFM1025	C57BL/6J mice	• reduced depression- and anxiety-like behaviors	[49]
	C57BL/6J mice	• decreased depressive-like behaviors and neurological abnormalities of chronically stressed mice • reshaped the gut microbiome of chronically stressed mice	[50]
	Mice with AD	• improved synaptic plasticity and increased the concentrations of brain-derived neurotrophic factor, fibronectin type III domain-containing protein 5, and postsynaptic density protein 95	[51]
	pregnant mice	• protected the offspring from maternal separation-induced neurobiological and gastrointestinal disorders such as depression-like behavior and delayed defecation	[52]
B. longum NCC3001	adults with irritable bowel syndrome (IBS)	• reduced depression, but not anxiety scores, and increased quality of life	[53]
B. longum 1714™	healthy volunteers	• reduced stress and improved memory	[54]
	healthy volunteers	• increased social stress	[55]
B. infantis 35624	adult rats	• normalization of the immune response, reversal of behavioral deficits, and restoration of basal noradrenaline concentrations in the brainstem	[56]
B. bifidum ATCCVR 29521	Wistar rats	• reduced the number of dead cells and increased acetylcholine in the brains of rats with AD	[26]
Bacillus coagulans MTCC 5856	patients diagnosed for major depressive disorder with IBS	• the improvement in depression and IBS symptoms	[57]
Clostridium butyricum MIYAIRI 588	adult patients diagnosed with treatment-resistant major depressive disorder	• significant improvement in depression (in combination with antidepressants)	[58]

Studies indicate that strains producing high amounts of SCFAs have the greatest effect on microglia and can also restore the changes caused in the microglia of "germ-free" mice [59]. The psychophysiological effects of psychobiotics include systemic effects on the hypothalamic–pituitary–adrenal axis and the glucocorticoid response, as well as on the inflammation itself, which is caused by inflammatory cytokines and, more specifically, their abnormal concentration [60]. Pro-inflammatory cytokines, such as interferon α, can cause mental illnesses, such as depression. This has been confirmed by studies on rats and mice, based on numerous experiments [61–63]. However, human studies are limited for safety reasons. In a study involving 124 participants (both men and women), one half of the study group consumed a fermented milk beverage containing the probiotic strain *Lactobacillus casei* Shirota for 3 weeks, while the other half received a placebo. People in the study group who described themselves as depressed at the beginning of the study rated themselves as much happier at the end of the experiment. This could point to the beneficial effects of psychobiotic consumption [44].

As mentioned earlier, one of the factors disrupting the functioning of the intestinal microbiota is stress, which is also directly related to an increased frequency of mental

problems. In a study by Ma et al. [21], a 12-week supply of psychobiotics increased the diversity of intestinal microbiota. The authors indicated that the bacteria whose number increased were responsible for the production of SCFAs and gamma-aminobutyric acid (GABA). Psychobiotics, by modulating the function and composition of the intestinal microbiota, can alleviate nervous tension and anxiety in adults, through the microbiota–gut–brain axis [21].

Chronic stress is also associated with elevated levels of cortisol, which is commonly known as the stress hormone. Cortisol is a steroid hormone produced by the adrenal cortex and belongs to the group known as glucocorticosteroids—compounds that are involved in the regulation of glucose levels in the human body. All nervous, hormonal, and circulatory messages reach the intestines through the gut–brain axis. These messages induce the activation of mast cells and changes in the functions of the intestinal barrier. Activation of the autonomic nervous system causes an increase in the concentration of cortisol and pro-inflammatory cytokines, such as tumor necrosis factor-alpha, interleukin-8, or interleukin-6. In such cases, psychobiotic intervention can be very helpful in reducing the blood cortisol concentration [64].

Certain groups of workers, including those employed in the information technology (IT) industry, are particularly affected by stress and work-related emotional tension. Often, this population is at a greater risk of developing diabetes, high blood pressure, and depression. Specific psychobiotic strains can relieve stress and improve overall mood. For instance, the effectiveness of *Lactiplantibacillus plantarum* PS128TM strain was tested in an 8-week intervention in IT workers. This short-term psychobiotic therapy improved participants' overall self-esteem, decreased blood cortisol levels, and reduced sleep disturbances and night-time awakenings [24].

3. Psychobiotics in Fermented Food

In recent times, consumers have shown great attention toward foods that have additional health benefits [65,66]. This has resulted in the growing popularity of functional food, which is often defined as food that, in addition to its nutritional effect, significantly affects the functions of the body, improving health and well-being and/or reducing the risk of diseases [67]. Food is no longer intended to only satisfy hunger and provide necessary nutrients for humans but also offer health benefits that may reduce disease risks, as well as promote optimal wellness and improve both physical and mental well-being [68,69]. This can be attributed to consumers' awareness of the deterioration of health caused by a busy lifestyle, poor food choices, and low physical activity [70]. Among functional foods, fermented products, which are carriers of probiotic strains with a multidirectional impact on human health, are particularly popular [71].

3.1. Food Fermentation

Fermentation is a process used by humans since the need for extended food storage arose. Various food preservation techniques, including fermentation, were followed in the Neolithic period approximately 10,000 years ago [72]. Fermentation is an anaerobic process that converts sugars to other ingredients while generating energy for the microorganism or cell [73]. This process helps to preserve food by lowering its pH and producing antimicrobial ingredients such as organic acids (lactic acid, acetic acid, formic acid, and propionic acid), ethanol, carbon dioxide, diacetyl, reuterin, and bacteriocins [74,75]. In addition, the taste and texture of the product are changed from those of the starting materials [74,76].

Fermentation is used worldwide to produce a wide range of products, either spontaneously from original ingredients and environment or in a controlled manner through the addition of specific starter cultures [77,78]. The type of fermented food produced most often depends on community food habits and the availability of plant or animal sources [75,79]. Therefore, various species of microorganisms are used in fermentation and produce substances that shape the properties of the final products. In particular, bacteria,

yeasts, and molds are used, which, due to their enzyme portfolio, can carry out different types of fermentation (e.g., lactic, alcohol, butter, propionic) [80,81].

Among bacteria, lactic acid bacteria (LAB) and bifidobacteria are currently used worldwide to produce various types of fermented products, including fermented milk (such as yogurt, kefir, cheese, ice cream) [82,83], sauerkraut [84], kimchi [85], fermented meat and fish [86,87], fermented cereals [88,89], and traditional dishes [73,90]. LAB includes bacteria such as *Lactobacillus*, *Streptococcus*, *Enterococcus*, *Lactococcus*, *Pediococcus*, and *Leuconostoc*. Bifidobacteria are often described with LAB because they are also anaerobic Gram-positive bacteria and produce lactic acid as a major product of carbohydrate metabolism [91,92]. Fermentation with LAB and bifidobacteria converts pyruvate molecules from glycolysis into lactate [73].

Alcoholic fermentation is mainly carried out with yeasts, which are widely applied in baking and brewing [93]. This process converts sugars into ethanol and carbon dioxide [75]. Yeasts of the genus *Saccharomyces* are often used, e.g., for leavening dough during the production of bread, as well as in the production of beer [94], wine [95], and some fermented milk products (e.g., kefir) [96]. Molds are frequently used in fermentation mainly due to their ability to produce enzymes (such as α-amylase, acid/alkaline proteases, amyloglucosidase-galactosidase, cellulase maltase, invertase, lipases) and reduce antinutrients [75]. The micro-organisms involved in fermentation also exhibit probiotic properties and are classified as "Generally Recognized As Safe (GRAS)" by the US Food and Drug Administration [97,98].

Food fermentation extends shelf life, promotes food safety, increases the nutritional value, and shapes the taste and texture of products, due to the activity of the microbial ecosystem [78,99]. Fermented foods have gained popularity among consumers for their beneficial effects on human health. This is mainly related to the modification of the intestinal microflora, as well as the positive health effect of fermentative metabolites, such as lactic acid, vitamins, and exopolysaccharides [78,100]. It has been reported that fermentation increases the antioxidant, anti-inflammatory, antiapoptotic, and anticancer properties of food [75,101,102]. Moreover, microbial enzymes involved in fermentation reduce the content of antinutrients (such as phytates, tannins, oligosaccharides) in food, which, in turn, increases the bioavailability of protein and vitamins [103].

Consumption of fermented foods can also prevent microbial dysbiosis, regulate the lipid profile, and protect against IBS, IBDs, cardiovascular disease, type 2 diabetes, and some types of cancers such as bladder and colorectal cancer [74,98,104]. There is also growing evidence that fermented foods have an influence on the gut–brain axis and, consequently, neurological and mental health conditions [105,106]. The health benefits of consuming fermented foods are summarized in Figure 2.

3.2. Effect of Fermented Foods on the Gut–Brain Axis and Brain Health

Consumption of fermented foods can result in some modifications of the gut microflora, which can have a direct impact on brain health. This is mediated by various mechanisms, including the effect of microbiota on the production of neurotransmitters (e.g., GABA, noradrenaline, serotonin, dopamine, acetylcholine), direct activation of neural pathways between the gut and brain (vagus and enteric nervous system), modulation of neurotrophic chemicals (e.g., brain-derived neurotrophic factor—BDNF) and immune cells (e.g., interleukin-1, interferon), and analgesic properties [107,108].

Intestinal microbes produce essential molecules with neuroactive functions that affect the gut–brain axis [107]. One of these molecules are SCFAs, such as butyrate, acetate, and propionate, which are produced during microbial fermentation mainly from dietary fiber in the gut. SCFAs are known to have neuroactive properties and an essential function in the CNS [75,107,109]. Moreover, the products of food fermentation enhance the neuroprotective effects of SCFAs by increasing their bioavailability through intestinal absorption and the utilization of ingested nutrients within the body. Thus, the gut microbiota also regulates the absorption of phytochemicals and their anti-inflammatory and antioxidant functions [75,110].

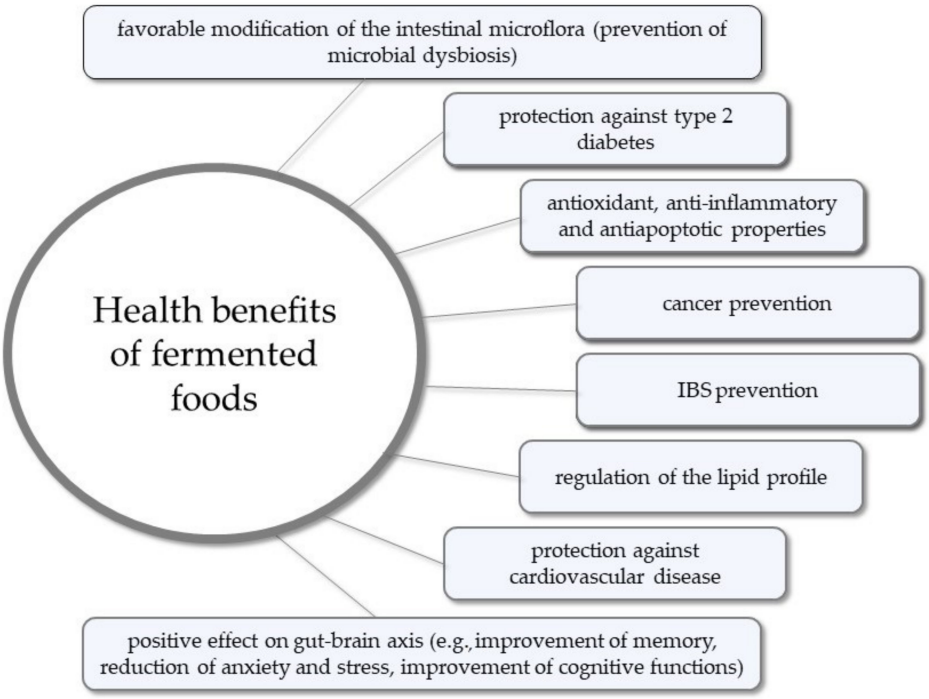

Figure 2. Health benefits of consuming fermented foods.

Sustained colonization of the gut microbiome by beneficial probiotic micro-organisms contributes to the gut–brain relationship [111,112]. Communication between the gut and brain is stabilized through the nervous system, including the vagus nerve, and this in turn regulates the physiological functions of metabolism, digestion, assimilation, indulgence, immunity, and stress reactions [98]. The gut–brain axis moderates the coordination between the brain, the intestinal tract, and the endocrine and immune systems, which play a role in maintaining gut functions. Disruptions in this axis have been associated with psychiatric symptoms, such as anxiety; functional gastrointestinal disorders, such as IBS; and neuroimmunological disorders [106,109]. The consumption of fermented foods can, therefore, affect the complex relationship between the gut microbiota and the brain. Several animal and human studies have proven the influence of fermented foods on neurological disorders, behavior, and mood.

3.2.1. Animal Studies

Some animal studies have examined the effects of consumption of both plant- and animal-based fermented foods on neurological disorders. Musa et al. [113] analyzed the neuroprotective (anti-inflammation) effect of cow milk fermented with *Limosilactobacillus fermentum* LAB9 or *L. casei* LA-BPC in mice with induced neuronal inflammation. Mice fed with fermented milk for 28 days showed a significant improvement in nitrosative stress, attenuation of memory deficit caused by neuronal inflammation, and an increase in antioxidants, as well as a reduction in lipid peroxidation and the levels of acetylcholinesterase and pro-inflammatory cytokines. The results indicated that the consumption of fermented milk may contribute to alleviating nerve inflammation and memory deficit caused by induced neuronal inflammation [113].

In a study by Van de Wouw et al. [114], two distinct kefirs (Fr1 and UK4, with microflora dominated by *Lactococcus lactis*), or unfermented milk control, were administered to mice. Consumption of both types of kefir caused a significant change in the composition and functional capacity of the host microbiota and enhanced the GABA-producing ability of the gut microbiota. The intake of Fr1 ameliorated the stress-induced decrease in serotonergic signaling in the colon, while UK4 ameliorated stress-induced deficits in reward-seeking behavior and increased fear-dependent contextual memory [114].

Woo et al. [115] investigated the efficacy of kimchi (KME) and its bioactive compounds in ameliorating amyloid beta(Aβ)-induced memory and cognitive impairments. Mice treated with KME bioactive compounds and KME methanolic extract for 2 weeks showed a restoration of Aβ-induced cognitive deficits. The groups treated with KME and bioactive compound groups showed increased expression of antioxidant enzymes but decreased expression of inflammation-related enzymes. The authors concluded that due to its antioxidative and anti-inflammatory properties, kimchi rich in bioactive compounds might help to attenuate the symptoms of Alzheimer's disease (AD) [115].

Wu et al. [116] studied the effect of adzuki bean sprout milk fermented with *Streptococcus thermophilus*, *Lactobacillus bulgaricus*, *L. plantarum*, and *Levilactobacillus brevis* J1 in a chronic depression mouse model. Mice treated with fermented product showed an increase in the levels of 5-hydroxytryptamine, norepinephrine, and dopamine in the hippocampus. The authors indicated that treatment with fermented plant milk can reduce and possibly prevent mild depression-like symptoms in mice by increasing social interaction and enhancing the pleasure derived from movement [116].

Several studies also describe the effects of fermented soy and its products on brain health. For instance, Go et al. [117] investigated the effects of soybean products (Cheonggukjang) fermented with *Bacillus subtilis* MC31 and *Latilactobacillus sakei* 383 on induced cognitive defects in mice. After 4 weeks of administration of Cheonggukjang at various doses, the mice showed a significant improvement in induced short-term and long-term memory loss. In addition, a decrease in the number of dead cells was observed in the granule cell layer of the dentate gyrus, as well as a dose-dependent increase in nerve growth factor concentration and an increase in superoxide dismutase activity, which may be beneficial in the treatment of neurodegenerative diseases, including AD, Parkinson's disease, and Huntington's disease [117].

Yoo and Kim [118] studied the effectiveness of defatted soybean powder fermented with *Lactiplantibacilluspentosus* var. *plantarum* C29 in the protection against scopolamine-induced memory impairment in mice. Fermented soybean powder caused an increase in BDNF expression in the hippocampi of scopolamine-treated mice and inhibited acetylcholinesterase activity in vitro and ex vivo, which indicates that the fermentation process might increase the ameliorating effect of soybean against memory impairments [118]. Similarly, Lee et al. [119] determined whether *L. plantarum* C29-fermented defatted soybean could attenuate memory impairment in transgenic mice. The authors observed increased cognitive function and suppressed Aβ expression in mice fed with fermented soy [119].

3.2.2. Human Studies

Human studies have shown that the consumption of fermented foods in general as well as foods fermented with individual bacterial strains can lead to an improvement in neurological disorders and behavior. Kim and Shin [120] conducted a cross-sectional analysis of a large, nationwide, population-based database to evaluate the association between probiotic food consumption and depression status. The population included in the analysis comprised 26,118 individuals aged 19–64 years. The authors observed that compared with the lowest tertile of probiotic food consumption, the highest tertile had significantly lower odds of depression severity and self-reported clinical depression. Although no significant association between probiotic food consumption and clinical depression was observed in women, men showed a significantly lower prevalence of clinical depression in the highest tertile [120]. In a randomized, double-blind controlled study by Ohsawa et al. [121], healthy, middle-aged adults who consumed *Lactobacillus helveticus*-fermented milk drink for 8 weeks (190 g/day) showed a significant improvement in attention score and delayed memory score compared to the placebo group [121]. Mohammadi et al. [122] studied the effects of probiotic yogurt (containing *L. acidophilus* LA5 and *Bifidobacterium lactis* BB12) and multispecies probiotic capsule (containing *L. casei*, *L. acidophilus*, *Lacticaseibacillus rhamnosus*, *L. bulgaricus*, *Bifidobacterium breve*, *Bifidobacterium longum*, *S. thermophilus*) supplementation (100 g/day, for 6 weeks) on mental health in petrochemical workers (n = 70). After the

intervention, a significant improvement in general health, as well as in depression, anxiety, and stress scale scores, was observed in the probiotic yogurt group and probiotic capsule group, while there was no significant improvement in the conventional yogurt group [122]. A study by Tillisch et al. [123] examined the effect of the consumption of milk fermented with *Bifidobacterium animalis* subsp. *lactis*, *S. thermophilus*, *L. bulgaricus*, and *L. lactis* subsp. *lactis* on intrinsic connectivity in the brain or responses to emotional attention tasks. The consumption of probiotic-fermented milk for 4 weeks in healthy women resulted in a reduced task-related response of a distributed functional network involving affective, viscerosensory, and somatosensory cortices, i.e., affected activity of brain regions that control central processing of emotion and sensation [123].

The consumption of fermented food may influence regulation of stress hormones and, thus, reduce the perception of stress in humans [75]. Berding et al. [124] investigated the effect of a psychobiotic diet (rich in prebiotic and fermented foods) on the microbial profile and function as well as mental health outcomes in a healthy human population. Forty-five adults were randomized and received a psychobiotic (n = 24) or control (n = 21) diet for 4 weeks. The psychobiotic diet resulted in a reduction in perceived stress, particularly in those who were most adherent to the diet, and greater changes in perceived stress scores associated with volatility in microbial function [124]. Nishihira et al. [125] conducted a placebo-controlled, randomized, double-blind clinical trial with yogurt containing *Lactobacillus gasseri* SBT2055 and *B. longum* SBT2928 to test its immunomodulatory and stress-related effects. The study involved healthy adult volunteers who consumed 100 g/day of probiotic yogurt (n = 115) or placebo yogurt (n = 109) for 12 weeks. The group consuming fermented yogurt showed a higher number of natural killer cells, as well as a significant decrease in adrenocorticotrophic hormone, which indicates improved immunity and alleviation of stress [125].

Studies with humans also indicate the effect of fermented food consumption on academic stress. Kato-Kataoka et al. [126] conducted a pilot study investigating the effects of the probiotic *L. casei* Shirota (LcS) on stress responses in medical students. Two groups (24 tested and 23 placebo participants) consumed either a fermented milk with LcS (100 mL once a day) or a placebo milk for 8 weeks. One day before the examination, the placebo group showed a significant increase in salivary cortisol and plasma L-tryptophan, along with a significant increase in anxiety. The number of subjects experiencing common abdominal and cold symptoms and the total number of days each subject experienced these physical symptoms were significantly lower in the LcS group than in the placebo group [126]. Academic stress was also evaluated in a group of medical students, before and after ingestion of an aguamiel-based beverage fermented with *Lacticaseibacillus paracasei*, *L. plantarum*, and *L. brevis* (n = 27), and a control group (n = 18). The results showed that the consumption of 100 mL of a fermented beverage for 8 weeks led to a significant reduction in academic stress, while there were no significant changes in the perception of academic stress in the control group (placebo intervention). Moreover, consumption of the fermented beverage significantly increased the phyla *Firmicutes* and *Bacteroidetes* but not *Gammaproteobacteria* in the microbiota of the subjects [127].

Probiotics and prebiotics (defined as substrates that are selectively utilized by host micro-organisms, eliciting health-beneficial effects) can cause an improvement in cognitive functions in patients with mild cognitive impairment (MCI) [92,128]. There are also reports indicating a similar effect of fermented foods. Handajani et al. [129] studied the effects of 6-month tempeh consumption on global cognition in MCI patients who were 60 years of age or older. The study involved a total of 90 subjects, who were divided into three groups: group A (consumed 100 g of Tempeh A/day), group B (consumed 100 g of Tempeh B/day), and group C (control). An increase in global cognitive scores was found in groups A and B, suggesting that both Tempeh A and Tempeh B were effective in improving global cognitive function in older people with MCI [129]. In a study by Hwang et al. [18], a population of 100 individuals with MCI consumed *L. plantarum* C29-fermented soybean (800 mg/day, n = 50) or placebo (800 mg/day, n = 50) for 12 weeks. Compared to the placebo group,

the group that consumed fermented soybean showed a greater improvement in combined cognitive functions, and this effect was associated with increased serum BDNF levels [18].

Studies suggest that the consumption of fermented foods can contribute to an improvement in cognitive deficits associated with neurological diseases, including AD. Ton et al. [130] investigated the effects of supplementation (2 mL/kg/day) with probiotic fermented milk with kefir grains for 90 days in AD patients with cognitive deficit. The subjects showed a marked improvement in memory, visual–spatial/abstract abilities, and executive/language functions. At the end of the intervention, there was an absolute/relative decrease in the levels of several cytokine inflammation markers and oxidative stress markers, as well as an improvement in serum protein oxidation, mitochondrial dysfunction, DNA damage/repair, and apoptosis [130]. Akbari et al. [131] assessed the effect of supplementation with 200 mL/day probiotic milk containing *L. acidophilus*, *L. casei*, *Bifidobacterium bifidum*, and *L. fermentum* on cognitive function and metabolic status in 60 AD patients. After 12 weeks of intervention, patients treated with probiotic milk showed a significant improvement in the mini-mental state examination score, compared with the control group. This indicates that the consumption of probiotic milk led to an improvement in cognitive function [131].

All the above-described studies indicate that fermented foods exert a positive effect on various aspects of brain health, by, for example, improving memory, reducing anxiety and stress, enhancing cognitive functions, and affecting the immune, hormonal, and antioxidant parameters of the body. Therefore, regular consumption of fermented food can help to prevent neurological disorders and may also be considered a nutritional therapy supporting the pharmacological treatment of neurodegenerative diseases and depression.

4. Survival of Psychobiotics in Fermented Food

The ingestion of fermented foods results in a potential increase in the numbers of microbes in the diet by up to 10,000-fold. A diet based on fermented foods is contradictory to the typical Western diet, which is rich in highly processed and sanitized foods [74,132]. Fermented foods have a high potential to carry probiotic strains, including psychobiotic ones [98,133]. However, it is important that the micro-organisms in these foods remain viable at a concentration of about 10^6–10^9 CFU/g or mL during processing, storage, and even digestion [74,83]. The use of probiotics in food products is associated with technological and therapeutic challenges since probiotic viability is an important factor affecting the biological effects of these products on the consumers. Products containing probiotics must meet stringent criteria to ensure that probiotic survival is maintained from large-scale industrial production until consumption [83,134].

The survival of bacteria in a product is influenced by many factors, including those related to the type of food (e.g., pH, macronutrient content, water activity, presence of natural antibiotics) as well as the conditions of production and storage (e.g., time, temperature, inoculation rate, oxygen content, packing materials) [83,135–137]. Therefore, when designing psychobiotic products, it is extremely important to monitor bacterial viability and maintain it at an appropriate level so that the products offer therapeutic benefits to humans [133]. The matrix of fermented products is critical for the survival of bacteria, which may either favor or interfere with their long-term activity [74]. Dairy products are the most popular carriers of psychobiotics in food, but their survival has also been analyzed in plant matrices in recent times [108,138,139]. Table 2 shows the survival of psychobiotics in different types of fermented foods.

Table 2. The survival of psychobiotics in fermented foods.

Food Category	Type of Fermented Food Product	Micro-Organisms Used in Fermentation	Viability of Micro-Organisms after Fermentation [log CFU/mL]	Viability of Micro-Organisms after Storage		References
				Storage Time [Days]	Population Viability [log CFU/mL]	
Dairy products	Yogurt	*L. plantarum* 299v	8.0	56	7.5	[140]
	Cheese		9.5	56	9.0	[140]
	Ice cream	*L. plantarum* ATCC 8014	7.5	60	7.6	[141]
	Cow milk	*L. rhamnosus* GG	9.0	-	-	[142]
	Cow milk		8.0	-	-	[143]
	Goat milk		9.5	-	-	[144]
	Ice cream		8.3	90	7.3	[145]
	Sheep milk yogurt		7.5–8.0	21	7.4–7.8	[146]
	Milk-based dessert with cranberry sauce	*L. casei* Shirota	8.0	21	7.3	[147]
	Cow Milk		8.0	31	8.0	[148]
	Cow Milk		8.8	28	7.8	[149]
	Pudding		7.3	20	9.0	[150]
	Skimmed milk with milk protein concentrate	*B. coagulans* MTCC 5856	8.4	60	8.1	[151]
Plant products	Watermelon juice	*L. plantarum* ATCC 8014	8.8	14	11.0	[152]
	Apple juice		11.0–11.5	42	7.7–8.6	[153]
	Sesame	*L. plantarum* P8	8.6	-	-	[154]
	Whole soybeans		10.5	-	-	[155]
	Bread		5.0	5	8.0	[156]
	Sourdough	L. plantarum 299v	7.9	-	-	[157]
	Dark chocolate		8.2	360	5.5	[158]
	Tomato juice	*L. reuteri* DSM 17938	7.1	28	5.7	[159]
	Coconut milk		8.6	30	8.6	[160]
	Blueberry pomace	*L. rhamnosus* GG	11.6	-	-	[161]
	Hazelnut milk		7.9	28	8.3	[162]
	Pineapple and jussarajuice		7.2	28	7.7	[163]
	Teff-based beverage		8.1	25	7.8	[164]
	Coffee brews		7.8	49	7.0	[165]
	Coconut water	*B. coagulans* MTCC 5856	9.73	-	-	[166]

4.1. Survival of Psychobiotics in Dairy Products

Dairy products are considered to be excellent carriers for delivering probiotic bacteria to the human gastrointestinal tract [167]. Yogurt, fermented milk drinks, cheese, or ice cream are some of the dairy products that are often used for carrying probiotics [168,169]. This is mainly due to the physicochemical composition of these products, which includes a large amount of proteins, fats, and lactose, as well as their high buffering capacity. These factors enable the protection of probiotic bacteria during their passage through the gastrointestinal tract [75,83].

As shown in Table 2, dairy products also provide a good matrix for the development of probiotic psychobiotics. A study showed that after 20 h of fermentation of cow milk with *L. rhamnosus* GG, a viable cell count of 2.4×10^9 CFU/mL was achieved. Milk supplementation with ingredients that are essential for *L. rhamnosus* GG (cysteine, serine, arginine, proline, aspartic acid, glutamic acid, guanine, uracil, and xanthine) made it possible to increase the viable cell count to 4.6×10^9 CFU/mL [142]. A similarly high and viable population of *L. rhamnosus* GG was achieved after 48 h of fermentation of cow milk (8.0 log CFU/mL) [143] and 18 h of fermentation of goat milk encapsulated in buttermilk proteins (9.3 log CFU/mL) [144]. For the fermentation of goat milk, buttermilk protein was used as a thermoprotector for the probiotic cells undergoing the spray-drying process.

In fermented dairy products, psychobiotics reach a therapeutic dose of micro-organisms (above 10^6 CFU/mL) not only directly after the fermentation but also after storage. Fermentation of yogurt and cheese with *L. plantarum* 299v resulted in a cell count of 8.0 and 9.5 log CFU/mL, respectively. After 56 days of storage, the bacterial count of psychobiotic cells in yogurt increased to 7.5 log CFU/mL, while in cheese, it was 9.0 log CFU/mL [140]. Probiotic ice cream fermented with *L. plantarum* ATCC 8014 had a cell count of 7.55 log CFU/mL after fermentation and 7.65 log CFU/mL after 60 days of storage. In addition, the viable population of bacteria in these products was increased by the addition of coconut residue fiber (0.03 g/mL), which resulted in a cell count of 7.75 log CFU/mL after fermentation and 8.1 log CFU/mL after storage [141]. In milk ice cream fermented with *L. rhamnosus* GG, the cell count was 8.3 log CFU/mL after fermentation and 7.3 log CFU/mL after 90 days of storage. In this case, the addition of dietary fiber did not significantly increase the population of micro-organisms in the product [145].

High survival of psychobiotics has also been reported for various types of fermented milk. Zamberlin and Samaržija [146] fermented sheep milk with *L. rhamnosus* GG by applying different milk thermal treatments. In the probiotic yogurt that was produced by using the nonstandard heat treatment of milk (60 °C/5 min), the bacterial cell count after fermentation was 7.5 log CFU/mL, and after 21 days of storage, it was 7.4 log CFU/mL, while in the yogurt produced by using the standard heat treatment of milk (95 °C/5 min), the counts were 8.0 and 7.8 log CFU/mL, respectively [146]. Lavrentev et al. [151] fermented skimmed milk containing milk protein concentrate with *Bacillus coagulans* MTCC 5856. The cell count was 8.4 log CFU/mL after fermentation and 8.1 log CFU/mL after 60 days of storage. The authors concluded that fermented milk is an excellent carrier of *B. coagulans* [151]. Fermented milk is also a good carrier for the psychobiotic *L. casei* Shirota. Sumalapao et al. [148] fermented cow milk with *L. casei* Shirota and achieved a viable cell count of 3.64×10^8 CFU/mL after fermentation and 2.65×10^8 CFU/mL after 31 days of storage, while Angmo et al. [149] achieved 8.8 log CFU/mL after fermentation and 7.8 log CFU/mL after 28 days of storage.

Psychobiotic micro-organisms can also be found in dairy desserts. In a milk-based dessert (2.7% fat) with cranberry sauce fermented with *L. casei* Shirota, a cell count of 8.0 log CFU/mL was observed after fermentation and 7.3 log CFU/mL after 21 days of storage [147]. A milk pudding fermented with *L. casei* Shirota had a cell count of 7.3 log CFU/mL after fermentation and 9.0 log CFU/mL after 28 days of storage [150]. These results indicate that a wide range of dairy products can serve as excellent carriers for psychobiotics, which show high survival not only after the fermentation process but also after storage.

4.2. Survival of Psychobiotics in Plant Products

The consumption of probiotic micro-organisms with dairy products has some disadvantages, including the presence of allergens (e.g., lactose, casein) and a high content of fat and cholesterol [75,167]. This has led to the introduction of new products based on nondairy matrices such as fruits, vegetables, legumes, and cereals. These alternative products can provide a good matrix for the development of probiotics (including psychobiotics) since they contain nutrients such as minerals, vitamins, dietary fibers, and antioxidants [75,167,170]. However, some nondairy matrices exhibit unfavorable properties such as high acidity (e.g., in fruit juices) or low water activity, which may affect probiotic development [83]. Furthermore, designing plant-based probiotic products is a great challenge, as these products should have the same survival rate of micro-organisms as in dairy products in order to exhibit therapeutic properties [171].

Probiotics in plant matrices should also be protected against acidic conditions. This can be achieved by microencapsulation technologies, in which cells are entrapped into matrices with a protective coating [167,172]. Giordano et al. [159] applied microencapsulation for *L. reuteri* DSM 17938 to inhibit changes in a probiotic tomato juice. The authors observed a cell count of 7.1 log CFU/mL after fermentation and 5.7 log CFU/mL after 28 days of

storage in tomato juice, and these values increased to 7.6–7.8 log CFU/mL after storage with microencapsulation of micro-organisms [159]. Mirkovic et al. [158] prepared fermented dark chocolate with encapsulated *L. plantarum* 299v. After fermentation, the viable cell count was 8.2 log CFU/mL, and after 360 days of storage, it was 5.5 log CFU/mL. The count remained above 7 log CFU/mL until 90 days of storage. Based on these observations, the authors concluded that encapsulated *L. plantarum* 299v could be successfully used in the production of probiotic dark chocolate [158].

Even without encapsulation, a therapeutic viable population level of psychobiotics can be achieved in plant-based foods. A study showed that 24 h fermentation of blueberry pomace by using *L. rhamnosus* GG resulted in a viable cell count of 11.6 log CFU/mL [161]. Similarly, 24 h fermentation of sesame with *L. plantarum* P8 resulted in a viable cell count of 8.6 log CFU/mL [154]. It has been shown that *L. plantarum* P8 is an effective psychobiotic for the fermentation of whole soybeans, and after 24 h of fermentation, the bacterial survival rate was 10.5 log CFU/mL [155].

The literature data indicate that fruit juices are a good carrier for psychobiotics. Fermentation of pineapple and jussara juice with *L. rhamnosus* GG resulted in a viable cell count of 7.2 log CFU/mL, and after 28 days of storage at 8 °C, the count increased to 7.7 log CFU/mL [163]. Zoghi et al. [153] studied apple juice supplemented with different levels of fructo-oligosaccharide, ascorbic acid, and citric acid and subsequently fermented with *L. plantarum* ATCC 8014. Regardless of the concentration of additives, a cell count of 11.0–11.5 log CFU/mL was achieved after fermentation, and a cell count of 7.7–8.6 log CFU/mL was achieved after 6 weeks of storage [153]. Amanda and Choo [152] studied the fermentation of watermelon juice by using *L. plantarum* ATCC 8014 and observed that after fermentation, the viable cell count was 8.8 log CFU/mL and remained at about 11.0 log CFU/mL even at week 2 of refrigerated storage at 4 °C [152].

Currently, various types of nondairy fermented beverages are gaining popularity, which can be considered to be convenience foods rich in probiotics [173,174]. They can also be a carrier of highly viable psychobiotic micro-organisms. Fermentation of a teff-based beverage with *L. rhamnosus* GG resulted in a viable cell count of 8.1 log CFU/mL after fermentation and 7.8 log CFU/mL after 25 days of refrigerated storage [164]. Coconut milk fermented with *L. reuteri* DSM 17938 showed a cell count of 8.6 log CFU/mL, which remained stable during 30 days of storage [160], while coconut water fermented with *B. coagulans* MTCC 5856 had a count of 9.73 log CFU/mL after fermentation [166]. Fermentation of hazelnut milk with *L. rhamnosus* GG resulted in a cell count of 7.9 log CFU/mL after fermentation and 8.3 log CFU/mL after 28 days of cold storage [162]. Coffee brews fermented with *L. rhamnosus* GG had a cell count of 7.8 log CFU/mL after fermentation and 7.0 log CFU/mL after 7 weeks of storage at 4 °C. After 7 weeks, the number of *L. rhamnosus* GG drastically decreased in the tested product. However, in the coffee brews fermented with a mixed culture of *L. rhamnosus* GG and *Saccharomyces boulardii* CNCM-I745, the cell count of *L. rhamnosus* GG was maintained at 7.0 log CFU/mL for 14 weeks of storage. This indicated that yeasts can effectively enhance probiotic bacterial viability in coffee brews and may, thus, be useful for formulating shelf-stable probiotic food products [165].

Bread is an interesting nondairy vehicle for probiotics given its daily consumption worldwide. However, probiotic incorporation in this product is challenging due to the application of high baking temperatures. Zhang et al. [156] analyzed the influence of various baking conditions and subsequent storage on the survival of *L. plantarum* P8, which exhibits psychobiotic properties. Under all baking conditions, the probiotic viability decreased from 10^9 to $10^{4–5}$ CFU/g after baking; however, after 5 days of storage, the cell viability in bread crust was 8.0 log CFU/mL [156]. Supasil et al. [157] studied the characteristics of sourdough and sourdough bread prepared by using fermented water from Asian pears and Assam tea leaves with *L. plantarum* 299v and *Saccharomyces cerevisiae* TISTR 5059 as starter cultures. The authors noted that fermented water with the studied cultures improved dough fermentation and bread quality, and the viable cell count of psychobiotic *L. plantarum* in sourdough was 7.9 log CFU/mL [157].

The development of novel, economic, and technological matrices is essential to design non-diary probiotic products for consumers who avoid dairy products [75]. The cited studies indicate that plant products can be a good matrix for probiotics exhibiting psychobiotic properties, but the viability of probiotic bacteria depends on their species and strain. Further research is needed to understand the survival of probiotics in various plant matrices.

5. Survival of Psychobiotics in Human Gastrointestinal Tract

The key objective of studies on probiotics is to control their activity and survival during the gastrointestinal passage. Such studies are carried out mainly on laboratory animals, such as mice and rats, but often, model digestive systems that accurately reproduce the conditions in the human digestive tract are also used. The results from these studies are crucial for classifying a given strain under the group of probiotics and using it in targeted probiotic therapy. A graphical presentation of the variety of conditions in the digestive system to which psychobiotics are exposed is shown in Figure 3 [12].

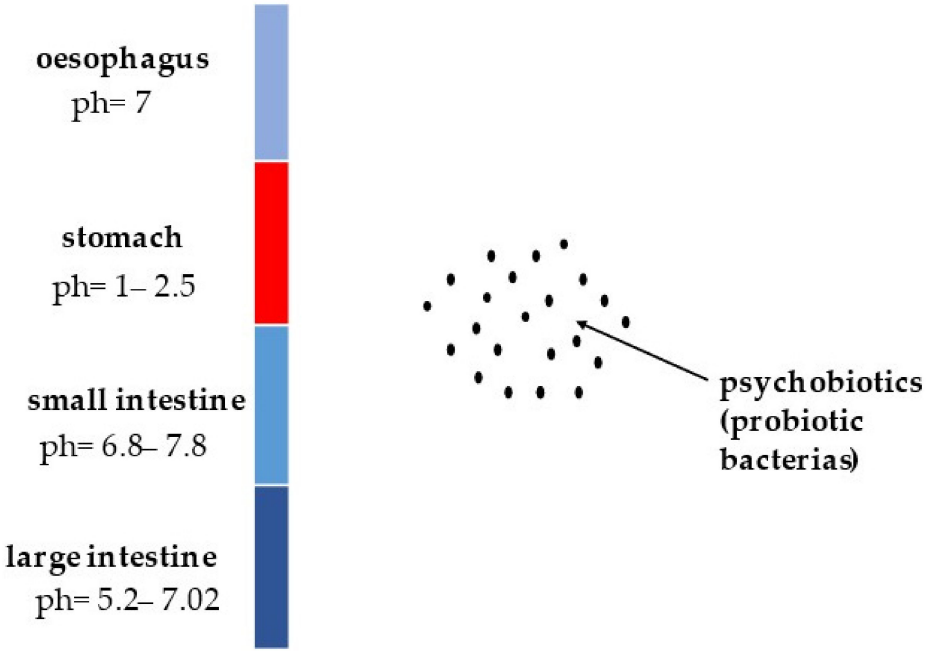

Figure 3. Graphical presentation of the conditions in the digestive system to which psychobiotics are exposed.

Unfortunately, there is limited research on the gastrointestinal survival of these less common psychobiotic strains. The available studies should be supplemented with new ones to make the best use of psychobiotics. The findings of some studies on the survival of selected psychobiotic strains in model digestive systems and clinical trials on humans are presented below.

Strains of the species *B. animalis*, *S. thermophilus*, and *Lactobacillus delbrueckii* subsp. *bulgaricus* have been studied for their psychobiotic effects and their potential to produce increased amounts of GABA, a neurotransmitter involved in mood modulation. Although studies have shown a significantly increased diversity of the intestinal microbiota, the intake of these bacterial strains resulted in an increase in the population of *Bacteroidetes*, which are mainly responsible for the anti-inflammatory functions of the intestinal microbiota. All the tested strains were detectable after 48 h in the bioreactors, but a decrease in their population was observed. Statistical analysis, however, showed that this decrease was not statistically significant [175].

One of the better-studied probiotic strains, with a strong effect on the microbiota–gut–brain axis, is *L. plantarum* 299v. This strain has long been used in the probiotic treatment

of many digestive diseases, such as IBS, as well as intestinal dysbiosis and abnormal iron absorption. The organism also remains viable in unfavorable conditions, such as in gastric juice supplemented with a proton pump inhibitor—pantoprazole. Despite the increased secretion of gastric juice, after a week of probiotic intervention, *L. plantarum* 299v bacteria were observed in stool samples, which implies their resistance to the acidic environment in the stomach [176]. This strain can survive even in extremely unfavorable conditions of the digestive tract and successfully adapt to the conditions in the large intestine, where it can persist for a long period of time. In a study by Goossens et al. [177], *L. plantarum* was isolated from human stool samples 8 days after the last administration of a probiotic fruit drink containing this strain [177].

Another most widely described probiotic strain is *L. rhamnosus* GG (LGG). In addition to the recently discovered psychobiotic effect, this strain is most often used in children and adults to support the intestinal microbiota during antibiotic therapy, as well as to treat traveler's diarrhea, *Clostridium difficile* infections, IBS, and IBDs. Similar to the previously described strain, *L. rhamnosus* GG shows a very high survival rate during the gastrointestinal passage. To improve its activity, it is often encapsulated with various materials, such as pectin or sodium alginate. The initial number of unencapsulated *L. rhamnosus* GG was 9.76 log CFU/mL, and after 4 h in a simulated colonic system, the number of viable bacterial cells decreased to 3.25 log CFU/mL. However, even a slight addition of glucose or pectins to the bacterial suspension resulted in an increase in the number of active probiotics to 5.36–6.52 log CFU/mL [178].

Many scientific publications describe the effect of the *L. casei* Shirota strain. The first reports on this strain appeared in the PubMed database in 1998. The strain has been proven to be beneficial for upper respiratory tract infections. Interestingly, Shirota helps in treating digestive tract dysfunctions that occur in professional athletes due to intense training [179]. It exerts a wide spectrum of action on the microbiota–gut–brain axis as follows [179]:

- lowers the concentration of cortisol in the blood,
- relieves stress,
- reduces anxiety, and
- soothes the symptoms of irritable bowel syndrome.

One of the most popular studies on the *L. casei* Shirota strain is a clinical trial conducted on a population of healthy Chinese subjects who were given a probiotic drink containing 10^8 CFU/mL for 2 weeks. The presence of the strain was confirmed via the culture method followed by ELISA. The strain showed excellent survival during gastrointestinal transit. The number of viable cells in the recovered fecal samples was 6.86–7.17 log CFU/mL, indicating the high resistance of the bacteria to both gastric acid and intestinal fluids [180].

Several factors affect the final number of viable bacterial cells, including the origin of the studied population and the type of diet [181]. In the United Kingdom population, the survival of the Shirota strain was assessed at 7.1 log CFU/mL when 65 mL of a probiotic beverage was consumed. In comparison, the Thai population consuming 80 mL of the probiotic beverage had a higher final number of live bacterial cells in the feces, which reached a level of 8.04 log CFU/mL. It can be assumed that the Thai diet, similar to the Mediterranean diet, is richer in dietary fiber and sources of vegetable fiber compared to the English diet, which ultimately affects the number of probiotic bacteria [182].

The *B. breve* strains, such as *B. breve* CCFM1025 and *B. breve* A1, are recognized as probiotics, but they also have psychobiotic effects. It has been proven that when administered at the right amount, these probiotic bacteria reduce the symptoms of AD and can also complement the preventive treatment of this disease. Such supplementation will be particularly beneficial in people who are genetically burdened with AD [183]. A study of the survival of *B. breve* bacteria was carried out by Adamberg et al. [184] from the Tallinn University of Technology. The authors observed that bacteria exposed to model digestive juices were largely resistant to the action of digestive enzymes and the low pH in the stomach. After 5 h of exposure to digestive juices, the number of bacteria decreased from 7.77 to 6.94 log CFU/mL and from 7.20 to 6.73 log CFU/mL. Another strain of *B.*

breve also showed similar results. The number of bacterial cells decreased slightly after 5 h of exposure to digestive conditions from 7.53 to 6.94 log CFU/mL and from 7.20 to 6.99 log CFU/mL [184].

Unfortunately, there are a number of mental diseases, and most of these are associated with disturbed functions of the intestinal microbiota. According to recent data, IBS affects up to 10% of the population of North America and Europe [185]. Strains of the genus *Bifidobacterium* are particularly helpful in the probiotic treatment of this condition, as they alleviate unpleasant symptoms such as bloating, abdominal pain, diarrhea, or constipation. *Bifidobacterium* also has a positive effect on the microbiota–gut–brain axis and, by increasing the production of butyrate and serotonin, it modulates mood and may alleviate the accompanying stress and short-term inflammation. For example, *B. infantis* 35624 strain was shown to be highly effective in alleviating IBS symptoms. A randomized, double-blind study tested the survival of this strain during gastrointestinal transit. It was observed that a high number of bacteria survived gastrointestinal transit in patients with ulcerative colitis. Analysis of stool samples revealed the presence of *B. infantis* 35624 in the colon of study participants at 10^5–10^8 log CFU/mL. Such a high number of viable probiotic bacteria meets the therapeutic minimum, which indicates their potential health benefits to consumers [186].

A strain that is less known for its probiotic properties is *L. helveticus* NS8. This lactobacillus strain is widely used in the production of Italian and Swiss cheeses. The NS8 strain was isolated from the probiotic beverage kumis, which is very popular in Central Asia and Mongolia [187]. Subsequent reports indicated that this strain can inhibit the expression of interleukin-10, which is responsible for inducing an inflammatory cascade in the human body. The *L. helveticus* NS8 strain has been proven to be beneficial in the treatment of atopic dermatitis and has recently been recognized as a psychobiotic that can improve brain function as well as modulate cognitive functions. In vitro tests showed a high capacity of the strain to adhere to the surface of the intestinal epithelium of humans. Interestingly, this strain is characterized by a long period of intestinal colonization and the ability of self-aggregation, which facilitates its extended retention in the large intestine [188]. Together with commensal organisms present in the intestinal microbiota, *L. helveticus* NS8 can form biofilm-like structures, which ultimately allows the exclusion of other intestinal pathogens or inhibition of their development. The strain is also characterized by high survival during gastrointestinal transit; however, it exhibits low resistance to pancreatic enzymes [189].

6. Conclusions

Reports indicating a high prevalence of mental health and brain disorders urge researchers to develop methods to prevent or alleviate them. One of the key strategies is to influence the functioning of the microbiota–gut–brain axis, which connects the CNS and the digestive system through the vagus nerve, the dorsal root ganglia of the spinal cord, and the autonomic nervous system of the intestines. Data suggesting the indirect effect of the microbiota on the nervous system by modulating its action, the hypothalamic–pituitary–adrenal axis, neurotransmitters, and the synthesis of metabolites have led researchers to analyze the factors influencing this relationship. A promising approach to modulating the function of microbiota is to use psychobiotics, which are probiotic micro-organisms that affect the neuroimmune axis and cognitive processes, such as memory, learning, and general behavior.

One important factor affecting the effect of psychobiotics is their viability during processing, storage, and digestion, which must be at the level of 10^6 to 10^9 CFU/mL to achieve the desired therapeutic outcome. This paper has presented results showing the high viability of different strains of psychobiotics in fermented foods. However, the level of bacterial viability is closely related to the type of food matrix and the strain of the micro-organism; therefore, when designing food products rich in psychobiotics, it is necessary to analyze the survival of these bacteria and the factors influencing their survival.

The most popular source of probiotic micro-organisms are dairy products, but there is a growing interest in plant-based fermented foods, which provide a promising matrix for the development of psychobiotics. Further research is needed to analyze the effectiveness of various types of plant matrices as carriers of psychobiotics.

A key factor to be analyzed while examining the functional properties of psychobiotics is their survival during the gastrointestinal passage. Studies conducted with animals and studies in laboratory conditions in model digestive systems have shown promising results regarding the therapeutic properties and viability of psychobiotics. Unfortunately, human research in this field is still limited. Therefore, it is necessary to broaden the existing knowledge about the survival of psychobiotics in the human digestive tract, their resistance to gastric and pancreatic enzymes, and their ability to colonize the microbiota. This will allow for an in-depth understanding of the nature and properties of psychobiotic micro-organisms and further analysis of their effect on improving brain and mental health.

Author Contributions: Conceptualization, P.C., E.K. and M.Z.; formal analysis, P.C. and E.K.; investigation, P.C. and E.K.; writing—original draft preparation, P.C. and E.K.; writing—review and editing, P.C. and M.Z.; visualization, P.C. and E.K.; supervision, M.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data sharing not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Zagórska, A.; Marcinkowska, M.; Jamrozik, M.; Wiśniowska, B.; Paśko, P. From probiotics to psychobiotics—The gut-brain axis in psychiatric disorders. *Benef. Microbes* **2020**, *11*, 717–732. [CrossRef] [PubMed]
2. Bollwahn, W.; Bahr, K.H.; Hazem, A.S.; Amtsberg, G.; Schmidt, U. Investigations into the aetiology of moist eczema in pigs. *DTW* **1970**, *77*, 601–603.
3. Food and Agriculture Organization of the United Nations and World Health Organization. *Joint FAO/WHO Working Group Report on Drafting Guidelines for the Evaluation of Probiotics in Food*; Food and Agriculture Organization of the United Nations: Rome, Italy; World Health Organization: Geneva, Switzerland, 2002.
4. Dinan, T.G.; Quigley, E.M. Probiotics in the Treatment of Depression: Science or Science Fiction? *Aust. N.Z.J. Psychiatry* **2011**, *45*, 1023–1025. [CrossRef] [PubMed]
5. Carabotti, M.; Scirocco, A.; Maselli, M.A.; Severi, C. The gut-brain axis: Interactions between enteric microbiota, central and enteric nervous systems. *Ann. Gastroenterol.* **2015**, *28*, 203–209. [PubMed]
6. Zhou, L.; Foster, J. Psychobiotics and the gut–brain axis: In the pursuit of happiness. *Neuropsychiatr. Dis. Treat.* **2015**, *11*, 715–723. [CrossRef]
7. Sarkar, A.; Lehto, S.M.; Harty, S.; Dinan, T.G.; Cryan, J.F.; Burnet, P.W. Psychobiotics and the Manipulation of Bacteria–Gut–Brain Signals. *Trends Neurosci.* **2016**, *39*, 763–781. [CrossRef]
8. Milani, C.; Duranti, S.; Bottacini, F.; Casey, E.; Turroni, F.; Mahony, J.; Belzer, C.; Delgado Palacio, S.; Arboleya Montes, S.; Mancabelli, L.; et al. The First Microbial Colonizers of the Human Gut: Composition, Activities, and Health Implications of the Infant Gut Microbiota. *Microbiol. Mol. Biol. Rev.* **2017**, *81*, e00036-17. [CrossRef]
9. Martinez, T.M.; Meyer, R.K.; Duca, F.A. Therapeutic Potential of Various Plant-Based Fibers to Improve Energy Homeostasis via the Gut Microbiota. *Nutrients* **2021**, *13*, 3470. [CrossRef]
10. Hamaker, B.R.; Tuncil, Y.E. A Perspective on the Complexity of Dietary Fiber Structures and Their Potential Effect on the Gut Microbiota. *J. Mol. Biol.* **2014**, *426*, 3838–3850. [CrossRef]
11. Das, P.; Babaei, P.; Nielsen, J. Metagenomic analysis of microbe-mediated vitamin metabolism in the human gut microbiome. *BMC Genom.* **2019**, *20*, 208. [CrossRef]
12. Wang, Z.-K.; Yang, Y.-S. Upper gastrointestinal microbiota and digestive diseases. *World J. Gastroenterol.* **2013**, *19*, 1541–1550. [CrossRef] [PubMed]
13. Walsh, C.J.; Guinane, C.M.; O'Toole, P.W.; Cotter, P.D. Beneficial modulation of the gut microbiota. *FEBS Lett.* **2014**, *588*, 4120–4130. [CrossRef] [PubMed]
14. Quigley, E.M.M. Microbiota-Brain-Gut Axis and Neurodegenerative Diseases. *Curr. Neurol. Neurosci. Rep.* **2017**, *17*, 94. [CrossRef] [PubMed]
15. Sharma, R.; Gupta, D.; Mehrotra, R.; Mago, P. Psychobiotics: The Next-Generation Probiotics for the Brain. *Curr. Microbiol.* **2021**, *78*, 449–463. [CrossRef]

16. Mossad, O.; Batut, B.; Yilmaz, B.; Dokalis, N.; Mezö, C.; Nent, E.; Nabavi, L.S.; Mayer, M.; Maron, F.J.M.; Buescher, J.M.; et al. Gut microbiota drives age-related oxidative stress and mitochondrial damage in microglia via the metabolite N6-carboxymethyllysine. *Nat. Neurosci.* **2022**, *25*, 295–305. [CrossRef]
17. Chen, C.; Liao, J.; Xia, Y.; Liu, X.; Jones, R.; Haran, J.; McCormick, B.; Sampson, T.R.; Alam, A.; Ye, K. Gut microbiota regulate Alzheimer's disease pathologies and cognitive disorders via PUFA-associated neuroinflammation. *Gut* **2022**, *71*, 2233–2252. [CrossRef]
18. Hwang, Y.-H.; Park, S.; Paik, J.-W.; Chae, S.-W.; Kim, D.-H.; Jeong, D.-G.; Ha, E.; Kim, M.; Hong, G.; Park, S.-H.; et al. Efficacy and Safety of Lactobacillus Plantarum C29-Fermented Soybean (DW2009) in Individuals with Mild Cognitive Impairment: A 12-Week, Multi-Center, Randomized, Double-Blind, Placebo-Controlled Clinical Trial. *Nutrients* **2019**, *11*, 305. [CrossRef]
19. Chong, H.X.; Yusoff, N.A.A.; Hor, Y.Y.; Lew, L.C.; Jaafar, M.H.; Choi, S.-B.; Yusoff, M.S.B.; Wahid, N.; Abdullah, M.F.I.L.; Zakaria, N.; et al. *Lactobacillus plantarum* DR7 alleviates stress and anxiety in adults: A randomised, double-blind, placebo-controlled study. *Benef. Microbes* **2019**, *10*, 355–373. [CrossRef]
20. Lew, L.-C.; Hor, Y.-Y.; Yusoff, N.A.A.; Choi, S.-B.; Yusoff, M.S.B.; Roslan, N.S.; Ahmad, A.; Mohammad, J.A.M.; Abdullah, M.F.I.L.; Zakaria, N.; et al. Probiotic *Lactobacillus plantarum* P8 alleviated stress and anxiety while enhancing memory and cognition in stressed adults: A randomised, double-blind, placebo-controlled study. *Clin. Nutr.* **2019**, *38*, 2053–2064. [CrossRef]
21. Ma, T.; Jin, H.; Kwok, L.-Y.; Sun, Z.; Liong, M.-T.; Zhang, H. Probiotic consumption relieved human stress and anxiety symptoms possibly via modulating the neuroactive potential of the gut microbiota. *Neurobiol. Stress* **2021**, *14*, 100294. [CrossRef]
22. Liao, J.-F.; Cheng, Y.-F.; You, S.-T.; Kuo, W.-C.; Huang, C.-W.; Chiou, J.-J.; Hsu, C.-C.; Hsieh-Li, H.-M.; Wang, S.; Tsai, Y.-C. Lactobacillus plantarum PS128 alleviates neurodegenerative progression in 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine-induced mouse models of Parkinson's disease. *Brain, Behav. Immun.* **2020**, *90*, 26–46. [CrossRef] [PubMed]
23. Liu, Y.-W.; Liong, M.T.; Chung, Y.-C.E.; Huang, H.-Y.; Peng, W.-S.; Cheng, Y.-F.; Lin, Y.-S.; Wu, Y.-Y.; Tsai, Y.-C. Effects of Lactobacillus plantarum PS128 on Children with Autism Spectrum Disorder in Taiwan: A Randomized, Double-Blind, Placebo-Controlled Trial. *Nutrients* **2019**, *11*, 820. [CrossRef] [PubMed]
24. Wu, S.-I.; Wu, C.-C.; Tsai, P.-J.; Cheng, L.-H.; Hsu, C.-C.; Shan, I.-K.; Chan, P.-Y.; Lin, T.-W.; Ko, C.-J.; Chen, W.-L.; et al. Psychobiotic Supplementation of PS128TM Improves Stress, Anxiety, and Insomnia in Highly Stressed Information Technology Specialists: A Pilot Study. *Front. Nutr.* **2021**, *8*, 614105. [CrossRef]
25. Ho, Y.-T.; Tsai, Y.-C.; Kuo, T.B.; Yang, C.C.H. Effects of *Lactobacillus plantarum* PS128 on Depressive Symptoms and Sleep Quality in Self-Reported Insomniacs: A Randomized, Double-Blind, Placebo-Controlled Pilot Trial. *Nutrients* **2021**, *13*, 2820. [CrossRef] [PubMed]
26. Shamsipour, S.; Sharifi, G.; Taghian, F. An 8-Week Administration of *Bifidobacterium bifidum* and Lactobacillus plantarum Combined with Exercise Training Alleviates Neurotoxicity of Aβ and Spatial Learning via Acetylcholine in Alzheimer Rat Model. *J. Mol. Neurosci.* **2021**, *71*, 1495–1505. [CrossRef]
27. Morsheedi, M.; Valenlia, K.B.; Saghafi-Asl, M.; Hadi, S.; Hadi, V.; Mirghazanfari, S.M.; Askari, G. Can psychobiotics administration influence behavioral responses and physiological stress in healthy rats? *Pharm. Sci.* **2022**, *28*, 541–551. [CrossRef]
28. Andersson, H.; Tullberg, C.; Ahrné, S.; Hamberg, K.; Ahrén, I.L.; Molin, G.; Sonesson, M.; Håkansson, A. Oral Administration of *Lactobacillus plantarum* 299v Reduces Cortisol Levels in Human Saliva during Examination Induced Stress: A Randomized, Double-Blind Controlled Trial. *Int. J. Microbiol.* **2016**, *2016*, 8469018. [CrossRef]
29. Rudzki, L.; Ostrowska, L.; Pawlak, D.; Małus, A.; Pawlak, K.; Waszkiewicz, N.; Szulc, A. Probiotic *Lactobacillus plantarum* 299v decreases kynurenine concentration and improves cognitive functions in patients with major depression: A double-blind, randomized, placebo controlled study. *Psychoneuroendocrinology* **2019**, *100*, 213–222. [CrossRef]
30. He, B.; Hoang, T.K.; Tian, X.; Taylor, C.M.; Blanchard, E.; Luo, M.; Bhattacharjee, M.B.; Freeborn, J.; Park, S.; Couturier, J.; et al. Lactobacillus reuteri Reduces the Severity of Experimental Autoimmune Encephalomyelitis in Mice by Modulating Gut Microbiota. *Front. Immunol.* **2019**, *10*, 385. [CrossRef]
31. Kong, Q.; Wang, B.; Tian, P.; Li, X.; Zhao, J.; Zhang, H.; Chen, W.; Wang, G. Daily intake of *Lactobacillus* alleviates autistic-like behaviors by ameliorating the 5-hydroxytryptamine metabolic disorder in VPA-treated rats during weaning and sexual maturation. *Food Funct.* **2021**, *12*, 2591–2604. [CrossRef]
32. Liang, S.; Wang, T.; Hu, X.; Luo, J.; Li, W.; Wu, X.; Duan, Y.; Jin, F. Administration of *Lactobacillus helveticus* NS8 improves behavioral, cognitive, and biochemical aberrations caused by chronic restraint stress. *Neuroscience* **2015**, *310*, 561–577. [CrossRef]
33. Luo, J.; Wang, T.; Liang, S.; Hu, X.; Li, W.; Jin, F. Ingestion of Lactobacillus strain reduces anxiety and improves cognitive function in the hyperammonemia rat. *Sci. China Life Sci.* **2014**, *57*, 327–335. [CrossRef] [PubMed]
34. Bravo, J.A.; Forsythe, P.; Chew, M.V.; Escaravage, E.; Savignac, H.M.; Dinan, T.G.; Bienenstock, J.; Cryan, J.F. Ingestion of Lactobacillus strain regulates emotional behavior and central GABA receptor expression in a mouse via the vagus nerve. *Proc. Natl. Acad. Sci. USA* **2011**, *108*, 16050–16055. [CrossRef]
35. Chudzik, A.; Słowik, T.; Kochalska, K.; Pankowska, A.; Łazorczyk, A.; Andres-Mach, M.; Rola, R.; Stanisz, G.J.; Orzyłowska, A. Continuous Ingestion of *Lacticaseibacillus rhamnosus* JB-1 during Chronic Stress Ensures Neurometabolic and Behavioural Stability in Rats. *Int. J. Mol. Sci.* **2022**, *23*, 5173. [CrossRef] [PubMed]
36. Kantak, P.A.; Bobrow, D.N.; Nyby, J.G. Obsessive–compulsive-like behaviors in house mice are attenuated by a probiotic (*Lactobacillus rhamnosus* GG). *Behav. Pharmacol.* **2014**, *25*, 71–79. [CrossRef]

37. Sanborn, V.; Azcarate-Peril, M.A.; Updegraff, J.; Manderino, L.; Gunstad, J. Randomized Clinical Trial Examining the Impact of Lactobacillus rhamnosus GG Probiotic Supplementation on Cognitive Functioning in Middle-aged and Older Adults. *Neuropsychiatr. Dis. Treat.* **2020**, *16*, 2765–2777. [CrossRef] [PubMed]
38. Zhou, B.; Jin, G.; Pang, X.; Mo, Q.; Bao, J.; Liu, T.; Wu, J.; Xie, R.; Liu, X.; Liu, J.; et al. *Lactobacillus rhamnosus* GG colonization in early life regulates gut-brain axis and relieves anxiety-like behavior in adulthood. *Pharmacol. Res.* **2022**, *177*, 106090. [CrossRef]
39. Kumperscak, H.G.; Gricar, A.; Ülen, I.; Micetic-Turk, D. A Pilot Randomized Control Trial with the Probiotic Strain Lactobacillus rhamnosus GG (LGG) in ADHD: Children and Adolescents Report Better Health-Related Quality of Life. *Front. Psychiatry* **2020**, *11*, 181. [CrossRef]
40. Sawada, D.; Kuwano, Y.; Tanaka, H.; Hara, S.; Uchiyama, Y.; Sugawara, T.; Fujiwara, S.; Rokutan, K.; Nishida, K. Daily intake of *Lactobacillus gasseri* CP2305 relieves fatigue and stress-related symptoms in male university Ekiden runners: A double-blind, randomized, and placebo-controlled clinical trial. *J. Funct. Foods* **2019**, *57*, 465–476. [CrossRef]
41. Nishida, K.; Sawada, D.; Kuwano, Y.; Tanaka, H.; Rokutan, K. Health Benefits of Lactobacillus gasseri CP2305 Tablets in Young Adults Exposed to Chronic Stress: A Randomized, Double-Blind, Placebo-Controlled Study. *Nutrients* **2019**, *11*, 1859. [CrossRef]
42. Nishida, K.; Sawada, D.; Kuwano, Y.; Tanaka, H.; Sugawara, T.; Aoki, Y.; Fujiwara, S.; Rokutan, K. Daily administration of paraprobiotic *Lactobacillus gasseri* CP2305 ameliorates chronic stress-associated symptoms in Japanese medical students. *J. Funct. Foods* **2017**, *36*, 112–121. [CrossRef]
43. Adikari, A.M.; Appukutty, M.; Kuan, G. Effects of Daily Probiotics Supplementation on Anxiety Induced Physiological Parameters among Competitive Football Players. *Nutrients* **2020**, *12*, 1920. [CrossRef] [PubMed]
44. Takada, M.; Nishida, K.; Kataoka-Kato, A.; Gondo, Y.; Ishikawa, H.; Suda, K.; Kawai, M.; Hoshi, R.; Watanabe, O.; Igarashi, T.; et al. Probiotic *Lactobacillus casei* strain Shirota relieves stress-associated symptoms by modulating the gut–brain interaction in human and animal models. *Neurogastroenterol. Motil.* **2016**, *28*, 1027–1036. [CrossRef] [PubMed]
45. Otaka, M.; Kikuchi-Hayakawa, H.; Ogura, J.; Ishikawa, H.; Yomogida, Y.; Ota, M.; Hidese, S.; Ishida, I.; Aida, M.; Matsuda, K.; et al. Effect of *Lacticaseibacillus paracasei* Strain Shirota on Improvement in Depressive Symptoms, and Its Association with Abundance of Actinobacteria in Gut Microbiota. *Microorganisms* **2021**, *9*, 1026. [CrossRef]
46. Kobayashi, Y.; Sugahara, H.; Shimada, K.; Mitsuyama, E.; Kuhara, T.; Yasuoka, A.; Kondo, T.; Abe, K.; Xiao, J.-Z. Therapeutic potential of Bifidobacterium breve strain A1 for preventing cognitive impairment in Alzheimer's disease. *Sci. Rep.* **2017**, *7*, 135. [CrossRef]
47. Kobayashi, Y.; Kinoshita, T.; Matsumoto, A.; Yoshino, K.; Saito, I.; Xiao, J.Z. *Bifidobacterium breve* A1 supplementation improved cognitive decline in older adults with mild cognitive impairment: An open-label, single-arm study. *J. Prev. Alzheimers Dis.* **2019**, *6*, 1–75. [CrossRef]
48. Okubo, R.; Koga, M.; Katsumata, N.; Odamaki, T.; Matsuyama, S.; Oka, M.; Narita, H.; Hashimoto, N.; Kusumi, I.; Xiao, J.; et al. Effect of *Bifidobacterium breve* A-1 on anxiety and depressive symptoms in schizophrenia: A proof-of-concept study. *J. Affect. Disord.* **2019**, *245*, 377–385. [CrossRef]
49. Tian, P.; O'Riordan, K.J.; Lee, Y.-K.; Wang, G.; Zhao, J.; Zhang, H.; Cryan, J.F.; Chen, W. Towards a psychobiotic therapy for depression: *Bifidobacterium breve* CCFM1025 reverses chronic stress-induced depressive symptoms and gut microbial abnormalities in mice. *Neurobiol. Stress* **2020**, *12*, 100216. [CrossRef]
50. Tian, P.; Thomaz, F.; Bastiaanssen, S.; Song, L.; Jiang, B.; Zhang, X.; Zhao, J.; Zhang, H.; Chen, W.; Cryan, J.F.; et al. Unraveling the Microbial Mechanisms Underlying the Psychobiotic Potential of a *Bifidobacterium breve* Strain. *Mol. Nutr. Food Res.* **2021**, *65*, e2000704. [CrossRef]
51. Zhu, G.; Zhao, J.; Zhang, H.; Chen, W.; Wang, G. Administration of *Bifidobacterium breve* Improves the Brain Function of $A\beta_{1\text{-}42}$-Treated Mice via the Modulation of the Gut Microbiome. *Nutrients* **2021**, *13*, 1602. [CrossRef]
52. Zhu, H.; Tian, P.; Qian, X.; Gu, L.; Zhao, J.; Wang, G.; Chen, W. Perinatal transmission of a probiotic *Bifidobacterium* strain protects against early life stress-induced mood and gastrointestinal motility disorders. *Food Funct.* **2022**, *13*, 7520–7528. [CrossRef]
53. Pinto-Sanchez, M.I.; Hall, G.B.; Ghajar, K.; Nardelli, A.; Bolino, C.; Lau, J.T.; Martin, F.-P.; Cominetti, O.; Welsh, C.; Rieder, A.; et al. Probiotic *Bifidobacterium longum* NCC3001 Reduces Depression Scores and Alters Brain Activity: A Pilot Study in Patients with Irritable Bowel Syndrome. *Gastroenterology* **2017**, *153*, 448–459.e8. [CrossRef] [PubMed]
54. Allen, A.P.; Hutch, W.; Borre, Y.E.; Kennedy, P.J.; Temko, A.; Boylan, G.; Murphy, E.; Cryan, J.F.; Dinan, T.G.; Clarke, G. Bifidobacterium longum 1714 as a translational psychobiotic: Modulation of stress, electrophysiology and neurocognition in healthy volunteers. *Transl. Psychiatry* **2016**, *6*, 939. [CrossRef] [PubMed]
55. Wang, H.; Braun, C.; Murphy, E.F.; Enck, P. *Bifidobacterium longum* 1714™ Strain Modulates Brain Activity of Healthy Volunteers During Social Stress. *Am. J. Gastroenterol.* **2019**, *114*, 1152–1162. [CrossRef] [PubMed]
56. Desbonnet, L.; Garrett, L.; Clarke, G.; Kiely, B.; Cryan, J.F.; Dinan, T.G. Effects of the probiotic *Bifidobacterium infantis* in the maternal separation model of depression. *Neuroscience* **2010**, *170*, 1179–1188. [CrossRef] [PubMed]
57. Majeed, M.; Nagabhushanam, K.; Arumugam, S.; Majeed, S.; Ali, F. Bacillus coagulans MTCC 5856 for the management of major depression with irritable bowel syndrome: A randomised, double-blind, placebo controlled, multi-centre, pilot clinical study. *Food Nutr. Res.* **2018**, *62*. [CrossRef] [PubMed]
58. Miyaoka, T.; Kanayama, M.; Wake, R.; Hashioka, S.; Hayashida, M.; Nagahama, M.; Okazaki, S.; Yamashita, S.; Miura, S.; Miki, H.; et al. Clostridium butyricum MIYAIRI 588 as Adjunctive Therapy for Treatment-Resistant Major Depressive Disorder: A Prospective Open-Label Trial. *Clin. Neuropharmacol.* **2018**, *41*, 151–155. [CrossRef]

59. Dinan, T.G.; Butler, M.I.; Cryan, J.F. Psychobiotics: Evolution of Novel Antidepressants. *Mod. Trends Psychiatry* **2021**, *32*, 134–143. [CrossRef]
60. Chang, L.; Wei, Y.; Hashimoto, K. Brain–gut–microbiota axis in depression: A historical overview and future directions. *Brain Res. Bull.* **2022**, *182*, 44–56. [CrossRef]
61. Kim, Y.-K.; Na, K.-S.; Myint, A.-M.; Leonard, B.E. The role of pro-inflammatory cytokines in neuroinflammation, neurogenesis and the neuroendocrine system in major depression. *Prog. Neuro-Psychopharmacol. Biol. Psychiatry* **2016**, *64*, 277–284. [CrossRef]
62. You, Z.; Luo, C.; Zhang, W.; Chen, Y.; He, J.; Zhao, Q.; Zuo, R.; Wu, Y. Pro- and anti-inflammatory cytokines expression in rat's brain and spleen exposed to chronic mild stress: Involvement in depression. *Behav. Brain Res.* **2011**, *225*, 135–141. [CrossRef] [PubMed]
63. Hayley, S.; Scharf, J.; Anisman, H. Central administration of murine interferon-α induces depressive-like behavioral, brain cytokine and neurochemical alterations in mice: A mini-review and original experiments. *Brain, Behav. Immun.* **2013**, *31*, 115–127. [CrossRef] [PubMed]
64. Brzozowski, B.; Mazur-Bialy, A.; Pajdo, R.; Kwiecień, S.; Bilski, J.; Zwolinska-Wcislo, M.; Mach, T.; Brzozowski, T. Mechanisms by which Stress Affects the Experimental and Clinical Inflammatory Bowel Disease (IBD): Role of Brain-Gut Axis. *Curr. Neuropharmacol.* **2016**, *14*, 892–900. [CrossRef] [PubMed]
65. Karelakis, C.; Zevgitis, P.; Galanopoulos, K.; Mattas, K. Consumer Trends and Attitudes to Functional Foods. *J. Int. Food Agribus. Mark.* **2020**, *32*, 266–294. [CrossRef]
66. Topolska, K.; Florkiewicz, A.; Filipiak-Florkiewicz, A. Functional Food—Consumer Motivations and Expectations. *Int. J. Environ. Res. Public Health* **2021**, *18*, 5327. [CrossRef]
67. Goetzke, B.I.; Spiller, A. Health-improving lifestyles of organic and functional food consumers. *Br. Food J.* **2014**, *116*, 510–526. [CrossRef]
68. Betoret, E.; Betoret, N.; Vidal, D.; Fito, P. Functional foods development: Trends and technologies. *Trends Food Sci. Technol.* **2011**, *22*, 498–508. [CrossRef]
69. Bigliardi, B.; Galati, F. Innovation trends in the food industry: The case of functional foods. *Trends Food Sci. Technol.* **2013**, *31*, 118–129. [CrossRef]
70. Granato, D.; Branco, G.F.; Nazzaro, F.; Cruz, A.G.; Faria, J.A.F. Functional Foods and Nondairy Probiotic Food Development: Trends, Concepts, and Products. *Compr. Rev. Food Sci. Food Saf.* **2010**, *9*, 292–302. [CrossRef]
71. Diez-Ozaeta, I.; Astiazaran, O.J. Fermented foods: An update on evidence-based health benefits and future perspectives. *Food Res. Int.* **2022**, *156*, 111133. [CrossRef]
72. Bourdichon, F.; Casaregola, S.; Farrokh, C.; Frisvad, J.C.; Gerds, M.L.; Hammes, W.P.; Harnett, J.; Huys, G.; Laulund, S.; Ouwehand, A.; et al. Food fermentations: Microorganisms with technological beneficial use. *Int. J. Food Microbiol.* **2012**, *154*, 87–97. [CrossRef]
73. Chilton, S.N.; Burton, J.P.; Reid, G. Inclusion of Fermented Foods in Food Guides around the World. *Nutrients* **2015**, *7*, 390–404. [CrossRef] [PubMed]
74. Marco, M.L.; Heeney, D.; Binda, S.; Cifelli, C.J.; Cotter, P.D.; Foligné, B.; Gänzle, M.; Kort, R.; Pasin, G.; Pihlanto, A.; et al. Health benefits of fermented foods: Microbiota and beyond. *Curr. Opin. Biotechnol.* **2017**, *44*, 94–102. [CrossRef] [PubMed]
75. Kumar, M.R.; Azizi, N.F.; Yeap, S.K.; Abdullah, J.O.; Khalid, M.; Omar, A.R.; Osman, M.A.; Leow, A.T.; Mortadza, S.A.; Alitheen, N.B. Clinical and Preclinical Studies of Fermented Foods and Their Effects on Alzheimer's Disease. *Antioxidants* **2022**, *11*, 883. [CrossRef] [PubMed]
76. Han, X.; Yang, Z.; Jing, X.; Yu, P.; Zhang, Y.; Yi, H.; Zhang, L. Improvement of the Texture of Yogurt by Use of Exopolysaccharide Producing Lactic Acid Bacteria. *BioMed Res. Int.* **2016**, *2016*, 7945675. [CrossRef]
77. Ravyts, F.; De Vuyst, L.; Leroy, F. Bacterial diversity and functionalities in food fermentations. *Eng. Life Sci.* **2012**, *12*, 356–367. [CrossRef]
78. Taylor, B.C.; Lejzerowicz, F.; Poirel, M.; Shaffer, J.P.; Jiang, L.; Aksenov, A.; Litwin, N.; Humphrey, G.; Martino, C.; Miller-Montgomery, S.; et al. Consumption of Fermented Foods Is Associated with Systematic Differences in the Gut Microbiome and Metabolome. *Msystems* **2020**, *5*, 00901–00919. [CrossRef]
79. Tamang, J.P.; Cotter, P.D.; Endo, A.; Han, N.S.; Kort, R.; Liu, S.Q.; Mayo, B.; Westerik, N.; Hutkins, R. Fermented Foods in a Global Age: East meets West. *Compr. Rev. Food Sci. Food Saf.* **2019**, *19*, 184–217. [CrossRef]
80. Le Lay, C.; Coton, E.; Le Blay, G.; Chobert, J.; Haertlé, T.; Choiset, Y.; Van Long, N.N.; Meslet-Cladière, L.; Mounier, J. Identification and quantification of antifungal compounds produced by lactic acid bacteria and propionibacteria. *Int. J. Food Microbiol.* **2016**, *239*, 79–85. [CrossRef]
81. Rezac, S.; Kok, C.R.; Heermann, M.; Hutkins, R. Fermented Foods as a Dietary Source of Live Organisms. *Front. Microbiol.* **2018**, *9*, 1785. [CrossRef]
82. Shiby, V.K.; Mishra, H.N. Fermented Milks and Milk Products as Functional Foods—A Review. *Crit. Rev. Food Sci. Nutr.* **2013**, *52*, 482–496. [CrossRef] [PubMed]
83. Barros, C.P.; Guimarães, J.T.; Esmerino, E.A.; Duarte, M.C.; Silva, M.C.; Silva, R.; Ferreira, B.M.; Sant'Ana, A.S.; Freitas, M.Q.; Cruz, A.G. Paraprobiotics and postbiotics: Concepts and potential applications in dairy products. *Curr. Opin. Food Sci.* **2020**, *32*, 1–8. [CrossRef]
84. Yang, X.; Hu, W.; Xiu, Z.; Jiang, A.; Yang, X.; Ji, Y.; Guan, Y.; Feng, K. Comparison of northeast sauerkraut fermentation between single lactic acid bacteria strains and traditional fermentation. *Food Res. Int.* **2020**, *137*, 109553. [CrossRef]

85. Park, K.-Y.; Jeong, J.-K.; Lee, Y.-E.; Daily, J.W. Health Benefits of Kimchi (Korean Fermented Vegetables) as a Probiotic Food. *J. Med. Food* **2014**, *17*, 6–20. [CrossRef] [PubMed]
86. Xu, Y.; Zang, J.; Regenstein, J.M.; Xia, W. Technological roles of microorganisms in fish fermentation: A review. *Crit. Rev. Food Sci. Nutr.* **2021**, *61*, 1000–1012. [CrossRef]
87. Barcenilla, C.; Ducic, M.; López, M.; Prieto, M.; Álvarez-Ordóñez, A. Application of lactic acid bacteria for the biopreservation of meat products: A systematic review. *Meat Sci.* **2022**, *183*, 108661. [CrossRef]
88. Ashaolu, T.J.; Reale, A. A Holistic Review on Euro-Asian Lactic Acid Bacteria Fermented Cereals and Vegetables. *Microorganisms* **2020**, *8*, 1176. [CrossRef]
89. Ziarno, M.; Cichońska, P. Lactic Acid Bacteria-Fermentable Cereal- and Pseudocereal-Based Beverages. *Microorganisms* **2021**, *9*, 2532. [CrossRef]
90. Tamang, J.P.; Watanabe, K.; Holzapfel, W.H. Review: Diversity of Microorganisms in Global Fermented Foods and Beverages. *Front. Microbiol.* **2016**, *7*, 377. [CrossRef]
91. Teshome, G. Review on lactic acid bacteria function in milk fermentation and preservation. *Afr. J. Food Sci.* **2015**, *9*, 170–175. [CrossRef]
92. Cichońska, P.; Ziarno, M. Legumes and Legume-Based Beverages Fermented with Lactic Acid Bacteria as a Potential Carrier of Probiotics and Prebiotics. *Microorganisms* **2022**, *10*, 91. [CrossRef] [PubMed]
93. Davydenko, S.; Meledina, T.; Mittenberg, A.; Shabelnikov, S.; Vonsky, M.; Morozov, A. Proteomics Answers Which Yeast Genes Are Specific for Baking, Brewing, and Ethanol Production. *Bioengineering* **2020**, *7*, 147. [CrossRef]
94. Michel, M.; Meier-Dörnberg, T.; Jacob, F.; Methner, F.-J.; Wagner, R.S.; Hutzler, M. Review: Pure non- *Saccharomyces* starter cultures for beer fermentation with a focus on secondary metabolites and practical applications. *J. Inst. Brew.* **2016**, *122*, 569–587. [CrossRef]
95. Benito, Á.; Calderón, F.; Benito, S. The Influence of Non-Saccharomyces Species on Wine Fermentation Quality Parameters. *Fermentation* **2019**, *5*, 54. [CrossRef]
96. Hong, J.-Y.; Lee, N.-K.; Yi, S.-H.; Hong, S.-P.; Paik, H.-D. Short communication: Physicochemical features and microbial community of milk kefir using a potential probiotic Saccharomyces cerevisiae KU200284. *J. Dairy Sci.* **2019**, *102*, 10845–10849. [CrossRef]
97. Ranadheera, C.S.; Vidanarachchi, J.K.; Rocha, R.S.; Cruz, A.G.; Ajlouni, S. Probiotic Delivery through Fermentation: Dairy vs. Non-Dairy Beverages. *Fermentation* **2017**, *3*, 67. [CrossRef]
98. Dahiya, D.; Nigam, P.S. Clinical Potential of Microbial Strains, Used in Fermentation for Probiotic Food, Beverages and in Synbiotic Supplements, as Psychobiotics for Cognitive Treatment through Gut–Brain Signaling. *Microorganisms* **2022**, *10*, 1687. [CrossRef]
99. Nkhata, S.G.; Ayua, E.; Kamau, E.H.; Shingiro, J.-B. Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. *Food Sci. Nutr.* **2018**, *6*, 2446–2458. [CrossRef]
100. Xiang, H.; Sun-Waterhouse, D.; Waterhouse, G.I.N.; Cui, C.; Ruan, Z. Fermentation-enabled wellness foods: A fresh perspective. *Food Sci. Hum. Wellness* **2019**, *8*, 203–243. [CrossRef]
101. Van Hylckama Vlieg, J.; Veiga, P.; Zhang, C.; Derrien, M.; Zhao, L. Impact of microbial transformation of food on health—From fermented foods to fermentation in the gastro-intestinal tract. *Curr. Opin. Biotechnol.* **2011**, *22*, 211–219. [CrossRef]
102. Hur, S.J.; Lee, S.Y.; Kim, Y.-C.; Choi, I.; Kim, G.-B. Effect of fermentation on the antioxidant activity in plant-based foods. *Food Chem.* **2014**, *160*, 346–356. [CrossRef] [PubMed]
103. Şanlier, N.; Gökcen, B.B.; Sezgin, A.C. Health benefits of fermented foods. *Crit. Rev. Food Sci. Nutr.* **2019**, *59*, 506–527. [CrossRef] [PubMed]
104. Dimidi, E.; Cox, S.R.; Rossi, M.; Whelan, K. Fermented Foods: Definitions and Characteristics, Impact on the Gut Microbiota and Effects on Gastrointestinal Health and Disease. *Nutrients* **2019**, *11*, 1806. [CrossRef] [PubMed]
105. Rocks, T.; West, M.; Hockey, M.; Aslam, H.; Lane, M.; Loughman, A.; Jacka, F.N.; Ruusunen, A. Possible use of fermented foods in rehabilitation of anorexia nervosa: The gut microbiota as a modulator. *Prog. Neuro-Psychopharmacol. Biol. Psychiatry* **2021**, *107*, 110201. [CrossRef]
106. Selhub, E.M.; Logan, A.C.; Bested, A.C. Fermented foods, microbiota, and mental health: Ancient practice meets nutritional psychiatry. *J. Physiol. Anthr.* **2014**, *33*, 2. [CrossRef]
107. Cenit, M.C.; Nuevo, I.C.; Codoñer-Franch, P.; Dinan, T.G.; Sanz, Y. Gut microbiota and attention deficit hyperactivity disorder: New perspectives for a challenging condition. *Eur. Child Adolesc. Psychiatry* **2017**, *26*, 1081–1092. [CrossRef] [PubMed]
108. Del Toro-Barbosa, M.; Hurtado-Romero, A.; Garcia-Amezquita, L.E.; García-Cayuela, T. Psychobiotics: Mechanisms of Action, Evaluation Methods and Effectiveness in Applications with Food Products. *Nutrients* **2020**, *12*, 3896. [CrossRef]
109. Hemarajata, P.; Versalovic, J. Effects of probiotics on intestine microbiota: Mechanisms of intestinal immunomodulation and neuromodulation. *Ther. Adv. Gastroenterol.* **2013**, *6*, 39–51. [CrossRef]
110. Thangaleela, S.; Sivamaruthi, B.S.; Kesika, P.; Chaiyasut, C. Role of Probiotics and Diet in the Management of Neurological Diseases and Mood States: A Review. *Microorganisms* **2022**, *10*, 2268. [CrossRef] [PubMed]
111. Dinan, T.; Cryan, J.F. The Microbiome-Gut-Brain Axis in Health and Disease. *Gastroenterol. Clin. North Am.* **2017**, *46*, 77–89. [CrossRef]
112. Foster, J.A.; Rinaman, L.; Cryan, J.F. Stress & the gut-brain axis: Regulation by the microbiome. *Neurobiol. Stress* **2017**, *7*, 124–136. [CrossRef] [PubMed]

113. Musa, N.H.; Mani, V.; Lim, S.M.; Vidyadaran, S.; Majeed, A.B.; Ramasamy, K. Lactobacilli-fermented cow's milk attenuated lipopolysaccharide-induced neuroinflammation and memory impairment in vitro and in vivo. *J. Dairy Res.* **2017**, *84*, 488–495. [CrossRef] [PubMed]
114. van de Wouw, M.; Walsh, A.M.; Crispie, F.; van Leuven, L.; Lyte, J.M.; Boehme, M.; Clarke, G.; Dinan, T.G.; Cotter, P.D.; Cryan, J.F. Distinct actions of the fermented beverage kefir on host behaviour, immunity and microbiome gut-brain modules in the mouse. *Microbiome* **2020**, *8*, 67. [CrossRef] [PubMed]
115. Woo, M.; Kim, M.J.; Song, Y.O. Bioactive Compounds in Kimchi Improve the Cognitive and Memory Functions Impaired by Amyloid Beta. *Nutrients* **2010**, *10*, 1554. [CrossRef] [PubMed]
116. Wu, Z.; Wang, P.; Pan, D.; Zeng, X.; Guo, Y.; Zhao, G. Effect of adzuki bean sprout fermented milk enriched in γ-aminobutyric acid on mild depression in a mouse model. *J. Dairy Sci.* **2021**, *104*, 78–91. [CrossRef]
117. Go, J.; Kim, E.; Kwak, M.H.; Koh, E.K.; Song, S.H.; Sung, J.E.; Kim, D.S.; Hong, J.T.; Hwang, D.Y. Neuroprotective effects of fermented soybean products (Cheonggukjang) manufactured by mixed culture of *Bacillus subtilis* MC31 and *Lactobacillus sakei* 383 on trimethyltin-induced cognitive defects mice. *Nutr. Neurosci.* **2016**, *19*, 247–259. [CrossRef]
118. Yoo, D.-H.; Kim, D.-H. *Lactobacillus pentosus* var. *plantarum C29 increases the protective effect of soybean against scopolamine-induced memory impairment in mice. Int. J. Food Sci. Nutr.* **2015**, *66*, 912–918. [CrossRef]
119. Lee, H.-J.; Hwang, Y.-H.; Kim, D.-H. *Lactobacillus plantarum* C29-Fermented Soybean (DW2009) Alleviates Memory Impairment in 5XFAD Transgenic Mice by Regulating Microglia Activation and Gut Microbiota Composition. *Mol. Nutr. Food Res.* **2018**, *62*, 1800359. [CrossRef]
120. Kim, C.-S.; Shin, D.-M. Probiotic food consumption is associated with lower severity and prevalence of depression: A nationwide cross-sectional study. *Nutrition* **2019**, *63–64*, 169–174. [CrossRef]
121. Ohsawa, K.; Nakamura, F.; Uchida, N.; Mizuno, S.; Yokogoshi, H. *Lactobacillus helveticus*-fermented milk containing lactononadecapeptide (NIPPLTQTPVVVPPFLQPE) improves cognitive function in healthy middle-aged adults: A randomised, double-blind, placebo-controlled trial. *Int. J. Food Sci. Nutr.* **2017**, *69*, 369–376. [CrossRef]
122. Mohammadi, A.A.; Jazayeri, S.; Khosravi-Darani, K.; Solati, Z.; Mohammadpour, N.; Asemi, Z.; Adab, Z.; Djalali, M.; Tehrani-Doost, M.; Hosseini, M.; et al. The effects of probiotics on mental health and hypothalamic–pituitary–adrenal axis: A randomized, double-blind, placebo-controlled trial in petrochemical workers. *Nutr. Neurosci.* **2016**, *19*, 387–395. [CrossRef]
123. Tillisch, K.; Labus, J.; Kilpatrick, L.; Jiang, Z.; Stains, J.; Ebrat, B.; Guyonnet, D.; Legrain-Raspaud, S.; Trotin, B.; Naliboff, B.; et al. Consumption of Fermented Milk Product with Probiotic Modulates Brain Activity. *Gastroenterology* **2013**, *144*, 1394–1401.e4. [CrossRef] [PubMed]
124. Berding, K.; Bastiaanssen, T.F.S.; Moloney, G.M.; Boscaini, S.; Strain, C.R.; Anesi, A.; Long-Smith, C.; Mattivi, F.; Stanton, C.; Clarke, G.; et al. Feed your microbes to deal with stress: A psychobiotic diet impacts microbial stability and perceived stress in a healthy adult population. *Mol. Psychiatry* **2023**, *28*, 601–610. [CrossRef] [PubMed]
125. Nishihira, J.; Kagami-Katsuyama, H.; Tanaka, A.; Nishimura, M.; Kobayashi, T.; Kawasaki, Y. Elevation of natural killer cell activity and alleviation of mental stress by the consumption of yogurt containing Lactobacillus gasseri SBT2055 and Bifidobacterium longum SBT2928 in a double-blind, placebo-controlled clinical trial. *J. Funct. Foods* **2014**, *11*, 261–268. [CrossRef]
126. Kato-Kataoka, A.; Nishida, K.; Takada, M.; Suda, K.; Kawai, M.; Shimizu, K.; Kushiro, A.; Hoshi, R.; Watanabe, O.; Igarashi, T. Fermented milk containing Lactobacillus casei strain Shirota prevents the onset of physical symptoms in medical students under academic examination stress. *Benef. Microbes* **2016**, *7*, 153–156. [CrossRef]
127. Márquez-Morales, L.; El-Kassis, E.G.; Cavazos-Arroyo, J.; Rocha-Rocha, V.; Martínez-Gutiérrez, F.; Pérez-Armendáriz, B. Effect of the Intake of a Traditional Mexican Beverage Fermented with Lactic Acid Bacteria on Academic Stress in Medical Students. *Nutrients* **2021**, *13*, 1551. [CrossRef] [PubMed]
128. Zhu, G.; Zhao, J.; Zhang, H.; Chen, W.; Wang, G. Probiotics for Mild Cognitive Impairment and Alzheimer's Disease: A Systematic Review and Meta-Analysis. *Foods* **2021**, *10*, 1672. [CrossRef]
129. Handajani, Y.S.; Turana, Y.; Yogiara, Y.; Widjaja, N.T.; Sani, T.P.; Christianto, G.A.M.; Suwanto, A. Tempeh Consumption and Cognitive Improvement in Mild Cognitive Impairment. *Dement. Geriatr. Cogn. Disord.* **2020**, *49*, 497–502. [CrossRef]
130. Ton, A.M.M.; Campagnaro, B.P.; Alves, G.A.; Aires, R.; Côco, L.Z.; Arpini, C.M.; Guerra e Oliveira, T.; Campos-Toimil, M.; Meyrelles, S.S.; Pereira, T.M.C.; et al. Oxidative Stress and Dementia in Alzheimer's Patients: Effects of Synbiotic Supplementation. *Oxidative Med. Cell. Longev.* **2020**, *2020*, 2638703. [CrossRef]
131. Akbari, E.; Asemi, Z.; Daneshvar Kakhaki, R.; Bahmani, F.; Kouchaki, E.; Tamtaji, O.R.; Hamidi, G.A.; Salami, M. Effect of probiotic supplementation on cognitive function and metabolic status in Alzheimer's disease: A randomized, double-blind and controlled trial. *Front. Aging Neurosci.* **2016**, *8*, 256. [CrossRef]
132. Zinöcker, M.K.; Lindseth, I.A. The Western Diet–Microbiome-Host Interaction and Its Role in Metabolic Disease. *Nutrients* **2018**, *10*, 365. [CrossRef] [PubMed]
133. Casertano, M.; Fogliano, V.; Ercolini, D. Psychobiotics, gut microbiota and fermented foods can help preserving mental health. *Food Res. Int.* **2022**, *152*, 110892. [CrossRef] [PubMed]
134. Forssten, S.D.; Sindelar, C.W.; Ouwehand, A.C. Probiotics from an industrial perspective. *Anaerobe* **2011**, *17*, 410–413. [CrossRef] [PubMed]
135. Tripathi, M.K.; Giri, S.K. Probiotic functional foods: Survival of probiotics during processing and storage. *J. Funct. Foods* **2014**, *9*, 225–241. [CrossRef]

136. Terpou, A.; Papadaki, A.; Lappa, I.K.; Kachrimanidou, V.; Bosnea, L.A.; Kopsahelis, N. Probiotics in Food Systems: Significance and Emerging Strategies Towards Improved Viability and Delivery of Enhanced Beneficial Value. *Nutrients* **2019**, *11*, 1591. [CrossRef]
137. Cichońska, P.; Domian, E.; Ziarno, M. Application of Optical and Rheological Techniques in Quality and Storage Assessment of the Newly Developed Colloidal-Suspension Products: Yogurt-Type Bean-Based Beverages. *Sensors* **2022**, *22*, 8348. [CrossRef]
138. Misra, S.; Mohanty, D. Psychobiotics: A new approach for treating mental illness? *Crit. Rev. Food Sci. Nutr.* **2019**, *59*, 1230–1236. [CrossRef]
139. Kowalska, E.; Ziarno, M. Characterization of Buckwheat Beverages Fermented with Lactic Acid Bacterial Cultures and Bifidobacteria. *Foods* **2020**, *9*, 1771. [CrossRef]
140. Mirković, M.; Mirković, N.; Miočinović, J.; Radulović, A.; Paunović, D.; Ilić, M.; Radulović, Z. Probiotic yogurt and cheese from ultrafiltered milk: Sensory quality and viability of free-living and spray dried *Lactiplantibacillus plantarum* 564 and *Lactiplantibacillus plantarum* 299v. *J. Food Process. Preserv.* **2021**, *45*, 15713. [CrossRef]
141. Hanafi, F.N.A.; Kamaruding, N.A.; Shaharuddin, S. Influence of coconut residue dietary fiber on physicochemical, probiotic (*Lactobacillus plantarum* ATCC 8014) survivability and sensory attributes of probiotic ice cream. *LWT* **2022**, *154*, 112725. [CrossRef]
142. Sun, J.; Chen, H.; Qiao, Y.; Liu, G.; Leng, C.; Zhang, Y.; Lv, X.; Feng, Z. The nutrient requirements of Lactobacillus rhamnosus GG and their application to fermented milk. *J. Dairy Sci.* **2019**, *102*, 5971–5978. [CrossRef] [PubMed]
143. Lei, W.; Luo, J.; Wu, K.; Chen, Q.; Hao, L.; Zhou, X.; Wang, X.; Liu, C.; Zhou, H. Dendrobium candidum extract on the bioactive and fermentation properties of *Lactobacillus rhamnosus* GG in fermented milk. *Food Biosci.* **2021**, *41*, 100987. [CrossRef]
144. Alvarado-Reveles, O.; Fernández-Michel, S.; Jiménez-Flores, R.; Cueto-Wong, C.; Vázquez-Moreno, L.; Montfort, G. Survival and Goat Milk Acidifying Activity of *Lactobacillus rhamnosus* GG Encapsulated with Agave Fructans in a Buttermilk Protein Matrix. *Probiotics Antimicrob. Proteins* **2019**, *11*, 1340–1347. [CrossRef]
145. Sezer, E.; Ayar, A.; Yılmaz, S. Fermentation of Dietary Fibre-Added Milk with Yoghurt Bacteria and *L. rhamnosus* and Use in Ice Cream Production. *Fermentation* **2023**, *9*, 3. [CrossRef]
146. Zamberlin, Š.; Samaržija, D. The effect of non-standard heat treatment of sheep's milk on physico-chemical properties, sensory characteristics, and the bacterial viability of classical and probiotic yogurt. *Food Chem.* **2017**, *225*, 62–68. [CrossRef]
147. Magariños, H.; Cartes, P.; Fraser, B.; Selaive, S.; Costa, M.; Figuerola, F.; Pizarro, O. Viability of probiotic micro-organisms (*Lactobacillus casei Shirota* and *Bifidobacterium animalis* subspp. lactis) in a milk-based dessert with cranberry sauce. *J. Dairy Technol.* **2008**, *61*, 96–101. [CrossRef]
148. Sumalapao, D.E.; Mesina, J.A.; Cabrera, E.C.; Gloriani, N.G. Viability kinetics of *Lactobacillus casei* Shirota strain in a commercial fermented milk drink during refrigerated storage. *Natl. J. Physiol. Pharm. Pharmacol.* **2017**, *7*, 1242–1246. [CrossRef]
149. Angmo, K.; Kumari, A.; Bhalla, T.C. Probiotic characterization of lactic acid bacteria isolated from fermented foods and beverage of Ladakh. *LWT* **2016**, *66*, 428–435. [CrossRef]
150. Gul, O. Microencapsulation of *Lactobacillus casei* Shirota by spray drying using different combinations of wall materials and application for probiotic dairy dessert. *J. Food Process. Preserv.* **2017**, *41*, 13198. [CrossRef]
151. Lavrentev, F.V.; Ashikhmina, M.S.; Ulasevich, S.A.; Morozova, O.V.; Orlova, O.Y.; Skorb, E.V.; Iakovchenko, N.V. Perspectives of Bacillus coagulans MTCC 5856 in the production of fermented dairy products. *LWT* **2021**, *148*, 111623. [CrossRef]
152. Amanda, E.; Choo, W.S. Effect of refrigerated storage on the physicochemical characteristics and viability of *Lactobacillus plantarum* in fermented watermelon juice with or without supplementation with inulin or fructooligosaccharide. *J. Food Process. Preserv.* **2018**, *42*, 13831. [CrossRef]
153. Zoghi, A.; Khosravi-Darani, K.; Sohrabvandi, S.; Attar, H. Patulin removal from synbiotic apple juice using *Lactobacillus plantarum* ATCC 8014. *J. Appl. Microbiol.* **2018**, *126*, 1149–1160. [CrossRef] [PubMed]
154. Bae, J.-J.; Yeon, S.-J.; Park, W.-J.; Hong, G.-E.; Lee, C.-H. Production of sesaminol and antioxidative activity of fermented sesame with *Lactobacillus plantarum* P8, Lactobacillus acidophilus ATCC 4356, Streptococcus thermophilus S10. *Food Sci. Biotechnol.* **2016**, *25*, 199–204. [CrossRef]
155. Zhang, S.; Shi, Y.; Zhang, S.; Shang, W.; Gao, X.; Wang, H. Whole soybean as probiotic lactic acid bacteria carrier food in solid-state fermentation. *Food Control.* **2014**, *41*, 1–6. [CrossRef]
156. Zhang, L.; Taal, M.A.; Boom, R.M.; Chen, X.D.; Schutyser, M.A. Effect of baking conditions and storage on the viability of *Lactobacillus plantarum* supplemented to bread. *LWT* **2018**, *87*, 318–325. [CrossRef]
157. Supasil, R.; Suttisansanee, U.; Santivarangkna, C.; Tangsuphoom, N.; Khemthong, C.; Chupeerach, C.; On-Nom, N. Improvement of Sourdough and Bread Qualities by Fermented Water of Asian Pears and Assam Tea Leaves with Co-Cultures of *Lactiplantibacillus plantarum* and *Saccharomyces cerevisiae*. *Foods* **2022**, *11*, 2071. [CrossRef] [PubMed]
158. Mirković, M.; Seratlić, S.; Kilcawley, K.; Mannion, D.; Mirković, N.; Radulović, Z. The Sensory Quality and Volatile Profile of Dark Chocolate Enriched with Encapsulated Probiotic Lactobacillus plantarum Bacteria. *Sensors* **2018**, *18*, 2570. [CrossRef] [PubMed]
159. Giordano, I.; Abuqwider, J.; Altamimi, M.; Di Monaco, R.; Puleo, S.; Mauriello, G. Application of ultrasound and microencapsulation on *Limosilactobacillus reuteri* DSM 17938 as a metabolic attenuation strategy for tomato juice probiotication. *Heliyon* **2022**, *8*, 10969. [CrossRef] [PubMed]
160. Mauro, C.S.I.; Garcia, S. Coconut milk beverage fermented by *Lactobacillus reuteri*: Optimization process and stability during refrigerated storage. *J. Food Sci. Technol.* **2019**, *56*, 854–864. [CrossRef] [PubMed]

161. Yan, Y.; Zhang, F.; Chai, Z.; Liu, M.; Battino, M.; Meng, X. Mixed fermentation of blueberry pomace with *L. rhamnosus* GG and *L. plantarum*-1: Enhance the active ingredient, antioxidant activity and health-promoting benefits. *Food Chem. Toxicol.* **2019**, *131*, 110541. [CrossRef]
162. Bernat, N.; Cháfer, M.; Chiralt, A.; González-Martínez, C. Hazelnut milk fermentation using probiotic *Lactobacillus rhamnosus* GG and inulin. *Int. J. Food Sci. Technol.* **2014**, *29*, 2552–2562. [CrossRef]
163. de Almeida Bianchini Campos, R.C.; Martins, E.M.; de Andare Pires, B.; do Carmo Gouveia Peluzio, M.; da Rocha Campos, A.; Ramos, A.M.; de Castro Leite Júnior, B.; de Oliveira Martins, A.D.; da Silva, R.R.; Martins, M.L. In vitro and in vivo resistance of *Lactobacillus rhamnosus* GG carried by a mixed pineapple (*Ananas comosus* L. Merril) and jussara (*Euterpe edulis Martius*) juice to the gastrointestinal tract. *Food Res. Int.* **2019**, *116*, 1247–1257. [CrossRef] [PubMed]
164. Alemneh, S.T.; Emire, S.A.; Jekle, M.; Hitzmann, B. Effect of refrigerated storage on some physicochemical characteristics of a teff-based fermented beverage and the viability of the fermenting *Lactiplantibacillus plantarum* and *Lacticaseibacillus rhamnosus* used. *J. Food Process. Preserv.* **2022**, *46*, 17034. [CrossRef]
165. Chan, M.Z.; Toh, M.; Liu, S.-Q. Growth, survival, and metabolic activities of probiotics *Lactobacillus rhamnosus* GG and *Saccharomyces cerevisiae* var. *boulardii CNCM-I745 in fermented coffee brews. Int. J. Food Microbiol.* **2021**, *350*, 109229. [CrossRef] [PubMed]
166. Gangwar, A.S.; Bhardwaj, A.; Sharma, V. Fermentation of tender coconut water by probiotic bacteria Bacillus coagulans. *Int. J. Food Stud.* **2018**, *7*, 100–110. [CrossRef]
167. Soccol, C.R.; de Souza Vandenberghe, L.P.; Spier, M.R.; Medeiros, A.B.; Yamaguishi, C.T.; De Dea Lindner, J.; Pandey, A.; Thomaz-Soccol, V. The Potential of Probiotics: A Review. *Food Technol. Biotechnol.* **2010**, *48*, 413–434.
168. Granato, D.; Branco, G.F.; Cruz, A.G.; Faria, J.A.F.; Shah, N.P. Probiotic Dairy Products as Functional Foods. *Compr. Rev. Food Sci. Food Saf.* **2010**, *9*, 455–470. [CrossRef]
169. Kumar, B.V.; Vijayendra, S.V.; Reddy, O.V. Trends in dairy and non-dairy probiotic products—A review. *J. Food Sci. Technol.* **2015**, *52*, 6112–6124. [CrossRef]
170. Cichońska, P.; Ziębicka, A.; Ziarno, M. Properties of Rice-Based Beverages Fermented with Lactic Acid Bacteria and *Propionibacterium*. *Molecules* **2022**, *27*, 2558. [CrossRef]
171. Shori, A.B. Influence of food matrix on the viability of probiotic bacteria: A review based on dairy and non-dairy beverages. *Food Biosci.* **2016**, *13*, 1–8. [CrossRef]
172. Reque, P.M.; Brandelli, A. Encapsulation of probiotics and nutraceuticals: Applications in functional food industry. *Trends Food Sci. Technol.* **2021**, *114*, 1–10. [CrossRef]
173. Panghal, A.; Janghu, S.; Virkar, K.; Gat, Y.; Kumar, V.; Chhikara, N. Potential non-dairy probiotic products—A healthy approach. *Food Biosci.* **2018**, *21*, 80–89. [CrossRef]
174. Ziarno, M.; Zaręba, D.; Maciejak, M.; Veber., A.L. The impact of dairy starter cultures on selected qualitative properties of functional fermented beverage prepared from germinated White Kidney Beans. *J. Food Nutr. Res.* **2019**, *2*, 167–176.
175. Mousavi, R.; Mottawea, W.; Audet, M.-C.; Hammami, R. Survival and Interplay of γ-Aminobutyric Acid-Producing Psychobiotic Candidates with the Gut Microbiota in a Continuous Model of the Human Colon. *Biology* **2022**, *11*, 1311. [CrossRef] [PubMed]
176. Nordström, E.A.; Teixeira, C.; Montelius, C.; Jeppsson, B.; Larsson, N. *Lactiplantibacillus plantarum* 299v (LP299V®): Three decades of research. *Benef. Microbes* **2021**, *12*, 441–465. [CrossRef]
177. Goossens, D.; Jonkers, D.; Russel, M.; Thijs, A.; Van den Bogaard, A.; Stobberingh, E.; Stockbrügger, R. Survival of the probiotic, L. plantarum 299v and its effects on the faecal bacterial flora, with and without gastric acid inhibition. *Dig. Liver Dis.* **2005**, *37*, 44–50. [CrossRef]
178. Li, R.; Zhang, Y.; Polk, D.B.; Tomasula, P.M.; Yan, F.; Liu, L. Preserving viability of Lactobacillus rhamnosus GG in vitro and in vivo by a new encapsulation system. *J. Control. Release* **2016**, *230*, 79–87. [CrossRef]
179. Paniágua, A.L.; Correia, A.F.; Pereira, L.C.; de Alencar, B.M.; Silva, F.B.A.; Almeida, R.M.; de Madeiros Nóbrega, Y.K. Inhibitory effects of Lactobacillus casei Shirota against both Candida auris and Candida spp. isolates that cause vulvovaginal candidiasis and are resistant to antifungals. *BMC Complement. Med. Ther.* **2021**, *21*, 237. [CrossRef]
180. Wang, R.; Chen, S.; Jin, J.; Ren, F.; Li, Y.; Qiao, Z.; Wang, Y.; Zhao, L. Survival of *Lactobacillus casei* strain Shirota in the intestines of healthy Chinese adults. *Microbiol. Immunol.* **2015**, *59*, 268–276. [CrossRef]
181. Salonen, A.; de Vos, W.M. Impact of Diet on Human Intestinal Microbiota and Health. *Annu. Rev. Food Sci. Technol.* **2014**, *5*, 239–262. [CrossRef]
182. Yuki, N.; Watanabe, K.; Mike, A.; Tagami, Y.; Tanaka, R.; Ohwaki, M.; Morotomi, M. Survival of a probiotic, Lactobacillus casei strain Shirota, in the gastrointestinal tract: Selective isolation from faeces and identification using monoclonal antibodies. *Int. J. Food Microbiol.* **1999**, *48*, 51–57. [CrossRef] [PubMed]
183. Xiao, J.; Katsumata, N.; Bernier, F.; Ohno, K.; Yamauchi, Y.; Odamaki, T.; Yoshikawa, K.; Ito, K.; Kaneko, T. Probiotic Bifidobacterium breve in Improving Cognitive Functions of Older Adults with Suspected Mild Cognitive Impairment: A Randomized, Double-Blind, Placebo-Controlled Trial. *J. Alzheimer's Dis.* **2020**, *77*, 139–147. [CrossRef] [PubMed]
184. Adamberg, S.; Sumeri, I.; Uusna, R.; Ambalam, P.; Kondepudi, K.K.; Adamberg, K.; Wadström, T.; Ljungh, Å. Survival and synergistic growth of mixed cultures of bifidobacteria and lactobacilli combined with prebiotic oligosaccharides in a gastrointestinal tract simulator. *Microb. Ecol. Health Dis.* **2014**, *25*, 23062. [CrossRef] [PubMed]

185. Andrews, E.B.; Eaton, S.C.; Hollis, K.A.; Hopkins, J.S.; Ameen, V.; Hamm, L.R.; Cook, S.F.; Tennis, P.; Mangel, A.W. Prevalence and demographics of irritable bowel syndrome: Results from a large web-based survey. *Aliment. Pharmacol. Ther.* **2005**, *22*, 935–942. [CrossRef] [PubMed]
186. Charbonneau, D.; Gibb, R.D.; Quigley, E.M. Fecal excretion of Bifidobacterium infantis 35624 and changes in fecal microbiota after eight weeks of oral supplementation with encapsulated probiotic. *Gut Microbes* **2013**, *4*, 201–211. [CrossRef] [PubMed]
187. Collado, M.; Meriluoto, J.; Salminen, S. Adhesion and aggregation properties of probiotic and pathogen strains. *Eur. Food Res. Technol.* **2008**, *226*, 1065–1073. [CrossRef]
188. Velez, M.P.; De Keersmaecker, S.C.; Vanderleyden, J. Adherence factors of *Lactobacillus* in the human gastrointestinal tract. *FEMS Microbiol. Lett.* **2007**, *276*, 140–148. [CrossRef]
189. Rong, J.; Zheng, H.; Liu, M.; Hu, X.; Wang, T.; Zhang, X.; Jin, F.; Wang, L. Probiotic and anti-inflammatory attributes of an isolate Lactobacillus helveticus NS8 from Mongolian fermented koumiss. *BMC Microbiol.* **2015**, *15*, 196. [CrossRef]