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THE HEALTH BENEFITS OF FERMENTED FOOD: A NARRATIVE REVIEW

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Abstract: Fermented foods form a significant proportion of human diets from across the world. Increasing evidence promotes the health benefits of fermented foods on human health. The microorganisms present in these foods improve many health conditions. They include various fungi and probiotic bacterial species that are intentionally added as starter cultures or are naturally present in certain foods. Through fermentation, microbes metabolise food components including carbohydrates and proteins, to produce molecules that benefit the human host within and beyond the intestines. Among these are molecules that suppress the overgrowth of commensal and pathogenic microbes. Chronic dysbiosis is linked to inflammatory bowel diseases and has been reported in subjects with major depression and metabolic risk factors. Regular intake of fermented foods can improve these conditions and alleviate various risk factors of certain chronic diseases. Incorporating fermented foods as part of a healthy diet for chronic disease prevention offers a promising prospect. This study reviews the different types of fermented foods and the underlying microbes in modifying disease and health conditions. An overview of the disease-modulating effects is also summarised, which covers health conditions related to intestinal health, metabolic syndrome (MetS), cardiovascular health and neurological health.

Keywords: *Fermented food, gastrointestinal, probiotics, health, lactic acid bacteria (LAB)*

1. Introduction

Fermentation is one of the oldest chemical processes performed by humankind. Traces of fermented alcohol and grains can be found in ancient archaeological sites. Men utilised fermentation to prolong the edible life of food during times when refrigeration had not yet been invented, and freezing was only applicable to those living in frigid areas. Most commonly consumed foods are the products of fermentation, for example, cheese, yoghurt, tempeh and tapai. In many regions of the world then, fermentation started with the artisanal expertise of food makers and indigenous ways of food preservation. Today, fermentation has become the focus of many large-scale food industries, though the commercialised selection of food types remains limited, with cultured drinks and dairy products being the most popular (Intelligence, 2021). It follows that fermented foods and beverages make up a big part of human life.

In an anaerobic environment, fermentation involves the action of selected microbes, including yeasts and bacteria, on several substrates found in food, such as carbohydrates and proteins. A starter culture may initiate fermentation, spontaneously or otherwise, as when making tempoyak. In the case of alcoholic beverages, sugars in foods such as grapes, barley, wheat, and rice are fermented by yeast using zymase to form carbon dioxide and ethanol. Apart from this classic fermentation reaction, many other foods, such as fish, meat, fruits, and vegetables, can be fermented by various bacterial species, including lactic acid bacteria (LAB) and non-LAB.

Excluding alcoholic beverages, regular consumption of fermented foods has many benefits for human health (Parvez et al., 2006). Most fermented foods contain beneficial microbes called probiotics, live microbes that offer health benefits to the human host when consumed in adequate amounts (Hill et al., 2014). The reported health benefits of fermented foods include promoting gastrointestinal (GI) health, alleviating cardiovascular and metabolic disorders, and promoting brain functions (Dimidi et al., 2019; Galland, 2014; Gille et al., 2018).

The intake of fermented foods as part of a healthy diet is gaining interest in Malaysia. This study aims to explain the health benefits of fermented foods and relate them to the respective microbial and bioactive metabolite content. The common health conditions included in this review are GI health, metabolic syndrome (MetS), cardiovascular health, and neurological health. Fundamental knowledge of fermented foods and the interaction between the food components and the probiotic content with the human host becomes a prerequisite.

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2. Beneficial Microbes in Fermented Foods

The physicochemical and organoleptic properties of fermented foods are distinctive to the metabolic products of the microbes found in them. LAB are the most abundant microbes in fermented foods (Table 1) and has become the go-to starter culture in foods such as yoghurt and cultured drinks. These LAB-populated foods have a distinguished acidic taste from the lactic acid produced during fermentation. The genera that fall under this category of microbes are *Lactobacillus*, *Leuconostoc*, *Lactococcus*, *Weissella*, and *Streptococcus thermophilus*.

The non-LAB in fermented foods include other bacteria and fungi (Table 2). These microbes provide various characteristics to fermented foods, such as changes in flavour, a lower pH, and additive nutritional values. Among the non-LAB in fermented foods are acetic acid bacteria such as *Acetobacter* spp., lipolytic bacteria that include several species of the genus *Bacillus*, and fungi like *Saccharomyces* spp.

Table 1. LAB Genera Found in Different Fermented Foods

Genus	Fermented food	References
Bifidobacterium	Kefir *Lait caillé* *Yucha*	(Demir, 2020) (Parker et al., 2018) (Zhang et al., 2016)
Enterococcus	*Chicha* *Fu yu* *Koozh* *Lait caillé*	(Puerari et al., 2015) (J. K. H. Chen & Lim, 2018) (Veerapagu & Jeya, 2017) (Parker et al., 2018)
Lactobacillus	Cereal, dairy, cassava, alcoholic and locust bean fermentations *Chhurpi, churkam, gheu/mar, dahi* *Chicha* Fermented vegetables Kefir *Kisra, hulumur* *Kaeng-som* *Lait caillé* Palm wine Shanxi aged vinegar *Yucha*	(Diaz et al., 2019) (Shangpliang et al., 2018) (Puerari et al., 2015) (Peng et al., 2018) (Demir, 2020; Korsak et al., 2015; Walsh et al., 2016; X. Wang et al., 2018) (Eltayeb et al., 2020) (Sanchart et al., 2017) (Parker et al., 2018) (Djeni et al., 2020) (Zhu et al., 2018) (Zhang et al., 2016)
Lactococcus	*Chhurpi, churkam, gheu/mar, dahi* Kefir *Lait caillé* Shanxi aged vinegar *Yucha*	(Shangpliang et al., 2018) (Demir, 2020; Korsak et al., 2015) (Parker et al., 2018) (Zhu et al., 2018) (Zhang et al., 2016)
Leuconostoc	Cassava and alcoholic fermentations *Chhurpi, churkam, gheu/mar, dahi* *Chicha* Kefir Lait caillé Palm wine	(Diaz et al., 2019) (Shangpliang et al., 2018) (Puerari et al., 2015) (Korsak et al., 2015; Walsh et al., 2016) (Parker et al., 2018) (Djeni et al., 2020)
Pediococcus	Fermented vegetables *Fu yu* *Kalarei* *Kisra, hulumur* *Lait caillé* Shanxi aged vinegar *Yucha*	(Peng et al., 2018) (J. K. H. Chen & Lim, 2018) (Bhagat et al., 2020) (Eltayeb et al., 2020) (Parker et al., 2018) (Zhu et al., 2018) (Zhang et al., 2016)
Streptococcus	Cereal, dairy and alcoholic fermentations Kefir *Lait caille*	(Diaz et al., 2019) (Demir, 2020) (Parker et al., 2018)
Weissella	Cereal, dairy and cassava fermentations Fermented vegetables *Lait caillé* *Yucha*	(Diaz et al., 2019) (Peng et al., 2018) (Parker et al., 2018) (Zhang et al., 2016)

Table 2. Non-LAB and Fungi Genera Found in Fermented Food

Genus	Fermented food	Source
Bacteria		
Acetobacter	Cereal and dairy fermentations *Chhurpi, churkam, gheu/mar, dahi* *Hulumur* *Kefir* *Lait caillé* *Palm wine* Shanxi aged vinegar	(Diaz et al., 2019) (Shangpliang et al., 2018) (Eltayeb et al., 2020) (Korsak et al., 2015; Walsh et al., 2016) (Parker et al., 2018)

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		(Djeni et al., 2020) (Zhu et al., 2018)
Acinetobacter	*Chicha* Fermented vegetables *Lait caillé* *Yucha*	(Puerari et al., 2015) (Peng et al., 2018) (Parker et al., 2018) (J. Zhang et al., 2016)
Bacillus	Cassava, alcoholic and locust bean fermentations *Chicha* *Lait caillé* *Nham, pla-ra, kaeng-chom, sai-krog-prieo*	(Diaz et al., 2019) (Puerari et al., 2015) (Parker et al., 2018) (Phoottosavako et al., 2015)
Gluconobacter	*Chhurpi, churkam, gheu/mar, dahi* *Hulumur* *Kefir* Palm wine	(Shangpliang et al., 2018) (Eltayeb et al., 2020) (Korsak et al., 2015; Walsh et al., 2016) (Djeni et al., 2020)
Gluconacetobacter	Kefir Palm wine	(Walsh et al., 2016) (Djeni et al., 2020)
Paenibacillus	*Nham*	(Phoottosavako et al., 2015)
Rhizobium	Fermented vegetables Shanxi aged vinegar	(Peng et al., 2018) (Zhu et al., 2018)
Streptomyces	*Chicha*	(Puerari et al., 2015)
Zymomonas	Cereal, dairy, alcoholic and locust bean fermentations Palm wine	(Diaz et al., 2019) (Djeni et al., 2020)
Fungi		
Alternaria	*Hulumur*	(Eltayeb et al., 2020)
Aspergillus	*Kisra*	(Eltayeb et al., 2020)
Penicillium	*Hulumur*	(Eltayeb et al., 2020)
Rhizopus	*Kisra*	(Eltayeb et al., 2020)
Saccharomyces	Kefir Palm wine	(Demir, 2020; Walsh et al., 2016; X. Wang et al., 2018) (Djeni et al., 2020)
Kazachstania	Kefir	(Korsak et al., 2015; Walsh et al., 2016)

3. Improvement of Gastrointestinal Microbiota and Health

One of the essential health benefits of fermented foods is the improvement of GI health due to the significant content of the probiotic population. Probiotic-rich fermented foods contribute to intestinal health by modulating intestinal microbiota diversity, protecting the intestinal mucosal lining and modulating the humoral immune system.

Microbes with good probiotic potential can withstand the digestive conditions of the gut, including highly acidic pH, digestive enzymes and bile salts. These characteristics enable them to inhabit and multiply in the intestines, as demonstrated by the LAB derived from fermented foods, including the *Pediococcus acidilactici, Pediococcus pentosaceus* and *Enterococcus* strains (Bhagat et al., 2020; Gupta & Sharma, 2017; Veerapagu & Jeya, 2017). Similarly, the *Lactobacillus* strains can survive through high gastric acidity, resist GI digestion, adhere to the intestinal mucosal cells and lack antibiotic resistance (Bautista-Gallego et al., 2019; Khalil et al., 2018). Selecting probiotic strains that do not develop antibiotic resistance is essential, as pathogenic microbes can transfer to antibiotic resistance genes (Khalil et al., 2018).

To confer health benefits to the host, the probiotics in fermented foods must suppress the growth of commensal and pathogenic microbes, including bacteria, fungi, and viruses (Hernández-González et al., 2021). This competitive survival ability ensures that the probiotics can further multiply and increase in population. The *Lactococcus lactis* strain isolated from kaeng-som (a fermented shrimp product from Thailand) produces bacteriocin that inhibits the growth of *Staphylococcus aureus*, a dominant food pathogen and opportunistic bacterium (Saelao et al., 2017). Several LAB strains from various Chinese fermented foods demonstrate antimicrobial properties against many opportunistic pathogens, including *Staphylococcus aureus*, *Helicobacter pylori* and *Escherichia coli*, by producing biosurfactants that inhibit the formation of biofilm by pathogens (Kaur et al., 2015; Ren et al., 2018; Sun et al., 2018). This may explain why kefir (a Russian fermented dairy product) significantly inhibits the growth of *Enterobacter cloacae*, *Escherichia coli* and *Enterococcus faecalis*, as it is rich in several LAB genera such as *Lactobacillus*, *Lactococcus*, *Streptococcus*, and *Bifidobacterium* (Demir, 2020).

Probiotics also produce organic acids that create an unfavourable environment for the growth of pathogenic microbes in the intestines. Kefir, when inoculated with *Escherichia coli* and *Staphylococcus aureus*, inhibits the growth of both pathogens due to the development of acidic conditions from the lactic and acetic acid produced by the probiotics (Kivanc & Yapici, 2019). Hor et al. (2019) demonstrate the ability of aqueous extracts of khambir (fermented sourdough bread from India) to inhibit the growth of several enteropathogens such as *Salmonella typhi*, *Shigella dysenteriae* and *Streptococcus faecalis*.

Positive changes in the gut microbiota of individuals who regularly consume fermented foods have also been observed. First, the gut microbiota of these individuals show higher proportions of LAB, such as *Lactobacillus acidophilus*, *Lactococcus lactis*, *Leuconostoc mesenteroides,* and several other

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Lactobacillus strains (Taylor et al., 2020). Second, their intestines have significantly suppressed levels of harmful pathogenic bacteria such as *Clostridium* spp. and *Bilophila wadsworthia* (Messaoudi et al., 2011; Veiga et al., 2014). The evidence suggests that probiotic-rich fermented foods restore the gut microbiota to its healthy characteristic, which is crucial in maintaining GI health.

Probiotics and beneficial commensal bacteria also produce fatty acids like conjugated linoleic acid (CLA) and short-chain fatty acids (SCFA) that contribute to intestinal health. *Eubacterium* and *Bifidobacterium* spp. produce CLA, which has anti-inflammatory properties (Taylor et al., 2020). As the probiotics populate the gut and promote the growth of beneficial commensal bacteria, they also assist in maintaining the CLA at a high level to sustain the anti-inflammatory properties of the intestines. SCFA consist of acetate, propionate and butyrate, with a chain length of up to six carbon atoms. These fatty acids, particularly butyrate, are utilised by the colonocytes as an essential energy source (Venegas et al., 2019). Cow's milk, fermented with *Lactobacillus paracasei*, promotes the population of butyrate producers *Roseburia* and *Blautia* in a host (Berni Canani et al., 2017). This subsequently enhances the production of butyrate, supporting the intestinal physiological function (H. Liu et al., 2018).

Fermented foods also protect the integrity of the intestinal mucosal barrier. Chronic inflammation can disrupt the integrity and decrease the intestinal barrier function if triggered by an overgrowth of pathogenic bacteria such as *Clostridium* spp. and *Bilophila wadsworthia* (Messaoudi et al., 2011; Veiga et al., 2014). Regular intake of fermented dairy products like yoghurt may restore inflammation-disrupted intestinal integrity by improving the epithelial tight junction barrier (Putt et al., 2017). *Bifidobacterium bifidum,* a typical starter culture for fermented dairy products, has been shown to bind with Toll-like receptor-2 on the enterocytes, activating the p38 kinase pathway without causing NF-κB activation (Al-Sadi et al., 2021). This probiotic/enterocyte interaction prevents the proliferation and colonisation of pathogens and reduces inflammation (Ohland & MacNaughton, 2010). Probiotics in fermented foods also strengthen the intestinal mucous layer by increasing mucin secretion by goblet cells. The mucin creates a shield that restricts potentially harmful molecules and bacterial movement across the mucous layer (Ohland & MacNaughton, 2010).

Besides being a barrier, the intestinal mucosal surface produces immunoglobulin A (IgA), forming part of the intestinal immunological barrier. Probiotics interact with the enterocytes, stimulating the production of IgA to promote the clearance of antigens and pathogenic microbes from the intestinal lumen. Mice fed with dahi (Indian curd), containing *Lactobacillus acidophilus* and *Bifidobacterium bifidum*, show increased intestinal IgA levels with suppressed serum IgE, suggesting immunoprotection without causing hypersensitivity (Shandilya et al., 2016).

Other than the probiotic/enterocyte interaction, specific bioactive bacterial metabolites isolated from fermented foods can contribute to intestinal immunomodulation. D-phenyllactic acid (D-PLA), a LAB metabolite found in sauerkraut (German cabbage pickle), is a potent agonist of human hydroxycarboxylic acid receptor 3 (HCA3). HCA3 is highly expressed in immune cells, suggesting D-PLA's positive role in regulating the immune system and helping to maintain gut health (Peters et al., 2019). Consuming Bulgarian yoghurt, which has a starter culture of *Streptococcus thermophilus* and *Lactobacillus bulgaricus*, can result in elevated major faecal SCFA (Khuropakhonphong et al., 2021). Acetate, in particular, can promote the production of IgA and help strengthen the immunological barrier of a host (Wu et al., 2017). Certain intestinal inflammatory conditions, including irritable bowel syndrome and ulcerative colitis, have been associated with dysbiosis and gut microbiota imbalance, resulting in an immunocompromised intestinal mucosal barrier (L. Wang et al., 2020; Zakerska-Banaszak et al., 2021). Restoring the healthy balance of the gut microbiota is pivotal in reducing the immune dysregulation induced by pathogenic microbes. Consuming fermented foods containing probiotics may help restore that healthy balance, alleviating inflammation. Colitis-induced mice, administered with two *Lactobacillus* strains derived from Funazushi (fermented sushi), show significantly reduced inflammation in the colonic mucosa (Okada et al., 2018). It follows that the inflammation is reduced substantially with the expression of β8 integrin on dendritic cells, thereby inducing the proliferation and differentiation of regulatory T cells in the inflamed colonic mucosa (Okada et al., 2018). In another instance, one-year-old infants with gastroenteritis are fed yoghurt and subsequently display significantly attenuated inflammation (Nakamura et al., 2019).

Apart from the protective effect of probiotics on the intestinal lining, bioactive molecules derived from probiotics in fermented foods have also been reported to exhibit functional effects on the GI system. The pylorus in the stomach has a high expression of human trace amine-associated receptor 1 (hTAAR1). It is hypothesised that certain amino acids in fermented foods can interact with these receptors. Tyramine and phenylalanine, found in cheese and tofu-misozuke (Japanese fermented tofu), interact with hTAAR1r to stimulate gastric acid secretion and motility, and gastric epithelium proliferation by Stomach G cells (Ohta et al., 2017). The overall outcome is an improvement in protein digestion.

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4. Improvement of Metabolic Syndrome

MetS is a group of health risk factors that increases the risk of heart disease, stroke and diabetes. The underlying causes include insulin resistance, abdominal obesity and physical inactivity. Significant studies have been conducted to evaluate the effect of fermented foods from different regions of the world on various parameters of MetS. It follows that the intake of these foods relates to the improvement of blood pressure, insulin resistance, fasting blood glucose and blood lipid profile.

In the Mediterranean region, elderly subjects who routinely consumed full-fat yoghurt had a lower incidence of developing MetS risk factors (Babio et al., 2015). However, elevated risks of MetS were observed in individuals consuming cheese, partly because of its higher sodium, phosphorus and fat content than other dairy products (Babio et al., 2015). Prediabetic individuals consuming Korean had reduced body weight, increased insulin sensitivity, enhanced glucose tolerance, and improved systolic and diastolic blood pressure (An et al., 2013). These positive effects can be associated with a decrease in the Firmicutes/Bacteroidetes ratio, which becomes relatively greater in obese individuals (Crovesy et al., 2020; Han et al., 2015). In Indonesia, a trial conducted on obese women showed that tempeh gembus (fermented soybean pulp) reduced triglyceride and high-sensitivity C-reactive protein levels and improved insulin resistance and HDL cholesterol levels (Nadia et al., 2020; Wati et al., 2020). *Rhizopus oligosporus*, utilised in fermenting soybean pulp, increases fibre and decreases the carbohydrate content of tempeh gembus, which may partly explain the improvement in blood lipid levels and glucose tolerance (Olanipekun & Adelakun, 2015). A cohort study involving Japanese adults reported that an intake of 20 g of natto (fermented soy food) per day lowered the total cholesterol, LDL cholesterol, and triglyceride levels in obese and overweight subjects (Wilunda et al., 2020). However, these effects were not significantly evident in the subjects of the lower BMI categories. *Bacillus subtilis natto*, as the starter culture for the production of natto, contributes to the beneficial effect by regulating the gut microbiota. However, the direct impact on serum lipid levels has not been clearly defined (P. Wang et al., 2020). Lacto-fermented annurca apple increases serum HDL cholesterol levels and reduces trimethylamine-N-oxide, an essential marker of oxidative stress (Tenore et al., 2019). An increase in oxidative stress contributes to MetS (Roberts & Sindhu, 2009).

One possible mechanism to improve MetS with fermented foods is to modulate gene expressions in the normal metabolic pathways. A study has found that traditional kefir preparations can reduce the expression of the fatty acid synthase and the peroxisome proliferator-activated receptor (PPAR) γ, translated as a reduction in triglyceride deposition in the livers of mice (Bourrie et al., 2018). Another study demonstrates the improvement of insulin resistance in mice after the supplementation of a LAB-enriched fermented food paste (FFP) through the upregulation of glucose transporter proteins and insulin receptors in the adipose tissues (Zulkawi et al., 2018). The FFP-supplemented mice also showed an increase in the expression of genes encoding glycolytic enzymes such as glucose-6-phosphate dehydrogenase, glucokinase, phosphofructokinase, and 6-phosphogluconate dehydrogenase, also activated by insulin in normal conditions (Zulkawi et al., 2018).

Evidence also suggests that fermented foods directly attenuate the development of MetS. The supplementation of *Bifidobacterium* spp., isolated from an ethnic rice beverage, on diet-induced obese mice causes reduced weight gain, improved lipid parameters, lowered high blood glucose levels, and sustained liver function. These are outcomes from the elevated expression of the lipolysis-regulating enzymes PPARα and PPARδ. The downregulation of lipogenic factors and enzymes, including PPARγ, sterol regulatory element-binding protein 1s, acetyl-CoA carboxylase, fatty acid synthase, and tumour necrosis factor α, was also observed (Ray et al., 2018). *Lactobacillus paracasei* L3C21M6, isolated from an artisanal cheese, was reported to reduce cholesterol and histamine levels. *Lactobacillus* strains, isolated from fermented foods like tapai (fermented tapioca), display cholesterol-lowering abilities, increasing the catabolism of cholesterol to bile acid and reducing enterohepatic recycling of bile acid (Lim et al., 2020; Qu et al., 2020). All these properties potentially decrease the risk of heart disease and histamine intolerance (Domingos-Lopes et al., 2020).

SCFA from probiotics in fermented foods also contribute to preventing MetS. The SCFA supplementation in mice suppresses the accumulation of hepatic triglycerides and downregulates the genes related to fatty acid synthesis. These effects are mediated physiologically by the endogenous receptor free fatty acid receptor 3 (Shimizu et al., 2019). Fermented foods increase the population of SCFA-producing bacteria in the gut, indirectly reducing fatty acid synthesis.

Evidence indicates MetS risk factor improvement from animal studies, as trials on human subjects are still lacking.

5. Improvement of Cardiovascular Health

Many risk factors of cardiovascular diseases (CVD) overlap with those related to MetS. Studies selected for this research focus mainly on the cardiovascular risk factors without obesity and insulin resistance as part of the study design. In the absence of obesity, hypertension is the most significant CVD risk factor. Fermented dairy and cheese attenuate arterial stiffness in ageing individuals with isolated systolic hypertension (Ribeiro et al., 2018). Bioactive peptides, from milk proteins produced during fermentation, inhibit the Angiotensin-converting enzyme, reducing Angiotensin II (Rai et al., 2017). The outcome is a lowering of blood pressure and a decrease in the risk of arterial stiffness.

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A study in Japan reports that natto consumption has a significant inverse association with total CVD-related mortality (Katagiri et al., 2020). Nattokinase, a serine protease isolated from natto, exhibits fibrinolytic properties (Weng et al., 2017). Similarly, a fibrinolytic enzyme obtained from the *Stenotrophomonas* spp. and isolated from oncom (a soybean-based fermented food) can dissolve blood clots in rats injected with kappa-carrageenan (Nailufar et al., 2016). The formation of an obstructive thrombus is closely related to extensive vascular disease. Fibrinolysis is cardioprotective as it reduces pathological abnormalities in the fibrinolytic system and eliminates atherothrombotic risk.

Several other fermented foods also contain microbes that produce compounds with anticoagulant properties. Pickled opossum shrimp, a Korean delicacy, produces two novel fibrinolytic enzymes (Kim et al., 2020). Fermented garlic also exhibits cardiovascular protective properties due to S-allylcysteine (SAC) and S-allylmercaptocysteine (SAM), which prevents platelet aggregation and thrombus formation (Rahman & Billington, 2000). The LAB population in garlic increases during fermentation and is likely responsible for the formation of SAC and SAM. Other cardiovascular protective properties of SAC and SAM include reducing triglyceride levels to prevent hepatic steatosis, promoting angiogenesis, and protecting endothelial cells from oxidative injury (Irfan et al., 2019; X. Zhang et al., 2019).

6. Improvement of Neurological Health

Increasing evidence indicates the relationship between GI health and the brain, known as the gut-brain axis. Recent findings report that gut microbiota synthesises substances that act as signalling molecules, facilitating interaction between the gut and the brain. Such interactions represent normal brain functions such as memory, cognition, sleep patterns, stress reactivity and mood (Galland, 2014). Disturbances in the gut-brain axis increase the prevalence of chronic non-communicable diseases like irritable bowel syndrome (IBS), obesity, type 2 diabetes mellitus, chronic fatigue syndrome, and psychologic disorders such as depression (Slyepchenko et al., 2017). A matched cohort study reveals that patients diagnosed with IBS are more likely to experience depression and anxiety, along with several other physical problems such as asthma and diverticulosis (Jones et al., 2006). It follows that significant changes to the gut microbiome resulting from dietary habits are likely to affect one's psychological conditions.

Literature relating food consumption to mental health and brain function has been expanding, though studies with conclusive evidence remain sparse. However, promising findings demonstrate fermented foods and probiotics as dietary interventions. A cross-sectional survey of young adults indicated a significant effect of fermented food consumption on social anxiety, especially in subjects with high traits of neuroticism (Hilimire et al., 2015). In these subjects, a more frequent intake of fermented foods decreased the symptoms of social anxiety. Stress reduction is also another effect associated with the intake of fermented foods. The intake of fermented milk, which has *Lactobacillus* strains, decreases anxiety and stress and physical symptoms such as fever, headache, and abdominal pains, in medical students undergoing academic examination (Kato-Kataoka et al., 2016; Takada et al., 2016). Other positive effects of fermented foods related to mental health include reduced fatigue and eased depression, resulting in a better quality of life (Jiang et al., 2017).

However, some studies show a lack of relationship between fermented food intake and mental health. One study involved pregnant volunteers in their second and third trimesters (Takahashi et al., 2016). The lack of a positive effect was because the enrolled subjects were health-conscious pregnant women in the peak of good health; they displayed no signs of physiological stress. Another study found no physical or psychological improvements in patients with IBS after consuming yoghurt (Simrén et al., 2009). The above represents a limitation of this study.

Increasing evidence suggests microbiota dysbiosis is present at the onset of depressive disorders (Y. Liu et al., 2021). In patients with major depressive disorder, the gut microbial population is biased towards the phyla of *Bacteroidetes* and *Firmicutes* instead of the beneficial strains from the *Actinobacteria* phylum (Zheng et al., 2016). Therefore, diversifying the gut microbiota through a diet of fermented foods can promote mental and neurological health due to the content of beneficial probiotics and the associated bioactive molecules. Furthermore, probiotics can suppress the stress reactivity of the hypothalamus-pituitary-adrenal axis by reducing plasma corticosterone levels, the corticotropin-releasing factor neurons reducing the c-Fos expression (Takada et al., 2016). Fermented foods are rich in γ-aminobutyric acid (GABA), a well-known neurotransmitter. LAB, yeasts and moulds are among the microbes that can synthesise GABA; hence, fermented dairy products, tapai and tempeh are likely to contain a significant amount of GABA (Y.-C. Chen et al., 2021; Sahab et al., 2020; Yu et al., 2020). GABA in fermented foods induces a sedative effect, beneficial in managing insomnia and depression (Daglia et al., 2017; Embark & Abdalla, 2019; Mabunga et al., 2015). The mechanics behind the sedative effect have not been elucidated; whether it involves local regulation or changes to blood and/or CNS. Increased intestinal SCFA are likely related to the sedative effect, suggesting that modulating the gut microbiota induces more SCFA-producing bacteria such as *Actinobacteria* (including *Bifidobacterium* spp.) (Y.-C. Chen et al., 2021; Yu et al., 2020). In rats with anxiety-like behaviour induced by antibiotics, a cocktail of probiotics isolated from various fermented foods implies a neuroprotective reaction. The rats displayed reduced symptoms of neuron damage with better locomotor function, improved memory and reduced anxiety, alongside an enhanced intestinal microbial population (Luang-In et al., 2020). A link exists between the improvement of gut

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microbiota and mental health; however, it requires further investigation.

Evidence suggests that dietary intervention with fermented foods can improve cognition and enhance memory and learning. Fermented soybeans contain *Lactobacillus plantarum* and have been reported to improve mild cognitive impairment in subjects aged 55 to 85. It associates with increased serum brain-derived neurotrophic factor (BDNF) and improved cognition, including attention, working memory and verbal memory (Hwang et al., 2019). Camembert cheese, fermented with *Penicillium candidum,* has been found to suppress brain inflammation in mice with Alzheimer's. A novel bioactive metabolite, Oleamide, isolated from the cheese, is observed to possess *microglial anti-inflammatory properties (Ano et al., 2015).* An increase in BDNF and the *glial cell line-derived neurotrophic factor follows*, slowing the progress of the disease and preventing reduced cognition and further deterioration of the neurons (Ano et al., 2015)*.* Other bioactive molecules, isolated from various fermented dairy and cereal products, are found to prevent cognitive decline, including tryptophan-tyrosine and tryptophan-methionine peptides, fermented rice peptides, β-lactolin and poly-γ-glutamic acid (Ano et al., 2019; Corpuz et al., 2019; Jeong et al., 2021; Kita et al., 2019). These molecules possess anti-inflammatory properties, producing increased BDNF levels, suppressing brain insulin resistance and promoting neuroprotection (Ano et al., 2019; Jeong et al., 2021).

7. Fermented Food Safety and Quality Consideration

An essential aspect of fermented food safety in mass production is eliminating the risk of contamination by harmful microbes. To minimise this risk, it is crucial that the raw material is clean and has the lowest possible microbial load, ensuring fermentation is solely due to the starter culture. Microbial contaminants are metabolites produced by contaminating fungi or bacteria. Mycotoxins, such as *Aspergillus, Penicillium* and *Cladosporium,* are harmful secondary metabolites of fungi (Anal et al., 2020)*.* Certain LAB produce biogenic amines in cheese, fermented fish and soybean products. However, contaminating bacteria like *Enterobacteriaceae* and *Enterococci* can produce toxic levels of biogenic amines that are harmful if consumed (Anal et al., 2020). Reducing these contaminations is possible with the practice of hygiene throughout food production. Aseptic processes and a clean environment make for good manufacturing practice for large-scale productions.

Fermented foods are enjoyed in many regions due to the unique flavour developed during fermentation. Microbial metabolites, particularly the more volatile compounds, impart a distinctive smell and taste, characteristic of the type of fermented food. Temperature variations during fermentation can result in different flavours due to the various biochemical processes of the microbes and the varying amounts of microbial metabolites (Hong et al., 2016). It follows that fermented foods may have different flavours if prepared in other regions of the world due to variations in climate and temperature. To maintain consistent flavours, the fermentation environment, particularly the temperature, is controlled using bioreactors, with congruous monitoring of the metabolites. It represents another important quality aspect that requires attention especially when the fermented food is mass produced.

8. The Future of Fermented Foods in Malaysia

The regulated use of fermented foods as a dietary intervention for disease prevention in Japan has been well-established for over 30 years. Japan's Ministry of Health, Labour and Welfare initiated the Food for Specific Health Use (FOSHU) in 1991 to target people who were still healthy or in the preliminary stage of chronic disease (Iwatani & Yamamoto, 2019). The initiative involved highly regulated functional foods labelled with health claims that included those related to improving GI health. In 2017, 55% of the total sales of FOSHU products were from the GI health improvement category, related to prebiotics and fermented foods with the *Lactobacillus* spp.(Iwatani & Yamamoto, 2019). This evidence implies a healthy Japanese population with a high life expectancy.

Currently, awareness is lacking in Malaysia on the health benefits of traditional fermented foods because consumers need access to adequate information. Although strong evidence is available, awareness on the benefits of fermented foods is still far behind that of Japan. The prospect of widespread consumption of various fermented foods is promising. However, it can only be successful in maintaining the population's health and well-being if the use is regulated to ensure safety and all health claims are supported by solid evidence (Koirala & Anal, 2021).

Malaysians have a natural affinity for food and are receptive to different tastes and flavours across the country. The future holds new possibilities for industry-based research focusing on production processes, quality assurance and prolonged shelf-life of fermented foods to meet local and global demands. Efforts should identify and standardise the microbes utilised for commercially-available fermented foods, especially those from the cottage industry. Over time, these foods can establish a more robust commercial presence and be available for consumers locally and globally.

9. Conclusion

Can fermented foods be classified as functional foods? The answer is yes since these foods demonstrate a potentially positive effect on health beyond basic nutrition. Consuming fermented foods modulate the gut microbiota to a healthy characteristic, indirectly promoting the host's health. Although optimal health can be achieved without the routine intake of fermented foods, evidence suggests that fermented foods

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containing live probiotics improve health conditions, including intestinal and metabolic health. With the prevalence of chronic diseases, especially those relating to the lower GI tract depicting an upward trend, food-based intervention can be promoted as an adjunct to pharmacotherapy to manage selected health conditions. It is without side effects and is a more pleasant and delectable approach that can be part of an individual's healthy dietary habits. The prospect of these foods for health and wellness is promising. The market for fermented foods is growing, and consumers have begun to accept various food types from all cultural backgrounds. With strong, accessible evidence, consumers can make informed choices about their health. Fermented foods can then have an indicative place in the functional food market.

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