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Probiotic Potential of Indian Traditional Fermented Foods to Combat Listeriosis

*Priyanshi M Jain and Rajagopal Kammara**

Faculty Department of Microbiology and Fermentation Technology, CSIR-CFTRI, Mysore, India

Abstract

Due to their great nutritional content, certain traditional fermented foods and beverages from India have gained recognition on a global scale. In northeast India, fermented foods like pickles and bamboo beverages are widely consumed and well-liked. Probiotics found in fermented foods have been linked to better health. Probiotics are living bacteria that offer a number of health advantages when taken in the appropriate amounts. Beneficial bacteria improve immunity and digestion, which helps to avoid cancer and metabolic diseases like diabetes. The most widely used probiotics that have been identified from fermented foods include Bifidobacteria species, *Lactococcus lactis, and Lactobacillus acidophilus*. As fundamental characteristics, probiotics have antibacterial action, acid tolerance, and bile tolerance. Inhibitory substances like bacteriocins, organic acids are produced and secreted by probiotics to prevent the colonisation of harmful pathogens. By removing harmful microorganisms, the intestinal barrier is strengthened, which modifies the gut flora. The primary pathogen that causes listeriosis, *Listeria monocytogenes* (LM), has a special physiology that allows it to grow even in subfreezing temperatures and tolerating harsh conditions. Foods with a dairy or beef origin are specifically contaminated by the LM. Pregnant women, new babies, and the elderly in general are the pathogen's main targets. The current review focuses on worldwide LM infection-related abortions during pregnancy and foetal fatalities. The study also considers Indian fermented foods and drinks as potential sources of new probiotics because of their anti-listerial capabilities.

Keywords

Fermented Foods, Probiotics, *Listeria monocytogenes*, LAB

Introduction

Food is a symbol of a people's history, culture, and unique identity. Traditional knowledge, generational experience, agro-climatic conditions, and the availability of food resources have all influenced the development of fermented foods. Their development is influenced by conventional ideas, racial preferences, religious convictions, socioeconomic systems, gastronomic traditions, and social restrictions imposed over time by successive rulers. Non-fermented foods and fermented foods (including alcoholic beverages) are the two divisions of ethnic foods [1]. Food fermentation is an ancient technique in India, where uncontrolled or reverse fermentation is practiced as a domestic skill. Worldwide, there are more than 5000 different varieties of fermented foods and alcoholic beverages [2].

In the northeastern part of India, more than 250 different kinds of fermented foods and alcoholic beverages are produced and consumed [3]. Due to its probiotic properties, improved shelf life, protection, sensory benefits, and nutritional value, fermented foods, beverages have grown in popularity and are used more regularly [4]. Probiotics, or fermented meals with living bacteria, have gained appeal to improve human health in recent years [5]. The WHO (World Health Organization) defines probiotics as "live bacteria that, when administered in suitable amounts, confer a health benefit on the host" [6,7]. They serve as the foundational cultures in ethnic cuisine and stimulate numerous productive and profitable enterprises. They are used as a starter culture in ethnic foods, boost a variety of functional and economic activities. Probiotics aid in food preservation, and LAB's functional antibacterial activity reduces the number of undesirable microbes in milk products, making them safe for human consumption [8].

Fermented foods have been shown to include lactic acid bacteria (LAB) such as *Lactobacillus plantarum*, *Lactobacillus acidophilus* [9], *Lactobacillus mesenteroides, Lactobacillus lactis, and Pentobacillus pentosaceus* [10]. Fermented soybean meal contains Bacillus spp. as well [11]. Yeast and

***Corresponding author:** Rajagopal Kammara, Chief Scientist, Faculty Department of Microbiology and Fermentation Technology, CSIR-CFTRI, Mysore, India

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fungi considerably facilitate fermentation [9]. Pathogenic organisms like *B. cereus, S. aureus, and Enterobacteriaceae* have been found in fermented foods like ngari, hentak, and tungtap [12]. However, dominant lactic acid bacteria prevented these harmful strains from multiplying, resulting in reduced CFU (colony forming units) units and decreased pathogenicity [13]. Ocins, which are proteinaceous antibacterial compounds, are produced and secreted by probiotics. Ocins, proteinaceous antibacterial compounds, are produced and secreted by probiotics. *Listeria monocytogenes (LM), Listeria innocua, B. cereus, S. aureus S1, S. mutans DSM 6178, K. pneumonia, P. aeruginosa BFE162, E. bifidum BFE 282, and E. agglomerans BFE 154* are a few pathogenic Gram-positive and Gram-negative bacteria that have been deemed hostile [14,15].

LM is a serious contaminant that has caused the dairy industry to suffer enormous financial losses. Global listeriosis outbreaks have been documented, and LM is a concern for the food industry [16]. The northeast of India has very little LM, the cause of listeriosis, present or dispersed there [17]. The consumption of fermented foods rich in probiotics, which create ocins, may be the reason why these foods can affect infections like Listeria spp. LM is a zoonotic bacterium that can be found in food and can grow at temperatures between 4 and 37 °C. Listeria, which is brought on by consuming, causes septicemia, meningitis, stillbirths, and miscarriages.

Those who have compromised immune systems and pregnant women are more vulnerable to listeriosis. It is a serious foodborne infection that leads to health issues, including pregnancy-related abortions, in developing nations like India. Unlike bacteriocins or antimicrobials, the pathogen has developed resistance to antibiotics like daptomycin and tetracycline. Researchers are interested in the food spoilage bacteria's broad-spectrum antimicrobial activities, particularly against LM.

The major goal of the review is to investigate the health benefits of traditional fermented foods from India. The review then concentrates on listeriosis, its causes, and potential remedies. The greatest treatment and prevention method for listeriosis is to consume native fermented foods from India. According to historical records, listeriosis has never caused an abortion in a woman in northeast India. Locals in this region consume fermented foods because they've been proven to be healthier. We therefore want to investigate and link traditional fermented foods to listeriosis, especially in the northeastern section of the state.

Fermented Foods and Beverages

Around the world, everyone's diet contains a substantial amount of fermented foods and beverages. They have advantageous functional characteristics and are produced spontaneously as a preservation mechanism. They differ in their tastes, textures, enticing looks, and flavours as well as how they are used. They were made to give the body vitamins and minerals [18]. While spontaneous fermentation is employed in Asia and Africa, starter cultures are used in New Zealand, Europe, North America, and Australia to generate fermented foods [19]. India's traditional method of spontaneous fermentation is called backslopping [20]. The previous fermented product can be used in this process as an inoculum source to ferment the food samples [21]. Most fermented food producers and consumers are in Northeast India.

Ethnic groups made the traditional fermented foods utilising ingredients derived from animals or plants [3]. Probiotic bacteria included in fermented foods can act as a starter culture, changing substrates that are acceptable to consumers on a cultural and social level [22]. Probiotic attributes, such as fibrinolytic activity [23], antioxidant activities [24], antibacterial properties [25], and anti-nutritive chemical breakdown, were observed in the helpful bacteria found in fermented foods, according to Hill, et al. [7,26]. When choosing a starting culture to produce valuable meals, these traits serve as a defining attribute [27]. In general, the bacteria present in fermented foods enhance a variety of health benefits when consumed [28].

The "Kinema-natto-thua nao triangle" (KNT triangle) was created by Tamang (2015) and later expanded to Indonesia. It claims that naturally fermented soybean foods concentrated with bacteria and moulds are frequently consumed in India, Japan, and Thailand, the triangle's three vertices [29,30]. The main constituents are *Pediococcus pentosaceous (P. pentosaceous*), *Lactobacillus plantarum, and Lactobacillus brevis. P. pentosaceous* from Hamei, an alcoholic starter, produces bacteriocin against LM [31]. The production of Hawaijar, a traditional non-salted fermented soybean meal with Bacillus spp. as the main bacterium, is well-known in Manipur and has a considerable positive impact on human health [32].

Table 1 [3,10-12,14,31-40] shows fermented foods, sources, probiotics, and India's biggest consumer state. Figure 1B shows fermented foods produced by northeastern states including significant LAB bacteriocin producers. In South India, fermented foods made from rice are the most popular. Idli, dosa, and uthappam are among the most very well delicious foods in South India. Mixed yeast and LAB cultures mediate the fermentation [40]. Most LAB strains and Bacillus spp. are hostile to food spoilage germs, which presents a risk to the food industry. A major source of worry is the possibility that listeriosis would impact the dairy, meat, and vegetable industries. The potential for infection to be fatal [41].

Probiotics and Their Attributes in Fermented Foods

Metchnikoff's research around the beginning of the twentieth century gave rise to the idea of probiotics. The findings of Ilya Ilyich Metchnikoff's research showed that LAB intake can enhance host health. By consuming fermented foods like yoghurt, cheeses, other fermented milk products, and fermented meat products, people can frequently find LAB, a well-known probiotic that includes Lactococcus and Lactobacillus, in their guts. Other popular probiotics include Bifidobacterium, Pediococcus, and Leuconostoc strains [42-44]. The classic example of a symbiotic connection is the gut microbiota, which is crucial to the maintenance of the host's physiology and health. The intestinal bacterial community

Table 1: Fermented foods of Northeast India.

Sl. No	Fermented food (local name)	Substrate/Raw material	Sensory attributes, Nature, and use	Probiotic	Major consumer States in India	Reference
1	Kinema	Soybean	Alkaline, Sticky, flavoured; curry	*Bacillus subtilis*	Darjeeling hills and Sikkim	Sarkar, et al., [33] Tamang [34]
2	Hawaijar	Soybean	Alkaline, Sticky, flavoured; side-dish	*Bacillus* sp.	Manipur	Jeyaram, et al., [32] Singh, et al., [35]
3	Tungrymbai	Soybean	Alkaline, Sticky, flavoured; curry	*Bacillus* sp.	Meghalaya	Chettri and Tamang [11]
4	Bekang	Soybean	Alkaline, Sticky, flavoured; side-dish	*Bacillus* sp.	Mizoram	Chettri and Tamang [11]
5	Aakhone	Soybean	Alkaline, sticky, paste, curry	*Bacillus* sp.	Mizoram	Singh, et al., [35]
6	Peruyaan	Soybean	Alkaline, sticky, side-dish	*Bacillus* sp.	Arunachal Pradesh	Singh, et al., [35]
7	Gundruk	Leafy vegetable	Dried, sour-acidic; soup, pickle	LAB	Darjeeling hills, Sikkim	Tamang, et al., [36] Tamang, et al., [37]
8	Sinki	Radish tap-root	Dried, sour-acidic; soup, pickle	LAB	Darjeeling hills, Sikkim	Tamang, et al., [36] Tamang, et al., [37]
9	Inziangsang	Mustard leaves	Dried, sour; soup, curry	LAB	Nagaland, Manipur	Tamang, et al., [37]
10	Khalpi	Cucumber	Sour; pickle	LAB	Darjeeling hills, Sikkim Arunachal Pradesh	Tamang, et al., [36] Tamang, et al., [37]
11	Mesu	Bamboo shoot	Sour; pickle	LAB	Darjeeling hills and Sikkim	Tamang, et al., [30]
12	Soibum	Bamboo shoot	Sour-acidic; curry	LAB	Manipur	K. Jeyaram, et al., [10]
13	Soidon	Bamboo shoot tips	Sour-acidic; curry	LAB	Manipur	K. Jeyaram, et al., [10]
14	Ekung	Bamboo shoot	Sour-acidic; curry, soup	LAB	Arunachal Pradesh	K. Jeyaram, et al., [10]
15	Eup	Bamboo shoot	Dry, acidic; curry, soup	LAB	Arunachal Pradesh	K. Jeyaram, et al., [10]
16	Hirring	Only tips of bamboo shoot	Sour-acidic; curry, soup	LAB	Arunachal Pradesh	K. Jeyaram, et al., [10]
17	Dahi	Cow milk	Curd, savoury	LAB, yeasts	Assam, Sikkim, Meghalaya, Tripura	Tamang, et al., [31] Jeyaram, et al., [38]
18	Chhurpi	Cow milk	Curry, pickle	LAB, yeasts	Darjeeling hills, Sikkim	Tamang, et al., [31]
19	Chhu/Sheden	Cow/Yak milk	Soft, strong flavoured; curry	LAB, yeasts	Sikkim, Darjeeling hills, Arunachal Pradesh, Ladakh	Tamang, et al., [31]
20	Somar	Cow/Yak milk	Paste, flavoured; condiment	LAB	Darjeeling hills, Sikkim	Tamang, et al. [31]
21	Philu	Cow/Yak milk	Cream; fried curry with butter	LAB	Sikkim	Tamang, et al. [31]
22	Ngari	fish	Fermented fish; curry	LAB, yeasts	Manipur	Thapa, et al. [12]
23	Hentak	Fish and petioles of aroid plants	Fermented fish paste; curry	LAB, yeasts	Manipur	Thapa, et al. [12]
24	Tungtap	Fish	Fermented; pickle	LAB, yeasts	Meghalaya	Thapa, et al. [12]

25	Gnuchi	River fish	Smoked; curry	LAB, *Bacillus,* yeasts	Darjeeling hills, Sikkim	Tamang, et al. [14]
26	Suka ko Maacha	River fish	Smoked, sun-dried; curry	LAB, *Bacillus*, yeasts	Darjeeling hills, Sikkim	Tamang, et al. [14]
27	Sidra	Fish	Dried fish; curry	LAB, yeasts	Darjeeling hills, Sikkim	Tamang, et al. [14]
28	Sukuti	Fish	Dried fish; curry	LAB, yeasts	Nepalis	Tamang, et al. [14]
29	Hamei	Rice, wild herbs	Dry, ball-like, white starter, alcoholic beverage	Moulds, yeasts, LAB	Manipur, Sikkim	Tamang, et al. [31]
30	Marcha	Rice, wild herbs, spices	Dry, flattened ,ball-like, white starter, alcoholic beverage	Moulds, yeasts, LAB	Assam, Sikkim, Meghalaya, Arunachal Pradesh	Tamang, et al. [31]
31	Humao	Rice, barks of wild plants	Dry, flat, cake-like starter	Moulds, yeasts, LAB	Manipur	Tamang, et al. [39]
32	Thiat	Rice-herbs	Dry, flattened, ball-like, white starter	Yeasts	Meghalaya	Tamang, et al. [39]
33	Khekhrii	Germinated rice	Starter to ferment zhuchu	Yeasts	Nagaland	Tamang, et al. [39]
34	Inziang-dui	Mustard leaves	Liquid, sour; condiment	LAB	Nagaland, Manipur	Tamang, et al. [3]
35	Anishi	Taro leaves	Fermented; sour; curry	LAB	Nagaland	Tamang, et al. [3]
36	Lung-siej	Bamboo shoot	Sour-acidic; curry	LAB	Meghalaya	Jeyaram, et al. [10] Tamang, et al. [3]
37	Bastanga	Bamboo shoot	Sour-acidic; curry	LAB	Nagaland, Manipur	Tamang, et al. [3]
38	Miyamikhri	Bamboo shoot	wet, sour-acidic; curry	LAB	Assam, Nagaland	Tamang, et al. [3]
39	Soijim	Bamboo shoot	Liquid, sour; condiment	LAB	Manipur	Tamang, et al. [3]
40	Karati	Fish	Dried, salted; curry	LAB, yeasts	Assam	Tamang, et al. [3]
41	Bordia	Fish	Dried, salted; curry	LAB, yeasts	Assam	Tamang, et al. [3]
42	Lashim	Fish	Dried, salted; curry	LAB, yeasts	Assam	Tamang, et al. [3]

must be maintained with a healthy, balanced diet. Over the past ten years, it has become clear that metabolic illnesses including type 2 diabetes and obesity are greatly influenced by the gut flora (T2D). Intestinal homeostasis has been disturbed by the westernized obesogenic diet, which is high in simple carbohydrates and saturated or trans fats, which results in insulin resistance [45]. One important risk factor for type 2 diabetes is obesity [46]. Hyperglycemia, a metabolic condition marked by elevated blood glucose levels, is a feature of T2D [47].

According to several investigations, LAB has anti-diabetic potential. In high-fat diet animals demonstrating biochemical alterations, probiotic dahi containing *Lactobacillus acidophilus* and *Lactobacillus casei* prevented the progression of diabetes [48]. According to a different study, some LAB strains may act as bio-therapeutics for the treatment of diabetes by promoting the production of gut hormones like GLP-1 and GIP [49]. Additionally, LAB strains exhibit the highest levels of -glucosidase inhibition activity, which lowers blood glucose levels and glucose absorption to help prevent T2D [50]. VSL#3, a probiotic blend of eight distinct strains, is efficient in both the management and prevention of diabetes and obesity [51].

Serum cholesterol levels are lowered when fermented milk containing large amounts of *Lactobacillus* and *Bifidobacterium* is consumed [52]. By permeating the intestinal mucosal layer and promoting phagocytic activity in the spleen and other organs, Lactobacilli and Bifidobacterium, for instance, can assist in regulating the host immune response [53]. By lowering bacterial toxins, probiotics have positive effects in the treatment of liver illnesses [54]. Healthy adults who consume *Lactobacillus paracasei* for four weeks see a decrease in *Escherichia coli* in their faeces and ammonia levels as well as an increase in Lactobacillus, Bifidobacterium, acetic acid, and butyric acid [55].

Exopolysaccharides, bacteriocins, organic acids, and antibacterial substances are only a few of the various molecules that probiotics produce. In the gut, dangerous microorganisms are eliminated by the bacteriocins and acids [56,57]. It is well known that LAB can sense its surroundings

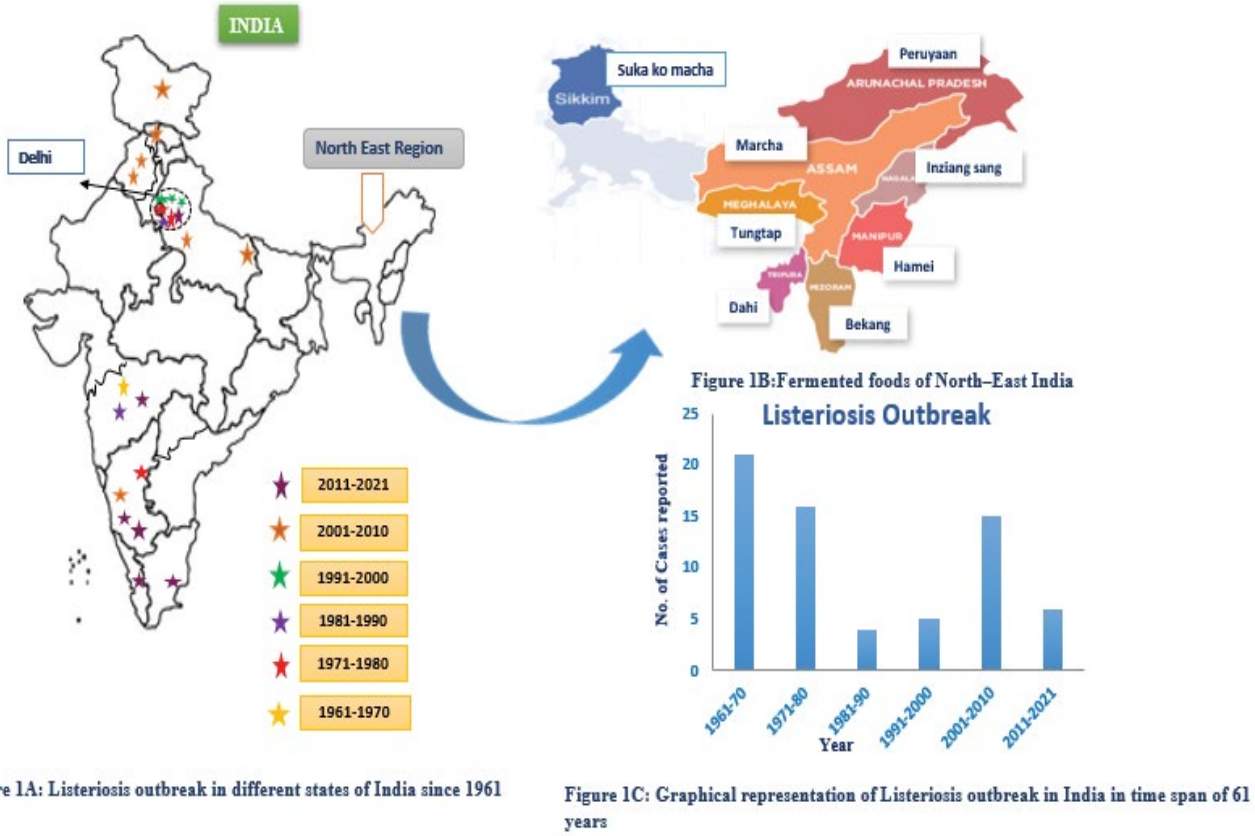

Figure 1A: Listeriosis outbreak in different states of India since 1961

Figure 1B:Fermented foods of North–East India

Figure 1C: Graphical representation of Listeriosis outbreak in India in time span of 61 years

Figure 1: Listeriosis Outbreak in India.

and create bacteriocins and organic acids that, by lowering pH and boosting peristalsis, prevent pathogen colonization. By keeping hazardous pathogens out, the intestinal barrier is strengthened, which directly affects the gut microbiota [58].

Mucin is secreted by intestinal epithelial cells to prevent the colonisation of microbial pathogens. Surface adhesins are secreted by certain Lactobacillus strains to aid in their ability to adhere to the mucosal layer [59-61]. The Caco-2 cell line has been successfully utilised for the past three decades to assess the probiotics' *in vitro* adhesion capacity. The ability of LAB strains to colonise intestinal epithelial cells with the maximum degree of adhesion makes them an effective barrier against harmful bacteria [47]. However, HT-29 cells can also be used to assess intestine adhesion capacity. The most significant amount of *L. rhamnosus* MG4502 adhered to HT-29 cells [46].

Listeria Monocytogenes (*LM*) and *Listeriosis*

Food safety is a serious concern in the modern public health world [62]. Disease outbreaks in a variety of foods have been linked to the genus LM of bacterial pathogens [63]. Food samples from around the world, including meat, milk, and dairy products, have all been shown to have Listeria spp [64-67]. LM is a zoonotic, non-sporulating, Gram-positive, rod-shaped, facultative, intracellular, virulent bacteria that thrives at temperatures between -2 °C and 50 °C, with optimal growth occurring between 30 °C and 37 °C [68,69]. It is a hazard to the food business and a pathogen that is found in food. It is a food-borne pathogen and a threat to the food industry, possessing attributes like the ability to grow even at 4.0 °C, resistance to extreme pH, metals, and disinfectants [70-72]. LM causes the invasive illness listeriosis [73].

LM infection

LM is connected to numerous public health problems all throughout the world. In addition to abortions, meningitis, meningoencephalitis, septicemia, and stillbirths, it is associated with visceral, neurologic, and reproductive clinical entities. A dangerous infection called listeriosis can harm expectant mothers, elderly people with compromised immune systems, newborns, people with kidney diseases, HIV patients, and even those who come into touch with animals [74-77].

It has been discovered that healthy people's intestines contain LM [78,79]. Contrary to typical foodborne pathogens like *Salmonella spp*., which seldom result in fatalities, listeriosis is now known to have a staggering fatality rate of up to 30% [78]. The common serotypes linked to human listeriosis include 1/2a, 1/2b, and 4b [80]. Since the placenta acts as a breeding ground for LM, pregnant women are more susceptible to infection. This can result in spontaneous miscarriages, neonatal infections, placental necrosis, stillbirths, severe necrotizing hepatitis, and a high risk of post-implantation failure [81,82]. Pregnant women with latent listeriosis are more likely to experience abortions, intrauterine deaths, and abnormalities in the foetus [83,84]. Pregnant

women have a 17-fold higher prevalence of listeriosis than the general population [85]. The clinical condition known as granulomatosis infantiseptica is brought on by the foetus' increased susceptibility to infection during pregnancy [86]. Meningitis and hydrocephalus are caused by infected moms during childbirth in newborns [87]. The most recent publications emphasise the significance of the pathogen as a contributor to infant mortality and spontaneous abortions.

Pathogenesis density Global Scenario

Women from different countries, including India, who have had numerous abortions and have a poor obstetric history, have been discovered to have listeriosis [88-90]. According to the CDC, spontaneous abortion occurs in the second and third trimesters of pregnancy in one-third of all human listeriosis cases (Centre for Disease Control and Prevention). 10-20% of cases in England and Wales result in pregnancy and neonatal disease, while 15-25% of infections result in stillbirths and abortions [91]. The CDC has reported a Listeria strain outbreak in six American states as of November 9, 2022. A total of 16 persons became ill after consuming *Listeria spp*.- contaminated meat and cheese from deli corners, one of whom became ill while pregnant and miscarried. The CDC reported a Listeria outbreak on May 14, 2021, in four states of the United States of America due to Quesco Fresco that was tainted with Listeria spp. Four of the 13 affected individuals were ill during pregnancy, which led to two miscarriages and one early birth. The eating of Olaf ice cream tainted with *Listeria monocytogenes* resulted in the infection of a total of 28 persons, the majority of whom are residents of Florida. Seven women experienced illness during pregnancy, with one miscarriage.

An outbreak of LM was caused by consumption of Listeria spp.-contaminated enoki mushrooms, a Korean product, and 36 illnesses were documented. Two foetuses died in six of the cases, which were related to pregnancy. In Los Angeles and Orange counties, California, in the first six months of 1985, 86 instances of *Listeria monocytogenes* illness linked to Mexican-style cheese were documented. This occurred in 58 mother-infant pairings, resulting in 29 fatalities. A total of 5576 instances of listeriosis were recorded in the 10-year (2010-2019) case study in Germany, with 9% of the cases being connected to pregnancy.

A sentinel hospital in China recorded 211 occurrences of listeriosis between 2013 and 2017, with 55 resulting in foetal fatalities. Due to a multistate outbreak of Listeriosis in 1998-1999, the CDC reported that two pregnant women in the United States spontaneously aborted their unborn children. In one of the 178 cases that were documented, 36 moms (or around 20%) suffered spontaneous abortions, according to Mylonakis. In the remaining 142 cases, 97 neonates (about 68%) had the infection at birth. Because of this, obstetricians give a lot of thought to avoiding, identifying, and managing pregnancy.

LM Infection in India

In India, there is less evidence than in developed nations to support the correlation between pathogenic LM and spontaneous abortions. Because of its irregular occurrence in India, Chugh's [92] growing concern over the novel foodborne illness Listeriosis is due to this. According to Prem Saran Tirumalai's clinical research, the prevalence of listeriosis in the Indian Subcontinent amply demonstrates both newborn and maternal listeriosis [93]. Listeria in humans was originally discussed by Usha, et al. in 1966 [94,95]. Figure 1A shows the geographical risk map for listeriosis in India from 1961 (61 years). According to Bhujwala, et al. [96], LM is the etiological cause causing abortions and premature births in India. They isolated LM from 3 of 100 women having bad obstetric history. Later again in 1975, they isolated LM from 9 of 670 women possessing terrible obstetric history. Krishna, et al. later isolated LM from the cervix of 21 women with a poor obstetric history. Stephen, et al., [97], found 4 abortion cases out of 40 women in their study of diverse LM infections. According to Kaur, et al. [77], *L. monocytogenes* was found in 3.3% of spontaneous abortion cases. Children born to LM infected mothers had meningitis and hydrocephalus, according to Gogate and Deodhar [87].

In order to comprehend the epidemiology of listeriosis, serology is a crucial technique. However, the cross-reactivity with other related bacteria hinders the study. Serological assays can use virulence factors unique to LM as antigens to investigate the pathophysiology of listeriosis. Listerolysin O (LLO), its main virulence factor, is detected using ELISA-based methods to determine whether an animal or a human has listeriosis [98-100]. With the help of the study, we have reason to believe that India's north and west had experienced a listeriosis outbreak with high fatality rates. Although reversal was seen after eating fermented meals high in probiotics, which stop pathogen growth in food, it is probable that this is connected to eating contaminated foods. Compared to the rest of India, South India has experienced fewer breakouts. The listeriosis outbreak in India is detailed in Table 2 [77,87-89,96,97,101-113], and the sickness is graphically shown in Figure 1C.

LM in foods

In India, LM has been found in both clinical cases and foods derived from animals [77,93,114,115]. This pathogen can be found frequently in raw tropical seafood and ready-to-eat foods. This bacterium might be living in a "biofilm" -a coating of extracellular polysaccharide matrix- in food processing facilities [63,93]. Gulab Jamun, Rasagolla, curd, and payasam have been identified as sources of *Listeria welshimeri, L. murrayi, and L. seeligiri* [116]. LM can be used to treat human listeriosis because it is responsive to some medicines and resistant to others; nevertheless, multidrug-resistant species have evolved.

Antibiotic Susceptibility and Resistance

Antibiotics are chemicals made naturally, semi-synthetically, and synthetically that prevent bacterial growth (bacteriostatic) or eradicate bacteria (bactericidal) [117,118]. Depending on their method of action, they are categorised as bacteriostatic or bactericidal, or as narrow-spectrum or broad-spectrum drugs [119,120]. In order to help reduce

Table 2: Listeriosis in India.

Year	Place	Report	No. of Cases	Reference
1966	Maharashtra	Maternal Listeriosis	21	Krishna, et al.,
1972	Delhi	Maternal Listeriosis	3	Bhujwala, et al. [96]
1975	Delhi	Maternal Listeriosis	9	Bhujwala, et al. [89]
1977	Karnataka	Maternal Listeriosis	4	Stephen, et al. [97]
1981	Delhi	Neonatal	3	Thomas, et al. [101]
1981	Maharashtra	Meningitis	1	Gogate and Deodhar [87]
1995	Delhi	Pericarditis	1	Revathi, et al. [102]
1997	Delhi	Septicaemia ,Neonatal	3	Gupta, et al. [103]
1998	Delhi	Perinephric abscesses	1	Gomber, et al. [103]
2003	Punjab	Maternal Listeriosis	1	Gupta, et al. [88]
2003	Karnataka	Abortion	2	Dhanashree, et al. [104]
2005	Varanasi	Neonatal	1	Srivastava, et al. [105]
2007	Punjab and Uttar Pradesh	Maternal Listeriosis	9	Kaur, et al. [77]
2010	Kashmir	Meningoencephalitis	1	Peer, et al. [106]
2010	Himachal Pradesh	Neonatal	1	Mokta, et al. [107]
2014	Karnataka	Meningitis	1	Dias, et al. [108]
2016	Maharashtra	Meningitis	1	Nirhale, et al. [109]
2018	Tamil Nadu	Septicemic Listeriosis	1	Miraclin, et al. [110]
2018	Karnataka	Meningitis	1	Mahadevaiah, et al. [111]
2019	Delhi	Meningitis	1	Gulla, et al. [112]
2021	Kerala	Sepsis and Meningitis	1	Ajimsha Ashna, et al. [113]

food-borne illness, antibiotics are employed in the food business. The evolution of antibiotic resistance in bacteria that cause food deterioration has been linked to the usage of antibiotics in the food industry. In LM, resistance has grown to gentamicin, tigecycline, tetracycline, ciprofloxacin, ceftriaxone, and trimethoprim-sulfamethoxazole. Because the strain is primarily serotype IV sensitive, ampicillin, benzyl penicillin, linezolid, meropenem, rifampicin, and vancomycin can be employed to prevent food contamination [121]. Antibiotics are not thought to be safe in the food and cattle industries and have detrimental effects when consumed by humans. It is prohibited to utilise them in agriculture and the production of food. Pressure to limit antibiotic use in agriculture and the food sector has made antimicrobial peptides and potential antibiotic surrogates more prominent as effective natural alternatives to fight contamination and microbial infections [122,123]. Less time was spent researching safe medicinal chemicals such antimicrobial peptides (bacteriocins) and more time was spent reducing the usage of antibiotics [124,125].

Antimicrobial peptides (AMPs) or Ocins

The potential natural antimicrobials known as bacteriocins were first found by Gratia around a century ago [126]. They are proteinaceous, heterogeneous groups of cationic, amphiphilic, and/or hydrophobic antimicrobial peptides derived from both Gram-positive and Gram-negative bacteria unfriendly to closely related strains, and act at pico- to nano-molar doses [127,128]. Unlike antibiotics, which are ribosomally generated, antimicrobials also contain post-translational changes, also referred to as "postbiotics" [129].

Bacteriocins have both restricted and broad-spectrum activity as they inhibit a wide variety of bacteria, both related and unrelated [128]. They are known to be rapid to kill germs that are resistant to antibiotics [130]. These substances are GRAS (generally acknowledged as safe) microorganisms that are utilised as food biopreservative in the food industry. Perhaps they are used in place of conventional antibiotics to treat illnesses in humans and livestock used for food production. Bacteriocins play a significant role in the food industry since they are absorbed by the human gastrointestinal (GI) tract [131]. In recent years, a substantial number of LAB bacteriocins have been characterized [132].

By generating channels in the target cell membrane that allow low-molecular-weight ions to exit, they cause the proton motive force to collapse [133]. According to Klaenhammer [134], there are four different types of LAB bacteriocins: Class I, which is commonly referred to as lantibiotics and includes lanthionine, dehydrated residues, and methyl lanthionine; class II, which includes non-lanthionine peptides (less than 10 kDa); class III, which includes large heat-labile proteins (greater than 30 kDa); and class IV, which is bac NISIN, a class I lantibiotic produced by the LAB *Lactococcus lactis* (GRAS), is one of them and inhibits both Gram-positive and Gram-negative bacteria [135,136]. It is the only bacteriocin for the preservation of processed cheese that has been approved by the FDA [137]. It is the only bacteriocin for processed

cheese preservation that has received FDA approval [137]. *Pediococcus acidilactici* produces Pediocin PA-1, a Class II bacteriocin, which prolongs the shelf life of ready-to-eat foods by inhibiting LM [138]. Bacillus subtilis Class I ocin subtilin suppresses LM in a variety of ways [139]. Both gram-positive and gram-negative bacteria, including *Salmonella spp., Campylobacter spp., Escherichia coli, Vibrio spp., Brucella spp.,* and *Yersinia spp*., can result in food poisoning. Well-known pathogenic bacteria include *B. cereus, C. botulinum, C. perfringens, B. anthracis,* and *S. aureus* [41]. Because of recurring and severe listeriosis outbreaks, pathologists have been studying LM for the past decade [132]. The search for bacteriocin-producing LAB has since been turned to compounds that target Listeria spp., yielding a huge number of anti-listerial bacteriocins. These days, probiotics with lactic acid bacteria, such as *Lactobacillus* and *Bifidobacterium*, are widely used [140-143]. In fermented foods, they prevent potentially harmful bacteria from expanding, colonising, and multiplying [144]. There is a long history of safe usage of Bacillus strains in the food industry, and they produce a variety of antimicrobial peptides and proteins [139].

Ocins against LM

Bacteriocins that block LM are particularly interesting and have drawn a lot of research funding [145]. There aren't many published investigations on the antibacterial activity of LAB strains obtained from fermented foods against Listeria spp. *P. pentosaceus* HS: B1 isolated from Hamei produces bacteriocin that is effective against *L. monocytogenes* and *L. innocua* [31]. *P. pentosaceus* MA: C1, an isolate from Marcha, contained inhibition zones against *Listeria spp* [31]. It was discovered that Sukako Maacha LAB strains were effective against *Listeria spp* [14]. Isolates of fermented foods that are resistant to food-borne illnesses are listed in Table 3.

Consuming some Bacillus strains has been demonstrated to be healthy [32]. *Bacillus subtilis* produces the bacteriocin Subtilosin A, which has antibacterial activity against LM [146]. However, Subtilosin A1 (3412.5 Da), which is produced by the hemolytic mutant of *Bacillus subtilis*, has more antibacterial activity against LM [139,147]. Additionally, a number of clinically significant drug-resistant pathogens, including methicillin vancomycin antibiotic-resistant *Staphylococcus aureus* (MVRSA), vancomycin-resistant *Enterococcus faecalis* (VRE), and methicillin-streptomycin antibiotic-resistant *Staphylococcus epidermidis* (MRSE), are susceptible to the antimicrobial effects of *Bacillus spp* [130].

Host Immune Response against LM

The pathogen of the genus Listeria that causes listeriosis in humans is called *Listeria monocytogenes* (LM) [148,149]. Similar to human infection, the pathogen is ubiquitous, saprophytic, and opportunistic [149]. Meningoencephalitis,

Table 3: Probiotics of fermented foods antagonistic to food spoilage bacteria.

Sl. No.	Fermented food	Probiotic	Pathogen	Reference
1	Dahi	LAB	*Enterobacter agglomerans, Enterobacter cloacae*, *Klebsiella pnuemoniae*	Tamang, et al. [31]
2	Mohi	LAB	*Enterobacter agglomerans, Enterobacter cloacae*, *Klebsiella pnuemoniae*	Tamang, et al. [31]
3	Chhurpi	LAB	*Enterobacter agglomerans, Enterobacter cloacae*, *Klebsiella pnuemoniae*	Tamang, et al. [31]
4	Somar	LAB	*Enterobacter agglomerans*, *Klebsiella pnuemoniae*	Tamang, et al. [31]
5	Cow philu	LAB	*Enterobacter agglomerans, Klebsiella pnuemoniae*	Tamang, et al. [31]
6	Yak philu	LAB	*Enterobacter agglomerans, Klebsiella pnuemoniae*	Tamang, et al. [31]
7	Hamei	*Pediococcus pentosaceous* HS B1	*Listeria monocytogenes,* *Listeria innocua*	Tamang, et al. [31]
8	Suka ko macha	*Lactococcus lactis*	*Listeria innocua* *Staphylococcus aureus*	N.Thapa, et al. [14]
9	Inziangsang	*Lactobacillus plantarum*	*Staphylococcus aureus*	Tamang, et al. [37]
10	tungtap	*Lactobacillus coryniformis, Bacillus subtilis*	*Enterococcus faecium* DSM 20477 *Streptococcus mutans* DSM 6178	N.Thapa, et al. [12]
11	Fermented milk products from Himalayan regions	*Lactobacillus* and *Lactococcus*	*Enterobacter agglomerans, Enterobacter cloacae*, *Klebsiella pnuemoniae, Pseudomonas aeruginosa*	Tamang, et al. [31]
12	Marcha	*Pediococcus pentosaceus* MA:C1	*Listeria* sp.	Tamang, et al. [31]

vomiting, diarrhoea, flu-like symptoms, and spontaneous abortions in pregnant women are all indications of the food-borne illness listeriosis [150]. Immune-compromised elderly people and pregnant women have died from listeriosis [149]. Since 1980, scientists have researched the molecular mechanisms behind LM's pathogenicity [151]. Understanding the immune response brought on by this intracellular infection is necessary to combat listeriosis [152]. Since the pathogen is present in both industrially produced and raw foods, LM consumption is prevalent. Considering both sporadic and epidemic cases, contaminated food is the major source of infection [67,153].

The number of bacteria in the liver rose, with the hepatocyte acting as the main site of infection. Kupffer cells (KC) in the liver gathered cytokine releases, T-lymphocyte proliferation, and anti-listerial immunity [154]. Macrophages, which are the major target of the innate immune response, cause the release of chemokines such interleukin-12 and tumour necrosis factor alpha (TNF-α) (IL-12). This triggers a bactericidal response by activating macrophages and triggering natural killer (NK) cells [155-157]. The host produces TNF-α, IL-6, IL-12, IL family, and gamma interferon (IFN-γ) as acute inflammatory cytokines in response to LM [155,158-160].

In the early stages of liver colonisation, IL-6 draws neutrophils to the sites of infection. Neutrophils then release chemokines like monocyte chemoattractant protein-1 (MCP-1) and colony stimulating factor-1 (CSF-1), which boost the number of macrophages at the localised infection site and kill LM-infected hepatocytes [161-163]. The entire clearance of the bacterial burden is aided by adaptive immunity, which is mediated by IFN-γ and CD-8, according to a week's worth of post-infection trials. TNF-α, IFN-γ, and IL-12 are produced by infected macrophages in addition to adaptive immunity [151]. In the hepatocytes of an immune-compromised host or a pregnant woman, bacteria grow without restriction before spreading hemogenously to the brain and other organs [164].

Studies on pregnant mice show that LM enters the foetus through haematogenous penetration of the placental barrier [151]. The placental villi are infected after the decidua basalis, causing necrosis and inflammation. Macrophages are not the primary participants in an immune response. To infected foci in the decidua basalis, CSF-1 draws neutrophils. LM may travel through the foetal bloodstream and cause stillbirth, early birth, or infection to the baby because to bacterial colonisation in the trophoblast layer and endothelial translocation. Due to high amounts of pregnancy hormones like oestrogen, the T-cell-mediated immune response is compromised during pregnancy. IFN-γ, IL-2, and IL-12 production are consequently decreased, all of which are necessary to remove infection. Consequently, increased susceptibility to LM was observed during pregnancy [165-167] in fetus and placenta due to local depression of cell-mediated response [168].

Although LM responds to a variety of drugs, listeriosis is challenging to treat. Only a small number of antibiotics have bactericidal qualities, while the majority have bacteriostatic properties [169]. Because of the rise of antibiotic resistance, several countries' antibiotic restrictions are a subject of concern [170]. LM is naturally resistant to antibiotics such cephalosporin, nalidixic acid, and fosfomycin [171]. As a result, as antibiotic resistance increases, antibiotic therapy fails [172]. Artificial preservatives may lower food quality because LM can flourish in any meal at any temperature [173]. Although the use of bacteriocins or other antimicrobial substances in the meat sector is well known, antimicrobial substances are currently being researched for use in the dairy industry. Bacteriocins from probiotics have been shown to stimulate an immune response against LM and so minimise the mortality rate from Listeriosis. Probiotics provide protection against intracellular bacterial infections when taken orally and function as an alternative to antibiotics [174]. Potential probiotic options Lactobacillus and Bifidobacterium are present in many foods, especially fermented dairy products [175]. Via preventing adhesion to intestinal epithelial cells by colonisation replacement, probiotics prevent the invasion of the intracellular pathogen [176,177].

By coming into touch with monolayers of intestinal epithelial cells, pre-treatment of enterocytes with probiotic bacteria prevents the invasion of Listeria [178]. By promoting mucin expression, maintaining tight junctions, and bolstering cytoskeletal integrity, the probiotics improve gut barrier function and decrease bacterial translocation [177,179-181]. Probiotic bacteria enhance the epithelial and mucosal barriers by releasing butyrate, a short-chain fatty acid produced during microbial fermentation [182]. Probiotic pre-treatment of monolayers prevents listeria infection by raising anti-inflammatory IL-10 cytokines and lowering pro-inflammatory IL-8 cytokines in the cells, according to *in-vitro* experiments using the C2eBb1 epithelial cell model [178].

The host response is changed by increased IgA production and decreased pro-inflammatory IFN-γ [183,184]. IL8 draws macrophages and leukocytes to the infectious inflammation region [185]. A visual illustration of listeriosis with Bacteriocin and the host immune response is shown in Figure 2. By raising TNF-α and IFN-γ levels, mono-association with LAB and subsequent Listeria infection strengthen mice's immune systems. By enhancing bacterial clearance from the liver and spleen, it also stops mice from dying when an illness lasts for a week. 2011 (Doss and associates). S-layer proteins, a type of probiotic bacterial cell component, neutralise toxins and prevent pathogen colonization [186]. Human beta-defensin-2 (hBD2) gene expression is induced by probiotics such as *Pediococcus pentosaceus, Lactobacillus acidophilus, Lactobacillus fermentum*, and the probiotic combo VSL#3, which results in the formation of defensins that improve mucosal barrier function. This was due to the signalling pathways of *AP-1, NF-kB* and mitogen-activated protein kinase (MAPK) [187].

The *P. acidilactici* UL5 strain of this LM inhibitor, which was isolated from fermented sausages, shows potential. According to *in-vivo* research, pre-treatment with Pediocin PA-1, followed by LM infection, causes the liver and spleen to be cleared of bacterial pathogens [188]. Oral administration of bioengineered *Lactobacillus casei* for the treatment of LM infection in pregnant and non-pregnant mice (BLP). The

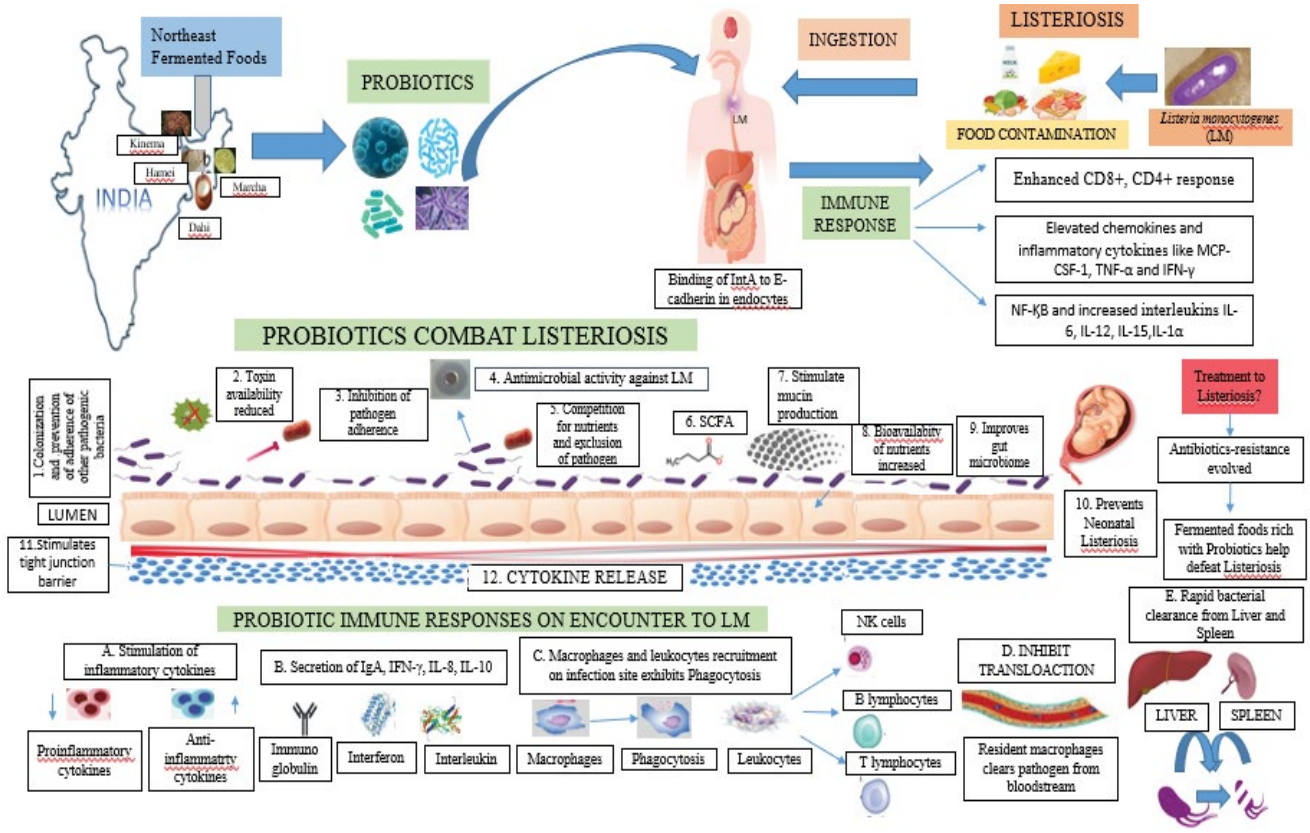

Figure 2: Listeriosis with Bacteriocin and The Host Immune Response.

maternal mesenteric lymph node (MLN), liver, and spleen were infected in the BLP-fed guinea pig model, but no LM was identified in the placenta, maternal blood, lungs, kidney, or foetal liver. Pregnant BLP-fed models had a lower inflammatory response to LM, which led to a healthy pregnancy [189]. Probiotics generally contribute in the improvement of digestive processes, and the prevention of food poisoning.

Conclusion

Each society has a distinct culinary tradition that includes fermented foods and drinks that highlight the history, social structure, and cultural characteristics of that society. Many traditional fermented meals have been produced and consumed all across the world for generations. The Eastern Himalayas are the only place in the world where soybeans are fermented into food. A range of helpful bacteria found in fermented foods have the power to enhance human health while eradicating harmful pathogenic microbes from the food supply. Probiotic strains such LABs, Bacillus spp., *P. pentosaceous*, and others are frequently found in fermented foods. These probiotic bacteria produce antimicrobial proteins and peptides and are antagonistic to a variety of food spoilage germs, especially LM. The recent decline in abortion rates in the Northeast and South India may be related to the region's high consumption of fermented foods. It has been discovered that fermented foods including Hamei, Marcha, and Sukako maccha contain LABs that inhibit *Listeria spp*. We conclude that abortion rates are reduced or non-existent in Northeast India, possibly as a result of the consumption of traditional fermented foods. Fermented foods rich in probiotics help foods develop immunity against LM, which lowers the rate of abortion. To fully understand the microbiota of all fermented foods from the Northeast, more study is required. It is necessary to record the ethnic tribal population of the region and their distinctive food customs. To fully comprehend the microbial repertoire in fermented foods, more study is required.

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