

The Power of Soy: Health Benefits of Soybean Fermented and Novel Food Products

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ABSTRACT

*Soybean seeds are rich in protein, oils, vitamins, minerals, and other essential nutrients that benefit human health. Despite its health benefits, it cannot be consumed directly due to intrinsic antinutritional factors (ANFs). Traditional fermentation practices employed in Asian and Northeastern India offer a promising solution by enhancing digestibility and potentially unlocking additional health benefits. This review comprehensively examines the diverse landscape of fermented soy foods (SFFs) across these regions, focusing on their background, manufacturing processes, and the microbial communities driving their unique characteristics. We explore the natural microflora involved, including bacteria (*Bacillus* spp.) and molds (*Rhizopus* spp., *Aspergillus* spp., *Mucor* spp.), and their role in generating bioactive compounds that contribute to human health. The importance of controlled fermentation with specific starter cultures is also discussed to optimize health benefits and minimize spoilage risks. Overviews of the bioactive compounds released by these fermenting microorganisms and their role in human health. The roles of spoilage and toxin-producing microorganisms, as well as of antimicrobial microorganisms, have been discussed. Furthermore, the review examined the recent surge in novel fermented soy foods (NFSFs), driven by consumer demand for plant-based alternatives, and their potential health benefits associated with specific strains and fermentation techniques. We highlighted the functional properties of NFSFs and their potential applications in diverse food categories. Breeding for fermented food-grade and vegetable-type soybean varieties was discussed. Finally, we explored the challenges and future directions for NFSF research and development, focusing on scalability, consumer acceptance, and the need for robust scientific data on health benefits.*

Keywords: Soybean fermented food (SFF), North-eastern India, Fermenting microbial diversity, Novel fermented soy foods, Controlled fermentation, Human health benefits

1 | INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) offers a versatile, readily available, and cost-effective reservoir of high-quality protein, containing approximately 40 % protein and 18 % oil. Its incorporation into the diet could help in addressing protein deficiency among Indians. However, in the past, we promoted it as an oilseed crop. Therefore, a profit could be extended to only 12 mha of land in India (Modgil et al., 2021). Since we have many options for oilseed crops with higher oil content than soybeans. So, if it had been promoted as a proteinaceous crop, it would have been extended to many parts of the world, including India. Since the Indian population suffers from protein deficiency, soybeans could be used for food and nutritional security.

Soybean protein carries a protein digestibility-corrected amino acid score (PDCAAS) equal to 1.00, similar to dairy or meat sources. It has all the essential amino acids except sulfur (Qin et al., 2022). The functional and health benefits of soy protein are further enhanced by fermentation. Fermented soybean contains bioactive compounds such as biopeptides, protein

hydrolysates, isoflavones, phytosterols, and enzymes, which play a significant role in anti-obesity, anti-cancer, anti-hypertensive, hypocholesterolemic, anti-microbial, anti-osteoporosis, anti-inflammatory, immunostimulatory, and anti-aging effects (do Prado et al., 2022; Tsai et al., 2020). The US Food and Drug Administration (USFDA) recommends 25 g of soy protein daily to reduce cholesterol and heart disease risk. Non-fermented soy products are soy dairy, meat, and egg analogs. In Indian households, soybean chunks are the most widely consumed for food purposes (Kumar et al., 2021). However, the use of fermented soybean products is restricted to north-eastern regions. Since soy chunks are a highly processed commodity, their health benefits are far more limited than those of incorporating fermented soy products, which have higher nutritional value, into the daily Indian diet.

Concern in direct consumption of soybean seed due to the presence of ANFs like Kunitz trypsin inhibitor (KTI), lipoxygenase, phytic acids, oxalate, and oligosaccharides, which cause bloating, flatulence, nausea, and other diseases upon consumption, as well as off-flavors caused by lipoxygenases (Bueno et al., 2018). Products with no beany

flavor and lower ANF content can be produced by exploiting the benefits of the fermentation process (Tao et al., 2022). Various soybean-fermented products are prepared in the north-eastern regions, such as bekang, aakhone, kinema, hawaijar, perayaan, and tungrymbai, across different states (Tamang, 2015). Further, mycotoxin contamination through external and internal seed-borne soybean pathogens and its impact on food were discussed. However, consumer acceptability of these products is limited to the Northeastern regions. Therefore, research efforts are needed to increase the popularity of fermented soy products across India. This review explores various methods of fermenting soybeans and the resulting health benefits. Additionally, it addresses the limited utilization of traditional fermented soy products in India. It discusses novel soy-fermented foods and vegetable soybean as a means of promoting their widespread adoption to improve nutritional security.

2 | TRADITIONAL SOYBEAN FERMENTED FOODS (SFFs): BACKGROUND, MANUFACTURING PROCESSES, AND MICROBIAL DIVERSITY

2.1 | Classification of Traditional SFFs

"Fermentation is life without oxygen," said Loise Pasteur. It can be alcoholic, lactic, butyric, mixed, propionic, or acetic

acid, depending upon the types of microorganisms. It can be achieved through natural fermentation by existing microflora or through controlled fermentation with starter cultures. Further, it may be mediated by bacteria, fungi, or both, and may involve solid-state or submerged fermentation, or both. Soybean fermented products are of two types based on salt taste: Salted includes miso, soy sauce, and douche, whereas non-salted are natto, tempeh, and kinema. Another classification may be predominantly bacterial-mediated fermentation processes, such as those with *Bacillus* spp. like kinema, natto, and chungkookjang. Similarly, fungal-mediated genera like *Mucor* spp., *Rhizopus* spp., *Aspergillus oryzae*, and *Fusarium* spp. involved in the production of miso and tempeh. Another classification involves bacterial and fungal partners, e.g., Doenjang (do Prado et al., 2022; Sanjukta & Rai, 2016). In northeastern India and Nepal, Japan, and northern Thailand, there exists a region known as the "natto triangle," recently renamed the Kinema-natto-thua nao (KNT) triangle (Table 1, Fig. 1), where non-salted soybean fermented foods, mediated by *Bacillus* sp., are prevalent (Tamang, 2009).

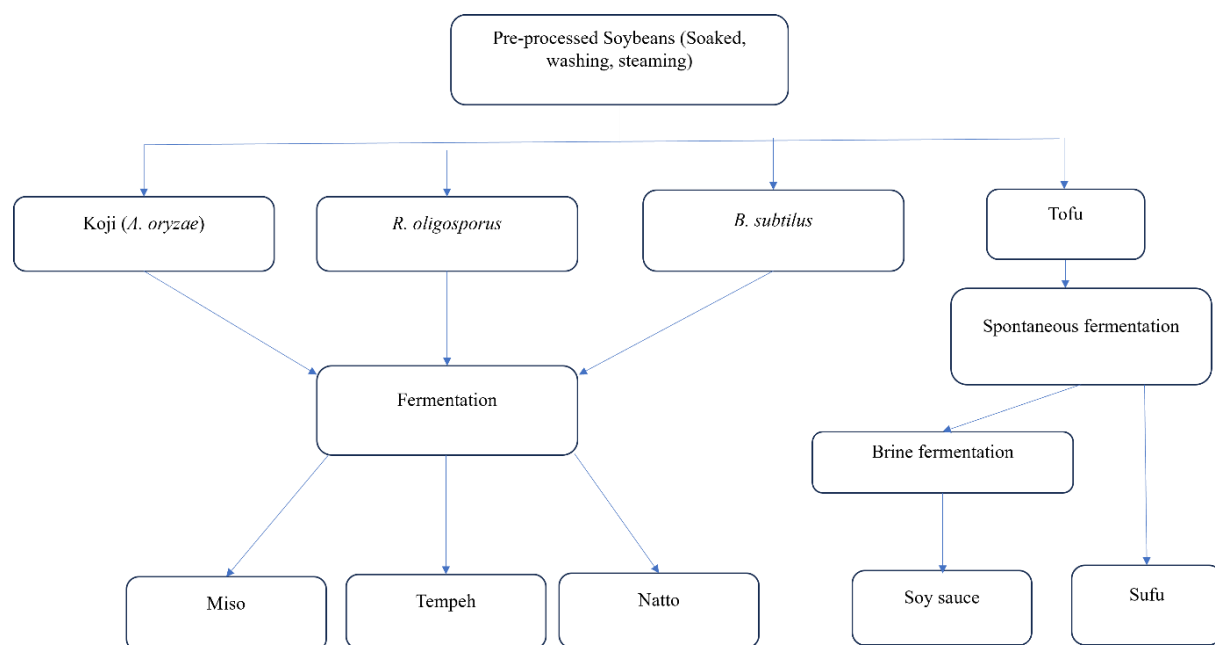


Fig. 1 Soybean fermented food (SFFs) based on the type of microorganisms and fermentation.

Table 1 Soybean-fermented products in Asian countries (Chettri & Tamang, 2015; do Prado et al., 2022; Liu et al., 2022).

Countries	Soybean fermented products
China	Douchi, Meitauza, Sufu, Feru
Taiwan	Douchi
Japan	Miso, Natto, Tofuyo, Soybean sauce
Korea	Doenjang, Meju Cheonggukjang, and Kanjang
Indonesia	Temphe, Kecap, Tauco
Thailand	Thua-nao
India	Kinema, Tungrymbai, Bekang, and Hawaijar
Myanmar	Pe-poke
Bhutan	Libi ippa, Kinema
Laos	Thua nao, Sieng

2.2 | Characteristics of Starter Cultures

Soybean seeds contain various indigenous microorganisms that may interfere with or compete with the starter cultures. Therefore, starter cultures adapted to fermentation conditions characterized by high temperature, high pH, alcohols, acids, and osmotic stress should be selected and multiplied under such conditions (Cruxen et al., 2019; Pereira et al., 2012). Further starter culture inoculum density and time of inoculation should be checked, especially in the case of co-culturing. Starter cultures should contain higher levels of microbial enzymes such as protease, amylase, and lipase to degrade biomolecules in the seed. Starter microorganisms should produce antagonistic compounds, secondary metabolites, and organic acids to reduce food-borne pathogens and contaminants (Russo et al., 2017).

Further, it should have higher nitrate reductase, catalase, and superoxide dismutase activities. In terms of safety, several parameters, including antagonism, hemolysis, DNase activity, decarboxylase activity, enterotoxins, and antimicrobial resistance, should be assessed before using indigenous microorganisms as starter cultures (Cruxen et al., 2019). Starter cultures should produce a range of metabolites, such as aldehydes, ketones, alcohols, and esters, to provide distinct aroma, taste, and texture in the finished products (Motlhanka et al., 2022). Starter cultures should be able to grow on cheap substrates. It can withstand the treatments used in downstream processes, such as drying or freeze-drying, as well as storage conditions. Further development of starter cultures can be achieved through genetic or metabolic engineering, or through high-throughput screening to utilize cheap substrates (Hatti-Kaul et al., 2018).

Table 2 Starter Cultures for Fermenting Soybean Foods.

Starter cultures	Fermented products	Role in fermentation	References
<i>Bacillus subtilis</i>	Natto, Douche, Chung-kook-jong, and Kinema	Carbohydrate, lipid, and protein metabolism/fermentation Volatile formations including pentrylfuran, butanone, dimethyl trimethyl pyrazines, disulfide, 2,3-hydroxy butanone, and 2-methyl butanoic acid. Enhanced anthocyanins, phenolic, and isoflavones content in fermented products.	(Hu et al., 2010; Liu et al., 2018)
<i>Bacillus amyloliquefaciens</i>	Natto, Kinema, and Douchi	β -glucosidases, proteolytic Enhanced flavonoid, phenolic, and antioxidant activities. Reducing ANFs	(Wang et al., 2021)
<i>Lactobacillus plantarum</i> <i>Levillactobacillus brevis</i>	Fermented soy milk and Soy yogurt	Higher amount of flavor, aroma, and bioactive compounds Lower biogenic amines Production of alcohols, aldehydes, esters, and ketones for pleasant aroma and taste.	(Hwang et al., 2021; Sirilun et al., 2017)
<i>Zygosachharomyces</i> , <i>Rhodotorula</i> , <i>Klyveromyces</i> , <i>Debaryomyces</i> , <i>hansenula</i> <i>Candida</i> <i>Pichia</i>	Kinema, Soya sauce, and Miso	Produces enzymes like protease, invertases, inulinases, and galactosidases Higher protein content, antioxidant activities Reducing crude fiber content Reduction in ANFs	(Harada et al., 2017; Hu et al., 2019; Zhao et al., 2023)
<i>Aspergillus oryzae</i>	Soy sauce, Miso, Tempeh, and Sufu	Saccharification and proteolytic activities Provide aroma, reduce mycotoxin levels, and a pleasing aroma	(Kitamoto, 2015; Yamashita, 2021)
<i>Rhizopus oryzae</i> <i>Rhizopus oligoporus</i>	Tempeh and Sufu	High proteolytic activities, Vitamin B12, degradation of soybean sachharides, production of riboflavin, vitamin B6, and nicotinamide nicotinic acid	(Handoyo & Morita, 2006)
<i>Mucor sufu</i> <i>Mucor racemosus</i> <i>Actinomucor taiwanensis</i>	Sufu and Tempeh	Higher activities of lipases, proteases, galactosidases, and amylases	(Liu et al., 2021; Wei et al., 2021)
<i>Monascus purpureus</i>	Red sufu	Red pigmentation	(Xie et al., 2018)

3 | SOYBEAN FERMENTED FOOD (SFF): BACTERIAL AND MOLD-MEDIATED

3.1 | Kinema

It is a fermented food from the state of Nagaland in the eastern Himalaya, and it is alkaline, unsalted, sticky, and consumed as a curry by Gorkha/Nepali communities (Chettri et al., 2016; Tamang, 2022). Traditionally, small-sized seeds (~6 mm) are selected, washed, cleaned, and soaked overnight (8-10 h) in cold water (Fig. 2). The soaked seeds are then boiled for approximately 2-3 h. Then, boiled soybean seeds are pounded with a wooden pestle to increase their surface area, and 1% firewood is added to maintain alkalinity. These mixed soybean seeds are kept in a bamboo basket wrapped with locally grown fern fronds, *Ficus* leaves, or banana leaves. The basket was further wrapped in a jute bag, and natural fermentation was allowed at room temperature (25-40 °C) by placing it near the kitchen fireplace. The finished product looks white and viscous with a typical flavor and ammoniacal odor (Tamang, 2022). In India, a finished kinema takes 2-3 days in the winter months and 1-2 days in the summer months, Nepal (2-4) days, and (2-3) days in Bhutan. Finished products are dried and stored at room temperature for many months (Kharnaier & Tamang, 2021). Organoleptically, the taste and texture of kinema vary across regions (Kumar et al., 2019).

Metagenomic studies showed that bacteria, molds, and yeasts govern natural fermentation. Firmicutes (78.4 %), followed by Proteobacteria (14.76 %), had a greater abundance among bacteria. Kinema is prepared dominantly by *Bacillus subtilis*. However, other species of *Bacillus* are also involved, such as *B. cereus*, *B. licheniformis*, *B. thermoamylovorans*, *B. thuringiensis*, *B. sonorensis*, *B. circulans*, and *B. sphaericus* (Kharnaier & Tamang, 2021; Tamang, 2015). Other bacteria are *Lactobacillus fermentum*, *Lactococcus lactis*, *Proteus penneri*, *Proteus mirabilis*, *Ignatzschineria indica*, and *Thermoactinomyces vulgaris*. Among fungi, Ascomycota was the dominant phylum, and key fungal genera are *Aspergillus* spp., *Penicillium* spp., *Exobasidium* spp., *Mortierella* spp., *Rhizopus*, *Mucor*, *Pichia*, *Trichosporon* spp., *Rhodotorula*, and *Saccharomyces* (Kharnaier & Tamang, 2021). Yeast such as *Geotrichum candidum* and *Candida parapsilosis* were also present (Tables 2 & 3). Kinema is rich in primary and secondary metabolites, vitamin B complex, amino acids, and phenolic compounds. Meta-analysis showed that these phenolic compounds play a significant role in cancer, diabetes, anti-aging, antibacterial, anti-inflammatory, anti-viral, antihypertensive, cardiovascular diseases, neurodegenerative disorders, osteoporosis, anti-HIV activities, and body weight management (Rahman et al., 2021).



Fig. 2 Flowchart for preparation of Kinema

3.2 | Hawaijar

Hawaijar is alkaline, mucilaginous, sticky, and pungent in odor, an ethnic vegan food prepared in Manipur's hilly terrains and sloping regions through the natural fermentation of small-sized soybean seeds by Maitey women. It is widely used in Manipuri cuisine as a signature dish, a condiment, consumed directly, a flavoring agent in the preparation of chagempomba and ametpa, a pickle, and in soya chutney (Keishing, 2013). It is prepared by washing and cleaning the soybean seeds, then boiling them in a cooker for 2-3 hours. The whole cooked soybean is packed in a bamboo basket lined with *Ficus hispida* leaves and kept in the kitchen, where it undergoes natural fermentation for 3-5 days at 25-40 °C (Fig. 3) (Singh et al., 2023a; Tamang, 2015). The natural fermentation process is mediated predominantly by *Bacillus subtilis* (70%), *B. licheniformis*, *B. cereus*, *Staphylococcus aureus*, *Staphylococcus sciuri*, *Alkaligenes* spp., and *Providencia rettgeri* (Chettri & Tamang, 2015). The preparation method is improved using a starter culture of *Bacillus subtilis* PHT4 (Singh et al., 2023). Hawaijar, prepared with selected starters under controlled conditions, would inhibit the growth of undesirable human pathogens and biogenic amines (BAs), thereby making it more acceptable to consumers and boosting consumer confidence. Fermented hawaijar has higher total crude protein, total crude fiber, and free amino acid content, whereas it has lower total soluble sugar and total fat content (General et al., 2011). Furthermore, the in vivo analysis of the hawaijar in animals or human volunteers should be conducted to support commercialization. These *Bacillus* species isolated from soybean-fermented products may act as promising alternatives to antibiotics (Gopikrishna et al., 2021).

Metagenomic studies detected foodborne bacterial pathogens, including *Yersinia enterocolitica*, *Bacillus cereus*, *Listeria monocytogenes*, *Clostridium botulinum*, *Escherichia coli*, *Proteus mirabilis*, and *Clostridium perfringens*. Therefore, controlled fermentation using starter cultures is required to prevent potential human risks (Keisam et al., 2019). However, recently, a few human pathogens, such as *Staphylococcus saprophyticus*, *Clostridium perfringens*, *Staphylococcus simulans*, *Staphylococcus sciuri*, *Proteus vulgaris*, *Proteus mirabilis*, *Vagococcus lutare*, and *E. coli*, were reported in the hawaijar (Tables 2 & 3).

Several clinical studies have documented the health risks associated with these fermented products (Gopikrishna et al., 2021). The *Proteus Mirabilis* and *Bacillus cereus* were identified at 10^{7-10} cfu/g, along with diarrheal toxin and emetic genes reported in Hawaijar samples from the market. There are intermittent reports of food poisoning after consuming hawaijar (Singh et al., 2023; Keisam et al., 2019). *Proteus mirabilis* and *P. vulgaris* are especially associated with urinary tract infections, whereas *Bacillus cereus* causes food poisoning. Moreover, the toxic compound urethane is carcinogenic, whereas biogenic amines affect neurotransmitters produced by aflatoxin, which is produced by molds (Shukla & Kim, 2016). Several health benefits include fibrinolytic and thrombolytic activity, antihypertensive, anti-obesogenic, anti-diabetic, against enteric pathogens and liver diseases, ACE-inhibitory, antiallergic, antioxidant, anticancer, anti-aging, and anti-osteoporotic (Singh et al., 2023; Keishing et al., 2015).



Fig. 3. Flowchart of the traditional method of *Hawaijar*-fermented soybean production practiced in Manipur

These human pathogens may cause human illness upon consumption, which renders the use of Hawaijar (Singh et al., 2023; Keisam et al., 2019). Therefore, hawaijar prepared with selected starters under controlled conditions would inhibit the growth of undesirable human pathogens and biogenic amines (BAs). This would be more acceptable to consumers and boost consumer confidence.

Meitei communities used hawaijar as a curry, called Chagempomba, and consumed it with boiled rice. Hawaijar is consumed as a condiment and a taste enhancer, with salt, chili, and onion. However, due to its short shelf life of only 3-4 days, traditional sun-drying methods are used for long-term storage. Hawaijar has many health benefits in humans, including thrombolytic and fibrinolytic activities, antihypertensive, anti-obesogenic, anti-diabetic, anti-inflammatory, immunostimulatory, anti-allergic, antioxidant, anti-cancer, anti-osteoporosis, anti-aging, and liver disease benefits; and protection against enteric pathogens (Singh et al., 2023). Hawaijar is important in the nutraceutical and food industries due to the presence of fibrinolytic enzymes and polyglutamate (PGA). It can be used as animal feed, edible/industrial oil, or printer ink (Singh et al., 2023). Hawaijar has a brief shelf life, typically lasting only 3 to 4 days. As a result, it is occasionally sun-dried for extended preservation (Premarani & Chhetry, 2011). It is rich in free amino acids, polyglutamate, vitamin B complex (VB12), minerals such as potassium and calcium, folic acid, tocopherols, bioactive compounds such as isoflavones (genistein and daidzein), and gamma-aminobutyric acid. *Bacillus subtilis*, commonly present in SFFs, exhibits higher proteolytic activity and significantly increases free amino acid levels (Singh et al., 2023).

3.3 | Tungrymbai

Tungrymbai is a fermented indigenous soy food typical of the tribes of Meghalaya. It is not only a famous delicacy among the tribes of Meghalaya but also a rich source of protein. Soybean seeds are washed, cleaned, and soaked in cold water for 4 to 6 hours. Subsequently, the seed coats are removed, and the soybeans are boiled for 45 minutes to 2 hours. Cooked soybeans are packed in leaves of *Clinogyne dichotoma* or *Phrynium pubinerve* and placed in a bamboo basket, wrapped with thick cloth or jute bags, for 3-4 days at 25-30 °C. Then, the fermented seeds are crushed with a wooden pestle. The primary microorganisms responsible for the natural fermentation process include *Bacillus cereus*, *B. brevis*, *B. coagulans*, *B. circulans*, *B. pumilus*, *B. subtilis*, and

Lysinibacillus fusiformis (Tables 2 & 3) (Chettri & Tamang, 2015; Joshi et al., 2020). Other microorganisms involved are *Lactobacillus fermentum* and *L. plantarum*, which may be used for controlled fermentation (Basaiaawmoit & Mishra, 2018). Tungrymbai starter culture was suggested for controlled fermentation using a combination of *Lactobacillus helveticus* K14 and *L. rhamnosus* K4E, as it increased ACE-inhibitory activity, antioxidant activity, and levels of soy isoflavones such as genistein and daidzein (Mishra et al., 2019). The yeasts involved in the process are *Debaryomyces hansenii*, *Saccharomyces cerevisiae*, and *Pichia burtonii* (Liu et al., 2021). Tungrymbai is mixed with garlic, onion, ginger, chili, sesamum, and salt to make a thick curry eaten with rice in Meghalaya by Khasi women (Tamang, 2022).

3.4 | Bekang or Bekang-um

It's an indigenous fermented food resembling kinema, hawaijar, and tungrymbai found in the northeastern regions. It has a sticky, alkaline taste and an ammoniacal smell and is prepared in Mizoram. It is prepared using yellow color. Small soybean seeds are soaked overnight in cold water, then boiled for 1-2 h, mixed with firewood ash, and finally wrapped in a bamboo basket lined with leaves of *Callicarpa arborea* or *Phrynium* sp. The tray is further covered with jute cloth and placed in the kitchen near the fireplace to allow natural fermentation (3-5 days) at the desired temperature of 25-40 °C. The finished product is curry with salt, chilies, and tomatoes (Chettri & Tamang, 2015). Key fermenting microorganisms are *B. subtilis*, *B. licheniformis*, *B. pumilus*, *Bacillus cereus*, *B. amyloliquefaciens*, *Pichia burtonii*, and *Debaryomyces hansenii* (Chettri & Tamang, 2015; Tamang, 2015, 2022).

3.5 | Aakhone

Aakhone, the ethnic food of Nagaland, is prepared similarly to Kinema by soaking and cooking the soybeans, then wrapping them in *Phrynium pubinerve*, Macaranga, or banana leaves, and allowing them to ferment naturally for 5-7 days by placing them in the kitchen near the fireplace. The aakhone is dried in the sun or an earthen oven and stored for future consumption. A key fermenting microorganism here is *Bacillus subtilis* (Tamang, 2015, 2022).

3.6 | Peruyyan

Peruyyan is a fermented food item from the Apatani tribes in northeastern Arunachal Pradesh. It is prepared similarly to kinema; however, in peruyyan, cooked soybeans are wrapped in a ginger leaf, and over about 3-5 days, a sticky product forms and is ready for human consumption. Key fermenting microorganisms are *Bacillus subtilis*, *B. amyloliquefaciens*, *Pediococcus*, and *Enterococcus* (Singh et al., 2014; Tamang, 2015).

3.7 | Natto

Natto is a fermented soybean product from Japan and was discovered accidentally when boiled soybeans were found to be tasty. It is prepared by soaking the soybean seeds in cold water, boiling them, and then fermenting them at 40 °C for 16 h. *Bacillus subtilis natto* predominantly mediates fermentation (Table 2) (Chen et al., 2022). The fermenting microorganisms release alkyl pyrazine to provide the aroma (Kłosowski et al., 2021). Furthermore, it produces metabolites that suppress the growth of foodborne pathogens (Kaboré et al., 2013).

3.8 | Tempeh

Tempeh is prepared in Indonesia by solid-state fermentation, soaking, dehulling, and boiling raw soybeans fermented with *Rhizopus* spp. Key species are *Rhizopus oligosporus*, *R. stolonifer*, and *R. oryzae*, which provide a mushroom or nutty taste. It is a sustainable, low-cost meat alternative from beans and is health-promoting (Ahnann-Winarno et al., 2021). The presence of endogenous molds, fungi, and bacterial enzymes, such as proteases, lipases, amylases, and pectinases, degrades soybean macromolecules. Furthermore, many compounds, such as diacetyl, pyridine, butanediol, alcohols, and acids, are produced to provide distinct aroma and flavor (Sarkar & Nout, 2014). It is also a source of vitamin B12 produced by contaminating bacteria like *Citrobacter freundii* and *Klebsiella* sp. (Kustiyawati et al., 2020). The antioxidative activities and isoflavone content (daidzein and genistein) increased during fermentation (Kuligowski et al., 2016).

3.9 | Miso

Miso, a traditional Japanese dish, is crafted by fermenting rice and soybeans in a two-step process. Initially, rice is soaked for 8-12 hours, boiled for 1 hour at 100 °C, then cooled and infused with *Aspergillus oryzae* spores. This mixture is left to ferment at 30 °C for 2 days to produce rice koji. Similarly, soybeans are soaked (8-12 h), boiled (3-4 h), and then mashed until smooth. Then mixed with rice koji and salt, packed tightly in a fermentation vessel, allowed to undergo a second fermentation at 20-30 °C for 2 to 24 months, and finally, miso is formed with a unique texture, taste, and aroma (Allwood et al., 2021). Key microorganisms involved in koji preparation are *Aspergillus oryzae* (fungal) and *Ochrobactrum lupini* (bacteria). Other miso fungi involved are *Aspergillus oryzae* and *Zygosaccharomyces rouxii*, whereas the bacteria involved are *Staphylococcus gallinarum*, *Tetragenococcus halophilus*,

and *Enterococcus faecium* (Table 2) (Escott et al., 2018; Hui et al., 2017).

3.10 | Douchi

Douchi is a traditional fermented food prepared using black soybeans in China. Its preparation involved sorting, soaking, steaming in a pressure cooker, preparing koji, mixing adjuncts with koji, adding starter cultures, fermenting, and ripening. Depending on the starter culture, it can be mold-mediated (e.g., *Aspergillus*, *Mucor*, and *Rhizopus*) or bacterial-type (e.g., *Lactobacillus*) (Table 2 & 3; Liu et al., 2022; Zhang et al., 2018). It is a source of soluble sugar, nitrogen, and vitamins B2, B9, C, and D (Walther et al., 2013).

3.11 | Dajiang

Dajiang is prepared in two stages: koji-making and brining. In the first stage, the soybean is soaked overnight, boiled, minced into a rectangular block, and left to air-dry for 1-2 months. In the second stage, 90% salt water (17%) is added to ferment the seed koji. Ripened dajiang looks brown or reddish-brown and has a strong aroma. *Aspergillus oryzae* and *Lactobacillus* are key fermenting microorganisms mediated at 45-47 °C for 30 days (Table 2 & 3) (Liu et al., 2022). Another study showed that the Da-Jiang preparation, produced by *Leuconostoc mesenteroides*, enhanced the accumulation of fat, proteins, and sugars and improved color. Further, it eliminated the nitrite peak and *Clostridium* from the finished product (Zhang et al., 2019).

3.12 | Sufu or Furu

Sufu is a nutritious Chinese fermented soybean product made from tofu with the help of microorganisms. Firstly, tofu is prepared by soaking the soybean seeds in water, grinding them to release the oil, and removing the insoluble okara. The soybean milk thus formed is boiled, and an appropriate coagulant is added. Then the coagulated beans are transferred to boxes to solidify, and salt and spices are added to promote controlled mold growth. These fermenting microorganisms degrade macromolecules such as proteins and starch, thereby providing a distinctly flavored sufu. In enzymatic sufu preparations, fermentation broth from lactic acid bacteria and yeast, containing protease and cellulase enzymes, is added to degrade protein and carbohydrate (Liu et al., 2022). Depending upon the mode of fermentation, it can be bacterial-type sufu (*Bacillus* or *Micrococcus*), mold-type sufu (*Mucor*, *Rhizopus*, or *Actinomucor*), and other sufu (Huang et al., 2018). Key microorganisms involved are *Enterobacter*, *Lactococcus*, and *Acinetobacter*. The unique flavor of sufu, attributed to esters and amino acids, was strongly correlated with *Lactococcus* and *Enterobacter* (Huang et al., 2018). Finished sufu contains 12-17% protein and has a digestibility of 92-96%. Further, it is a source of vitamin B12, riboflavin, phosphorus, calcium, zinc, and iron (Huang et al., 2018; Xie et al., 2018).

3.13 | Soy Sauce

Soy sauce, originating in China, is a liquid that ranges from light brown to black and has a salty flavor. It is prepared through a two-step fermentation process termed koji (solid-state) and moromi (brine fermentation). It is used as a seasoning in Japan, China, Korea, and many other Asian countries for its unique aroma and taste. It is prepared by soaking the soybeans in water for about 8 hr, boiling them in a pressure cooker for 40-45 minutes at 0.8-1.0 kg/cm², and then cooling them to room temperature. First, wheat is roasted at 150 °C for 30-45 s, then cracked and blended with soybeans. This mixture of soybeans and wheat is then combined and inoculated with *Aspergillus oryzae* or *Aspergillus sojae* (0.05-0.3% by weight) to produce koji, which is then incubated for 72 hours. Then, the salt solution is added to this mixture to form moromi, which is incubated for 6 months. Further, moromi is pressed and filtered to produce liquid soy sauce. Then, the liquid is pasteurized at 75-90 °C for 15-30 minutes, packed in plastic and glass bottles, and stored for 1.5-3 years. Soybean cake is formed as a by-product after pressing moromi (Devanthi & Gkatzionis, 2019; Yang et al., 2017).

Depending on the type of soy sauce and country, soy sauce fermentation is mediated by specific bacteria, molds, and yeasts. For example, in Chinese (Xianshi), the soybeans and wheat are taken in a 4:1 ratio, and 18-20 % NaCl is used. The starter cultures used for solid-state fermentation are *Aspergillus sojae* and *A. oryzae*. Similarly, microorganisms

used for brine fermentation include *Zygosaccharomyces rouxii*, *P. guilliermondii*, *Tetragenococcus halophilus*, *Candida versatilis*, and *Torulaspora delbrueckii*. Both solid-state and brine fermentation organisms are used as sequential inoculation or co-inoculation (Devanthi & Gkatzionis, 2019; Singracha et al., 2017; Song et al., 2015). The diversity of microorganisms involved in fermentation includes mold/fungi and bacteria. Key fungi/molds are *Meyerozyma guilliermondii*, *Aspergillus niger*, *Fusarium oxysporum*, *Cladosporium sphaerospermum*, *Sterigmatomyces halophilus*, *L. ramose*, and *Absidia blakesleeana*. Similarly, key bacteria involved are *Bacillus subtilis*, *B. amyloliquefaciens*, *B. coagulans*, *B. licheniformis*, *B. flexus*, *B. aerius*, *B. methylotrophicus*, *Lactococcus piscium*, *Weissella confuse*, *Clostridium oceanicum*, *Trichodesmium*, *Pantoea dispersa*, *Klebsiella pneumonia*, *Enterobacter sacchari*, *Erwinia toletana*, *Streptomyces hebeiensis*, *Shimwellia blattae*, *Microbunus phosphovorus*, and *Scopulibacillus darangshiensis* (Table 2 & 3) (Wei et al., 2013; Yan et al., 2013; Yang et al., 2017). Key metabolites such as glycerol, 4-ethylphenol, 2-phenylethanol, and 4-ethylguaiacol are produced during yeast and lactic acid fermentation (Song et al., 2015). Soy sauce contains vitamins B and E, as well as essential elements such as calcium, iron, zinc, and manganese (Chen & Hang, 2019). Zhang et al. (2023) reported that incorporating salt-tolerant *Staphylococcus* into soy sauce fermentation enhanced the sauce's ester, acidity, and alcohol aromas, while co-fermentation with *Zygosaccharomyces rouxii* further augmented the sauce's ester aroma profile.

Table 3 Microorganisms are involved in India's soybean-fermented food products (Tamang, 2015).

Fermented products	Sensory characteristics	Microorganisms involved	Countries/ regions	References
Kinema	Sticky, alkaline	<i>Bacillus licheniformis</i> , <i>B. cereus</i> , <i>B. thermoamylovorans</i> , <i>B. thuringiensis</i> , <i>B. sonorensis</i> , <i>B. sphaericus</i> , and <i>B. circulans</i>	Sikkim, Assam, Darjeeling hills	(Chettri & Tamang, 2015)
Hawaijar	Sticky, alkaline	<i>Bacillus subtilis</i> , <i>B. cereus</i> , <i>B. licheniformis</i> , <i>Staphylococcus sciuri</i> , <i>Staphylococcus aureus</i> , <i>Providencia rettgeri</i> and <i>Alkaligenes spp.</i> ,	Manipur	(Singh et al., 2014; Tamang, 2022)
Tungrymbai	Sticky, alkaline, curry,	<i>Bacillus cereus</i> , <i>B. brevis</i> , <i>B. coagulans</i> , <i>B. circulans</i> , <i>B. pumilus</i> , <i>B. subtilis</i> and <i>Lysinibacillus fusiformis</i>	Meghalaya	(Chettri & Tamang, 2015; Joshi et al., 2020)
Aakhone	Sticky, alkaline paste	<i>Bacillus subtilis</i> and <i>Proteus mirabilis</i>	Nagaland	(Singh et al., 2014)
Bekang	Sticky, alkaline, paste, curry	<i>Bacillus subtilis</i> , <i>B. circulans</i> , <i>B. pumilus</i> , <i>B. brevis</i> , <i>B. sphaericus</i> , and <i>B. licheniformis</i>	Mizoram	(Chettri & Tamang, 2015)
Peruya	Sticky, alkaline	<i>Bacillus amyloliquefaciens</i> , <i>Enterobacter faecalis</i> , <i>Pediococcus acidilactici</i>	Arunachal Pradesh	(Singh et al., 2014)

Table 4 Benefits of Fermented Soybean Foods for Health

Soybean fermented product	Bioactive compounds	Human health benefits	References
Kinema	Isoflavones aglycones, poly- γ -glutamic acid, and Group B saponins	Against hypercholesterolemia and hyperglycemia, antioxidants,	(Chettri et al., 2016; Sanjukta & Rai, 2016)
Miso		Type-2 diabetes reduces insulin resistance and antioxidant	(Hashimoto et al., 2024; Takahashi et al., 2020)
Natto	Gamma-polyglutamic acid	Reduces insulin resistance, antioxidants inhibit postprandial blood glucose levels, and affect lipid metabolism.	(Araki et al., 2020)
Doenjang	betaine and betaine aldehyde	Anti-diabetic, antioxidant, neuroprotective, and anti-obesity	(Kang et al., 2019; Yang et al., 2019)
Kochujang	methionine, <i>p</i> -coumaric acid, N6, N6,N6-trimethyl lysine, and threonine	Anti-obesity and anti-diabetic	(Yang et al., 2019)
Kochujang		Fibrinolytic, antioxidant, angiotensin-I-converting enzyme inhibition, and anti-obesity	(Ahn et al., 2006)
Tempeh		antioxidant effect, anti-glycemic, and triglyceride	(Cai et al., 2014)
Soy sauce		anti-diabetic, anti-cancer, anti-microbial, anti-hypertension, and anti-mutagenic	(Han et al., 2020)

4 | TOXINS PRODUCED BY SPOILAGE-CAUSING MICROORGANISMS

Although fungal microorganisms are involved in the fermentation processes, these organisms may get contaminated with mycotoxins such as aflatoxins (Afs), alternariol (AOH), deoxynivalenol (DON), ochratoxin A (OTA), fumonisins (FBs), rhizoxins, T-2 toxin (T2), and zearalenone (ZEA) (Tian et al., 2022). Similarly, bacterial toxins are mainly produced by *Bacillus* sp. and *Clostridium* spp. in fermented foods. The *Bacillus cereus* lato strains and *Bacillus thuringiensis* were reported in Chinese Doenjang food (Park et al., 2016; Yim et al., 2015). In douchi, aflatoxins B1, B2, G1, and M1 types were reported (Qiu et al., 2019). Similarly, in tempeh, the presence of AFs, FBs, ZEA, and rhizoxins was reported (Yudiono et al., 2021). Similarly, sufu was contaminated with Afs and rhizotoxins (Yang et al., 2020). In meju AFs and OTA (Jeong et al., 2019), doenjang has AFs, FBs, OTA, and ZEA (Woo et al., 2019), and in soy sauce, the presence of AFB1, DON, and OTA was reported (Lee et al., 2012; Zhao et al., 2013). Mycotoxin can be eliminated by improving fermentation conditions, such as raw soybean temperature, pH, salt concentration, and water activity. Further use of selected microbial strains in fermentation and application of plant-based antifungal agents may eliminate the mycotoxins (Ahmed et al., 2022). Furthermore, limiting mycotoxin contamination through specific guidelines, market oversight, advanced biosensors, and good agricultural practices may reduce mycotoxin levels in foods (Tian et al., 2022).

5 | SOYBEAN BIOACTIVE COMPOUNDS FOR HEALTH BENEFITS

Soybean seeds contain bioactive peptides, isoflavones, saponins, vitamins, oligosaccharides, protease inhibitors, minerals, and phytosterols. Key isoflavones are daidzein, glycitein, and genistein. These compounds have antioxidant, anti-cancer, anti-obesity, anticholesterolemic, anti-diabetic, anti-inflammatory, cardiovascular diseases, weight management, reducing the effect of menopause, blood pressure regulation, immune system modulator, anti-microbial action, neuroprotective, and anti-aging action (do Prado et al., 2022). Similarly, bioactive peptides include glycinin and β -conglycinin, which are produced by microbial hydrolysis of proteins, and microbes also produce unique bioactive peptides. These peptides are antimicrobial, antihypertensive, antioxidant, anticancer, and antidiabetic (Chatterjee et al., 2018; Sanjukta & Rai, 2016). Bioactive compounds play a role in the prevention of colorectal cancer (Kim et al., 2021), chronic inflammation (Kusumah & Gonzalez de Mejia, 2022), and lowering blood pressure (Tsai et al., 2020).

Soybean fermentation mediated by *Bacillus* spp. produced bioactive compounds such as poly- γ -glutamic acid for reducing blood glucose (Chettri & Tamang, 2015), isoflavone aglycone for flavonoid bioconversion (Kim et al., 2004), *Bacillus subtilis* LM7 produces Bacillomycin D and surfactin having anti-microbial activity, and *Bacillus subtilis* produces nattokinase having an anti-hyperlipidemic activity (Chen et al., 2018), *Bacillus amyloliquefacians* produced didzein having anti-diabetic action, and *Bacillus licheniformis* 67 produced poly- γ -glutamic acid having anti-obesity activities (Choi et al., 2016). Kinema contains isoflavones aglycones, polyglutamic acid, and group B saponins, which act as anti-

hyperglycemia, antioxidants, and hypercholesterolemia. Tempeh contains trans-cinnamic acid, isoflavones aglycone, and genistein, which help against oxidative stress and immunomodulation. Natto contains nattokinase, Bacillopeptidase-F, and other enzymes, which have anticoagulant, anti-thrombotic, fibrinolytic, and blood cholesterol-lowering properties.

6 | NOVEL FERMENTED SOY FOODS (NFSFs): EMERGING TRENDS AND APPLICATIONS

The landscape of fermented soy foods is experiencing a renaissance driven by innovation. NFSFs extend beyond traditional staples, catering to consumer demand for plant-based alternatives and exploring the potential health benefits of specific strains and fermentation techniques. The functional properties of NFSFs, including gelling, texturizing, and emulsification, make them valuable ingredients for diverse food applications, including plant-based meat and dairy

alternatives, bakery products, and functional foods. Emerging technologies such as controlled fermentation and co-fermentation offer further opportunities to tailor the functionality and sensory profiles of these novel products. Some recent research in this direction has given a plethora of NFSFs with wider consumer acceptance and additional health benefits from combining different processes. Some recent NFSFs are discussed in this section of the review to pave the way for future research directions in soy fermentation.

6.1 | Yogurt

Yogurt is a thick, fermented dairy product prepared using bacteria *L. bulgaricus* and *S. thermophilus*. Dairy analogs, such as plant-based yogurt, can be prepared with soy milk (Fig. 4).

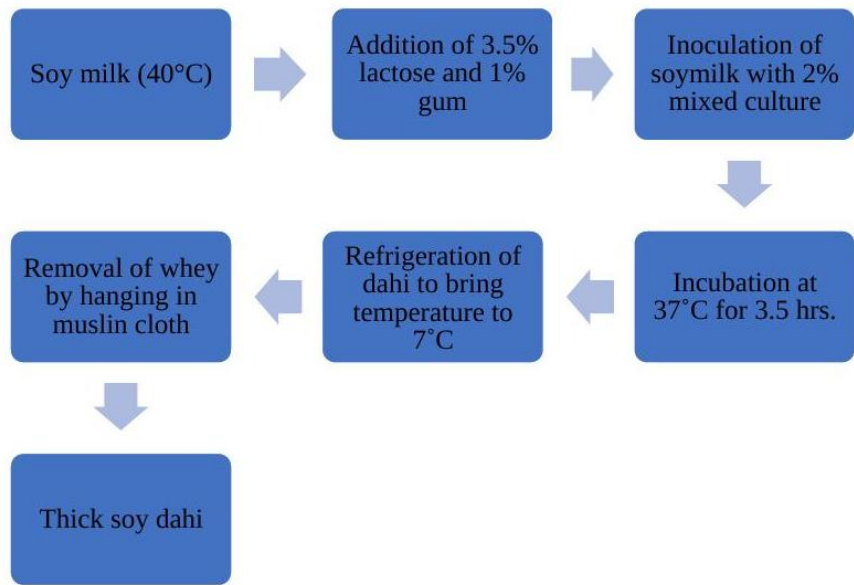


Fig. 4 Flow diagram for the manufacture of soy-dahi

(Luo et al., 2024). Recently developed a novel lycopene-rich soy yogurt using a two-stage fermentation process with engineered *Bacillus subtilis* and lactic acid bacteria (LAB). This yogurt enhanced functionality due to high lycopene content, increased soy isoflavones, and potent antioxidant capacity. Additionally, the fermentation process promoted the desired pH, accelerated protein breakdown, improved amino acid availability, and had appealing sensory characteristics, all

contributing to the yogurt's potential as a healthy, functional food. Various fermented dairy analogs, such as dahi, lassi, and shrikhand, can be prepared from soybeans, harnessing flavors and generating bioactive compounds via fermentation (Fig. 4) (Pandey et al., 2021; Pandey & Ramteke, 2020). *Aloe vera* was also incorporated to combine its medicinal properties with fermented soy beverages and enhance shelf life (Pandey & Ramteke, 2020).



Fig. 5 Fermented soy Indian dairy analogs: lassi, dahi, shrikhand

6.2 | Probiotic Drinks

Plant-based substrates like soy are also used as probiotic functional drinks as dairy analogs to improve gut health (Mishra et al., 2023). Bock et al. (2024) evaluated a specific strain of bacteria, *Lactiplantibacillus plantarum* KU210152, for its potential as a probiotic with neuroprotective effects. Researchers explored its application in soy milk. The bacteria showed good digestive tolerance and adhered well to intestinal cells. Additionally, it produced safe enzymes. This study suggests that bacteria in fermented soy milk have neuroprotective properties. In another study, Gungor et al. (2024) investigated fermenting soy milk with a probiotic culture and *Propionibacterium* to create probiotic soy beverages for the vegan population. Probiotic soy drink has higher calcium bioavailability and estrogenic activity, as well as improved gut health (Mishra et al., 2023). Furthermore, the Cholesterol-lowering effects of the probiotic strain (*Lactiplantibacillus plantarum* P101) studied by Zhang et al. (2023) showed that the beany flavor was reduced and that soy milk exhibited enhanced antioxidant activity, texture, and isoflavone bioavailability, leading to better cholesterol reduction.

6.3 | By-product Utilization

Fermentation can also valorize soy byproducts such as okara, soy meals, whey, and hulls. Okara, a soybean byproduct known for its prebiotic properties, can enhance the benefits of probiotic consumption. (Feng et al., 2021) immobilized *Lactobacillus plantarum* on okara, increasing β -glucosidase activity and converting inactive isoflavones to their more bioavailable aglycone forms. Additionally, okara improved vitamin B2 production and protein digestibility in fermented soy milk. In another study (Castellanos Fuentes et al., 2020), okara and EEM were used as sustainable substrates for the production of probiotic ingredients via solid-state

fermentation with *Lactobacillus casei*. Notably, *L. casei* thrived best in the okara medium. Conversely, EEM exhibited the slowest growth rate.

6.4 | Meat Analogs

Fermented Soybean products, such as tempeh, have been extensively used as meat analog ingredients, and the use of fermentation and enzymatic hydrolysis to improve soy press cake properties for meat analog applications adds a new dimension to byproduct utilization (Razavizadeh et al., 2022). Researchers fermented the press cake with *Lactobacillus* strains and hydrolyzed it individually with enzymes. The study showed that fermenting the press cake with *Lactobacillus plantarum* P1 improved the texture of the meat analogs. Microbial fermentation also decreases bitterness, enhances juiciness, and creates a better flavor profile. Soybean fermentation can be done using different methods, such as traditional tempeh production, fermenting after blending or mincing to reduce beany flavor, and introducing meaty flavor (Fig. 6).

6.5 | Flavor Enhancer

Fermentation produces new flavor profiles depending on the process and culture used. It opens the door to using fermented soy ingredients as flavor components or enhancers in animal food alternatives. Plant-based cheese alternatives struggle to mimic the taste and smell of actual cheese. (Nedele et al., 2022) addressed this challenge by fermenting soy drinks with a fungus (*Agrocybe aegerita*) to produce a cheesy aroma. Analysis showed that short-chain fatty acids contribute to the cheese-like odor, with a profile similar to that of Parmesan and Emmental cheeses. Furthermore, the study identified specific protein and oil fractions responsible for generating these desirable SCFAs, suggesting potential strategies to enhance the flavor profile of plant-based cheeses.



Fig. 6 Meat analog preparation using fermented soybean

6.6 | Cheese Analogs

Fermented tofu from 17th-century China might be considered an early ancestor; plant-based cheese has emerged as a distinct category in recent years. Soy cheese is an edible product made from soy and other plant ingredients that aims to replicate the sensory experience – appearance, texture, and flavor – of traditional cheeses made from animal milk. Unlike animal-based cheese production, which primarily uses milk, plant-based alternatives require careful ingredient selection and processing techniques to achieve the desired properties. Companies such as Follow Your Heart, Cheese, Thankyou, and Field Roast use soy ingredients to manufacture plant-based cheeses (Grossmann & McClements, 2021).

7 | BREEDING FOR FERMENTED FOOD-GRADE SOYBEAN VARIETIES

Breeding for high-yielding fermented food-grade soybean genotypes can help in upscaling the soybean from an oilseed crop to a food-industry crop. Genetic removal of antinutritional factors such as KTI and lipoxygenase, and genetic enhancement of nutritional factors such as isoflavones, saponins, vitamins, oligosaccharides, protease inhibitors, minerals, and phytosterols, can result in varieties suitable for the fermented food industry (Singer et al., 2023). The identification of genes/QTL governing these traits and their use in marker-assisted selection and gene pyramiding represent a novel approach to developing food-grade soybean cultivars (Patil et al., 2017). For example, in the case of natto, the desirable traits are small, round, yellow seeds with a high capacity for water absorption. Hard-seededness and low seed coat cracking are also essential for consumer acceptance (Escamilla et al., 2019). Nutritional traits such as higher protein and isoflavone content, and higher soluble sugar content are also desired in good-quality natto (Wei & Chang, 2004). Several genetic loci governing these traits have already been identified. Utilizing these loci in molecular breeding can aid in the development of high-yielding soybean varieties suitable for natto production. Soy-based fermented foods contain beneficial secondary metabolites such as saponins, isoflavones, and tocopherols. Studies should accelerate understanding of the genetic and biochemical basis of

metabolite accumulation in seeds, and future studies should focus on genetic enhancement and breeding for these metabolites (Dwiyanti & Gunawan-Puteri, 2023).

8 | VEGETABLE TYPE SOYBEAN

In Japan and China, vegetable-type soybeans are called edamame and maodou, respectively. It is rich in protein (13 %), carbohydrates (20-30 %), iron, calcium, phosphorus, and other vitamins and fiber. Vegetable-type soybean is generally harvested at the immature R6 growth stage when pods are green, and approximately 80 % are mature. It can be served as a snack with no beany flavor and tastes sweeter after boiling in salt water. China, Japan, and Taiwan are leading countries in the cultivation of vegetable-type soybeans (Nair et al., 2023; Zhang et al., 2024). The health benefits associated with consuming edamame include increased bone density, reduced cholesterol levels, prevention of cardiovascular disease, improved brain health, and reduced risk of mammary and prostate cancers (Moinuddin et al., 2023). Therefore, utilizing these varieties for fermented foods or soybean-based products, as discussed in the previous sections, may offer a new avenue for research and aroma improvement (Kumar et al., 2021).

9 | CHALLENGES WITH SOYBEAN FERMENTED FOOD

The high salt content commonly found in fermented foods, often reaching up to 20 %, poses a potential risk for hypertension with increased intake. Additionally, biogenic amines, resulting from the decarboxylation of amino acids, can induce toxic effects such as cardiac palpitations, changes in blood pressure, and headaches (Ladero et al., 2010). Another concern is the presence of pathogenic microorganisms that produce mycotoxins, such as ochratoxin and aflatoxins, which adversely affect human health. Further presence of coliform or human pathogenic bacteria, namely *Staphylococcus aureus*, *Bacillus cereus*, and other *Clostridium* spp. and *Proteus* spp., should be within an acceptable limit. Further inconsistencies in the quality of the fermentation process depend on various factors (Liu et al., 2018). Prominent instances from previous reports involved the presence of diarrheal and emetic bacterial toxins produced by *Bacillus cereus* in Korean fermented soybean products. The *B. amyloliquefaciens* RD7-7, exhibiting antimicrobial properties against *Bacillus cereus*,

was identified (Eom & Choi, 2016). Another study reported the toxic effects of *Bacillus thuringiensis* and *Bacillus cereus*, which produce diarrheal toxins in the soybean-fermented food doenjang (Park et al., 2016). Furthermore, many soybean phytopathogens are associated with seeds, externally or internally, and the use of such infested seeds affects the quality of final fermented products. Many fungi, such as *Aspergillus*, *Penicillium*, *Alternaria*, and *Fusarium*, associated with seeds at the pre-harvest stage or with field contamination, produce mycotoxins, including aflatoxins, ochratoxin, zearalenone, trichothecenes, deoxynivalenol, nivalenol, and fumonisins (Jabir Amza, 2018).

10 | SUMMARY AND FUTURE PERSPECTIVE

Soybean seeds contain a wealth of nutrients; nevertheless, their direct utilization is restricted due to (ANFs). Therefore, in the present review, we highlighted the natural and starter-based soybean fermented products of bacterial, fungal, or mold origin. However, isolating starter cultures with distinct characteristics for controlled fermentation is needed to identify them using advanced molecular tools. Further study of beneficial and pathogenic microbiota produced by natural fermentation is required, using metagenomic approaches to isolate beneficial starters. The optimization, processing, and packaging should be evaluated upon identifying starter cultures (single/mixed). Optimization of the finished product and storage of the products as per FSSAI guidelines for commercialization is needed. These products should be scaled up for commercialization through Self-Help Groups (SHGs) or startups. Finished products should be free of pathogenic microorganisms to improve consumer acceptability. Further, the role of bioactive compounds released during fermentation processes upon microbial action was limited to only in vitro studies. Hence, conducting in vivo studies to enhance consumer confidence is essential. Scientific validation of these health claims for SFFs through randomized controlled trials (RCTs) and assessment of patients' easily recordable blood hemoglobin, blood glucose, vitamin levels, and lipid profile may provide concrete results. Further study of these SFFs across two different population sets, in relation to the claimed diseases, may build consumer confidence. Safety studies of SFFs prepared using starter cultures (single/mixed) in animal models may help consumers gain greater acceptance. Microbial succession studies, complemented by metabolomic studies, may help isolate bioactive/novel metabolites/new chemical entities of commercial importance. The predominantly bacterial genus involved in SFFs, *Bacillus* spp., which has antimicrobial activity against pathogenic microorganisms, should be isolated and commercialized as an alternative to antibiotics and a source of probiotics. Furthermore, the use of bioactive compounds in immunocompromised patients requires testing. These bioactive compounds could be used for health and food supplements. Research on the growing consumer acceptance of fermented soy foods is another area that needs focus. This paves the way for reaping the maximum benefits of fermented soy foods for nutritional security in India.

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