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Fermented foods as alternative functional foods during post-pandemic in Asia

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According to research on the COVID-19 pandemic, consumption of a variety of foods, drinks, nutritional supplements, and other substances that could assist the immune system's defense against the disease is advised. Among these, fermented foods, an age-old method of food preservation, especially in Asia offer better advantages. Fermented foods provide diversity in food products, having unique flavors and aromas as well as acting as functional foods. In other words, fermentation may lessen the effects of COVID-19 by boosting the antioxidant activity of foods and increase immunity by improving digestion, especially in Asia. The purpose of this review was to evaluate the therapeutic responses of fermented foods and the relationship of respective bioactivities toward disease prevention during the COVID-19 pandemic. It has been suggested that traditional fermented foods in Asian countries could increase immunity and act as a first line of defense against the potential COVID-19 infection.

KEYWORDS

fermented food, Asian food, superfood, pandemic, functional food, COVID-19

1 Introduction

Unpredictable situations such as unfavorable political issues, terrorist activities, natural disasters, and pandemics might impact the destination preferences of individuals and cause the tourism sector to be adversely affected (Sahingoz and Yalcin 2022). Initially broke out in Wuhan, China, in 2019, the coronavirus (COVID-19) pandemic caused significant economic losses to the tourism sector, with such applications as the closures of countries' borders globally. The COVID-19 disease is an infectious disease caused by the SARS-CoV-2 virus and has affected the whole world, thus bringing tourism activities to a standstill. Officially termed on 11 February 2020 and acknowledged as a global pandemic in March 2020, COVID-19 has created an unprecedented social and economic impact (Bae and Chang 2021).

TABLE 1 Popular Asian plant-based fermented foods and their relationship with COVID-19 prevention.

Country	Local name	Substrate	Key health benefit	COVID-19 feasibility	Reference
Korea	*Kimchi*	Cabbage	Anti-tumor	Anti-tumor necrosis factor (TNF) antibody therapy	Feldmann et al. (2020), Qian, Liu et al. (2022)
Malaysia	*Kicap*	Soybean	Immune booster	First line of defense on viral exposure	Wan-Mohtar et al. (2019), Ahmed, Hassan et al. (2021)
China	*Douchi*	Soybean	Antihypertensive	Reduces oxidative stress and inflammatory responses of infected organs	Zhang et al. (2006), Lammi and Arnoldi (2021)
Korea	*Cheonggukjang*	Soybean	Anticancer	Anti-COVID-19 efficacy	Lee et al. 2012, El Bairi et al. (2020)
Indonesia	*Tempe*	Soybean	Antidiabetic	Glycemic control	Tamam et al. (2019), Singh and Khunti (2020)

The World Health Organization (WHO) has issued cautions and suggestions of using face masks, maintaining social distance, and practicing good hygiene to ward off the illness and stop it from spreading. In addition to these, medical professionals have stressed the significance of boosting immune function, claiming that increasing functional food consumption could help in the fight against the pandemic (Alkhatib 2020). Fermented foods are those products that involve the action of microorganisms or their respective metabolites that cause desirable biochemical changes. The global fermented food and beverage market is projected to grow at a CAGR of 6.35% during the forecast period of 2022–2027 due to the rising demand of healthy and nutritious product. It is claimed that while fermented foods alone may not be sufficient to prevent COVID-19 and safeguard people's health, they may help in strengthening immune systems. However, no research on the potential anti-COVID-19 efficacy of fermented meals derived from both plant and animal sources has been reported.

Up to 50% of those who died due to COVID-19 had metabolic dysfunctions, particularly in Asia, including diabetes, hypertension, obesity, non-alcoholic fatty liver, and obesity. Because it is customary for Asians to eat high-calorie staple foods like bread and rice, there is an increased chance of experiencing severe COVID-19 responses as well as indications of metabolic dysfunction (Yu et al., 2021). Fermented foods may be practical as novel therapy alternatives for patients with both diabetes and COVID-19 since they meet the local preference. In summary, this review intends to highlight the research findings about the link between Asian fermented foods and COVID-19 and the studies providing recommendations for safeguarding health, boosting immunity, and slowing down the progression of the illness during the COVID-19 outbreak.

2 Prominent plant-based fermented foods in Asia and COVID-19 feasibility

Fermented foods are popular in Asia, especially from plant-sources such as *kimchi* (cabbage) (Lee et al., 2021), soy sauce or *kicap* (soybean) (Sassi et al., 2021), *douchi* (soybean) (Wang et al., 2008), *cheonggukjang* (soybean) (Kim et al., 2021), and *tempe* (soybean) (Ahnan-Winarno et al., 2021). Due to high protein content, viability, ease of processing, and flavor output, soybeans are the most used plant source to produce fermented foods (Qin et al., 2022). Five well-known Asian plant-based foods are listed in Table 1, along with the information on how they could be used to reduce COVID-19 symptoms and increase preventive precautions.

Based on these local fermented foods, five key health benefits are found to have relation in preventing COVID-19 symptoms. The Korean traditional fermented *kimchi* leads the chart with anti-tumor effect, which could lead to the potential key antibody in generating anti-tumor necrosis factor (TNF) COVID-19 therapy. Meanwhile, the Malaysian *kicap* contains key immune-booster compound called gamma-aminobutyric acid (GABA) (Sassi et al., 2022), which provides first-line defense in combatting the initial exposure to COVID-19. The Chinese *douchi* provides a strong antioxidant effect both in *in vivo* and *in vitro* (Wang et al., 2008) which can reduce oxidative stress and inflammatory responses of infected organs of COVID-19 patients. As for drug repurposing, Korean *cheonggukjang* may improve anti-COVID-19 efficacy.

Even in the absence of other comorbidities, diabetes is related with a markedly increased severity and mortality in COVID-19. In individuals with COVID-19, uncontrolled hyperglycemia rises the likelihood of severity and fatality. Antidiabetic medications do not yet appear to have either a positive or negative impact on COVID-19 patients, despite the lack of available data. The Indonesian *tempe*, which has antidiabetic properties, may offer the best glycemic control in individuals with diabetes (Tamam et al., 2019).

As people become more aware of the health benefits of fermented foods, they choose them more regularly to bolster their immune systems. The common beneficial microorganisms associated with fermented foods are lactic acid bacteria (LAB) from *Lactobacillus* sp. and *Streptococcus* sp. and molds such as *Rhizophus* sp. and *Aspergillus* sp. that show favorable effect on health as a result of changes by enzymes and metabolites. The fermentation process retains and sometimes improves the

TABLE 2 Potential therapeutic effects of animal-based fermented foods and the associated microorganisms and bioactive compounds.

Fermented food	Associated microorganism or bioactivity	Claimed therapeutic effect	Reference
Fermented shrimp paste	Lactic acid bacteria (LAB)	Potential probiotic effects—survived low pH (pH 2–4) and bile salt (1–5%) conditions	Ar et al. (2017)
	Chitooligosaccharides	Strong cholesterol lowering effect, antioxidant activity, resists lipid peroxidation, and influences the growth of health beneficial microbes	Pongsetkul et al. (2015), Halder, Adak et al. (2013)
	Maillard reaction products	Antioxidant activity against the 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical, hydrogen peroxide, and lipid peroxidation	Peralta et al. (2008)
Fermented fish paste	*Staphylococcus piscifermentans*, *S. condimenti*, *S. carnosus*, and unknown *Staphylococcus*	Potential probiotics—highest tolerance to gastric juice, bile salts, and phenol	Singh et al. (2018a)
	Crude protein	Potential anticancer—high cytotoxic activity against cancer cell lines (HeLa and HT-29)	Singh et al. (2018b)
	Bacterial isolate HNS60	Antimicrobial activity against *Staphylococcus aureus*, *Escherichia coli*, and *Pseudomonas aeruginosa*	Singh et al. (2018a)
Fermented fish	*Bacillus megaterium* and *Pediococcus pentosaceus*	Antimicrobial activity against *Esherichia coli, Staphylococcus aureus,* and *Klebsiella* sp	Ida Muryany et al. (2017)
		Potential probiotics—no hemolytic activity and tolerant to various pH (pH 3, 5, and 7.5) and 0.3% (w/v) bile salts	
Fermented fish sauce	Peptides (Lue-Asp-Asp-Pro-Val-Phe-Ile-His)	High antioxidant activity	Najafian and Babji (2019)
Fermented meat	*Lactobacillus lactis* CTC 204 and *L. plantarum*	Potential probiotic effects—to prevail the digestion process and to colonize the intestinal environment	Munekata et al. (2022) Moreno et al. (2018)
	Angiotensin I-converting enzyme (ACE) inhibitor	Treats and manages hypertension by preventing an enzyme in the body from producing angiotensin II, a substance that narrows blood vessels	Stadnik and Kęska (2015)
Fermented sausages	*Lactiplantibacillus plantarum* and *Lacticaseibacillus rhamnosus*	Potential probiotic effects—modified the composition of fecal flora in human subjects	Rubio et al. (2014)
	Lacticaseibacillus paracasei	Induction of immunological response (antibodies against oxidized LDL and CD4 (T helper)- lymphocytes)	Jahreis et al. (2002)
Fermented meat sauce	Antioxidant (peptide Gln-Tyr-Pro)	High antioxidant activity against the hydroxyl radical	Ohata et al. (2016)

nutritional content of drinks and food products while extending their shelf-life.

3 Bioactivities of animal-based fermented foods in Asia

Animal-based fermentation is one of the preservation techniques used by older generation to extend the shelf-life of nitrogenous perishable food. Fermented foods have been associated with several positive health effects, including improved digestive health, preventing and treating diarrhea, and building stronger immunity, which could contribute in a positive way to fight against COVID-19. The mechanisms generally involve breaking down of proteins in food by the protease enzyme derived from microbes to various bioactive peptides and accessible nutrients. Table 2 shows the summary of animal-based fermented food categories, microorganisms, bioactivities involved, and potential therapeutic effects associated with selected fermented foods.

3.1 Fish-based fermentation

During fish fermentation, organic substances are transformed into simpler compounds such as peptide, amino acid, or another nitrogenous compound. These compounds are responsible for the unique flavor and aroma development in fermented foods (Peralta, Hatate et al., 2008). In addition, the digestibility of proteins is enhanced as protease enzymes from microbes bring about the improvement of various bioactive peptides. *Pekasam* (Malaysia) and *tungtap* (India) are examples of fermented fish produced in a traditional way. *Pekasam* is produced using freshwater fish and mixed with salt and ground-roasted uncooked rice, while *tungtap* is mixed with salt only followed by fermentation for a week in an airtight container. A potential probiotic activity was reported in fermented fish as they demonstrate tolerance toward low pH and bile salt and show antimicrobial activity against pathogenic microorganisms. In addition, no hemolytic activity was detected to prove that such strains are non-virulence (Ida Muryany et al., 2017).

Singh et al. (2018b) conducted a study on the fermented fish paste known as *Utonga-kupsu* and *hentak* in Northern India and reported the potential probiotic activity of the microbial isolates and anticancer activity of the crude protein. These traditional fish pastes are prepared by mixing several small fishes, such as *Esomus danricus* and *Puntius sophore*, with mustard oil and kept in an earthen pot (*hentak*) or bamboo pot (*Utonga-kupsu*) for months at room temperature (Singh et al., 2018a). *Budu* is another type of a fermented fish liquid produced from fresh anchovies and salt, followed by fermentation for 3–12 months. The proteolytic action during fermentation produced variety of amino acid sequences, such as Lue-Asp-Asp-Pro-Val-Phe-Ile-His, that show high antioxidant activity (Najafian and Babji 2019).

3.2 Shrimp-based fermentation

The shrimp paste is one of the popular semi-finished food ingredients made from fresh tiny shrimps (*geragau*) and is being used as a flavor enhancer in many Malaysian dishes. Known as *belacan* in Malaysia, *terasi* in Indonesia, *kapi* in Thailand, and *Mam Ruoc* in Vietnam, the shrimp paste processing varies according to the producer and regional culture. In general, shrimps are mixed with salt, semi-dried under the sun, pounded, sealed in airtight containers, and let to ferment for several days at 28–30°C. The fermented shrimp will then be mashed, dried, and molded to different shapes and sizes (Leong et al., 2009). During the fermentation process, lactic acid bacteria (LAB) together with halophilic bacteria are predominant among the microflora in the paste.

The shrimp paste shows a great potential as a functional food for hypercholesterolemic patients suffering from oxidative stress as it exhibits antioxidant, (Pongsetkul et al., 2015), probiotic and prebiotic activity and lowers cholesterol and blood pressure (Halder et al., 2013). A study on the Philippine-salted shrimp paste reported an increase in antioxidant activity against 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical, hydrogen peroxide, and lipid peroxidation after prolonged fermentations up to 12 months potentially due to the development of Maillard reaction products (Peralta et al., 2008). In addition, Ar et al. (2017) found that LAB isolated from the shrimp paste have potential probiotic properties because 7.8% of the isolates survived low pH (pH 2–4) and bile salt conditions (1–5%).

3.3 Meat-based fermentation

Meat-based fermentation provides a stable meat product with a unique flavor and aroma. Fermented sausages, known as *lap cheong* in China and *lap xuong* in Vietnam, are one of the fermented foods that are produced through drying or smoking pork or poultry. It is made from a mash of lean and fatty tissue, mixed with salt, spices, sugar, and sometimes curing agents such as nitrite, nitrate, and ascorbate. The mixture is then filled into a casing and left to ferment at 20–45°C for >4 weeks (Lücke 2003). In some cases, the starter cultures such as LAB, coagulase-negative staphylococci, and yeasts and molds are introduced (single or mixed culture) to initiate the fermentation process (Laranjo et al., 2019). Their functional role is to inhibit the growth of pathogenic microorganisms by reducing the pH or producing enzymes to degrade biogenic amines.

Munekata et al. (2022) reported that bioactive compounds from fermented meat are the potential sources of probiotics that could benefit the recovery of COVID-19 patients. Probiotic strains such as *Lactobacillus lactis* CTC 204 and *L. plantarum* CTC 368 have been isolated from fermented meat products. Scientific evidence has been found for a slight induction of immunological response (antibodies against oxidized LDL and CD4 (T helper)-lymphocytes) in 20 subjects that consumed fermented sausage containing *Lacticaseibacillus paracasei* (Jahreis et al., 2002). In addition, fermented meat-associated bioactive peptides play important roles as the angiotensin I-converting enzyme (ACE) inhibitor and as an antioxidant. As hypertension has been identified as a major risk factor for the increased severity and mortality associated with COVID-19 (Peng et al., 2021), the ACE inhibitor could be used as potent functional food to treat and manage hypertension by preventing an enzyme in the body from producing angiotensin II, a substance that narrows blood vessels (Stadnik and Kęska 2015). As for the antioxidant, Ohata et al. (2016) reported that the fermented meat sauce shows high antioxidant activity against the hydroxyl (OH)-radical from the peptide Gln-Tyr-Pro.

4 Challenges, current prospect, and future work

Fermented foods are now more frequently chosen to strengthen the immune system as a result of the growing health awareness (Sassi et al., 2021). The beneficial microorganisms found in fermented foods have a good impact on health because of the changes brought by the metabolites. However, the following significant hindrances of fermented foods need to be considered in the post-pandemic period, especially on a larger production scale:

- Consumption side effects

After consuming fermented foods, some people may experience side effects, such as bloating, a frequent reaction brought on by a brief rise in gas. Migraines, headaches, histamine intolerance, food-borne illnesses, probiotic infections, and antibiotic resistance are a few more side effects that have been described (Skowron et al., 2022). Food poisoning due to the growth of pathogenic microbes under unhygienic processing conditions can be tackled by food safety assurance systems such as HACCP, GMP, and GHP.

- Strain mutation or inconsistent starter culture

Fungal starter cultures are inoculated with foods as spore suspensions to assure predictable fermentation results (e.g., *Aspergillus oryzae* strain NSK in soy sauce) and used to generate mold-fermented foods (Yee et al., 2021). Likewise, bacteria-fermented foods (e.g., *Streptococcus thermophilus* strain 84C in Nostrano cheese) follow the same philosophy (Carafa et al., 2019). Today, the majority of these strains are screened and isolated from the natural population of organisms present in the ecosystem where food is grown. These strains frequently fall short of the standards of contemporary food production. There are few strains that are toxicologically unproblematic; hence, strategies for creating new strains with novel traits would include addressing strain mutation, which would lead to altered organoleptic features of end products.

- Halal regulatory

Alcohol is a common byproduct of fermented foods, which may have an impact on Muslim consumers, particularly regarding halal certification and regulation. There are dissimilarities in the practice of ethanol standard in the halal dietary product between Brunei, Indonesia, Malaysia, and Singapore. The differences in the criteria will make it difficult for halal producers to follow the certification laws of these nearby countries on an industrial scale. These differences were discovered to be centered around four variables: substance of desire, detecting method, BAC limit, and Islamic worldviews. As a key example for Southeast Asia context, the current practice for fermented food manufacturers to secure halal certification is *via* MABIMS (The Informal Meeting of Religious Ministries of Brunei, Indonesia, Malaysia, and Singapore).

- Consumer acceptance

Even while fermented foods are tangy, acidic, aromatic, delicious, and mouth-watering, they nevertheless contain 15–20% salt, which affects consumer acceptance, particularly those from non-Asian regions. Although sodium salt plays a key role in traditional fermented foods, excessive intake has negative effects on consumer health. The recommended nutrient intake (RNI) for sodium is 1,500 mg/day for adults of 19 years and above (Ahmad et al., 2021). As a result, efforts to lower the sodium content of traditional fermented foods and create low-sodium versions have gained momentum. The manufacturing of low-sodium fermented foods should follow proper procedures, given the crucial role that sodium salt plays in the safety and quality of fermented foods.

Fermented nutrients typically develop a wide range of useful characteristics. These qualities improve food's nutritional content, variety, flavor, and aroma, while also making proteins, carbs, vitamins, and minerals easier to digest. They have a beneficial impact on boosting the immune system. People with poor immune systems or malnutrition are more likely to become ill or become infected with COVID-19. Therefore, robust immune systems are necessary for people to maintain their lives by defending their health against COVID-19. The rates of sickness and mortality are said to be higher in undernourished civilizations although immunity can be increased with a variety of foods, drinks, and dietary supplements. Therefore, it is advised to take foods that could boost immune systems to lower the risk of COVID-19 infection.

The Thai people, who have been fermenting food wastes like eggshell, onion skin, and banana skin for decades after washing the leaves, seeds, roots, and soil of their plant with encouraging results, are an example of how the future of fermented foods remains relevant as biofertilizers once COVID-19 stabilizes (Mohd Zaini et al., 2022). Other significant future prospects are in gene transfer (Wang, Wu et al., 2022), diarrheal disease management (Olayanju et al., 2022), respiratory health (Kesika et al., 2022), and Alzheimer's disease (Kumar et al., 2022).

5 Conclusion

Future culinary trends are being paved by fermented foods. The evident benefits of fermented food, pressing itself as alluring alternatives for other meals, include their ability to be produced in large quantities, dependability, economy, environmentally friendly nature, and most crucially found to be regularly produced at high quality. We remain adamant that fermented foods adhere to and assist the United Nation's Sustainable Development Goals. Both goal #3, "Good Health and Well-Being," and goal #2, "Zero Hunger," have immediate consequences. Utilizing fermented food is consistent with the shorter-term goals of the 2030 Agenda for Sustainable Development, including goal 2.3, which calls for doubling agricultural productivity, and goal 2.4, which calls for ensuring sustainable food production systems and putting in place resilient agricultural practices that boost productivity and production. This is true even for fermented food served as a "superfood" during the post-pandemic era.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization: WW-M, ZI, and NM. Data curation: NM, AJ, and WD. Funding acquisition: WW-M, ZI, and NM. Investigation: WW-M and ZI. Methodology: NM, WW-M, and WD. Project administration: ZI and WW-M. Resources: WW-M and ZI. Software: WD. Supervision: WW-M and NZ. Visualization: NZ. Writing—original draft: NZ, WW-M, ZI, and WD. Writing—review and editing: NM, WW-M, ZI, and AJ. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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