REVIEW ARTICLE



Fermented marine foods of the indigenous arctic people (Inuit) and comparisons with Asian fermented fish

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Abstract

The Inuit, sometimes referred to as Eskimos, are indigenous people to the remote circumpolar regions of the northern hemisphere that remain relatively inaccessible to outsiders. The traditional diet consisted almost entirely of raw animal foods eaten fresh, dried, or fermented and was similar to the diets of wild carnivorous animals. From the 1950s onward, the Inuits gradually adopted Western foods. With the adoption of a more Western diet, there has also been a corresponding increase in Western diseases such as obesity, type 2 diabetes, hypertension, and some cancers. Asians have also consumed salted fermented fish, but the fermented fish are different due to environmental temperatures. Although the microbial content of Inuit fermented foods is uniquely different from that of Asian fermented foods, Asian and Inuit fermented foods appear to be similarly important for supporting gut and immune health. The benefits of Asian fermented fish for improving the biodiversity of the microbiome and the generation of bioactive amines from proteins may be similar to the fermented marine foods of the Inuits. This study reviewed traditional fermented fish consumed by the Inuit people and Asians, highlighting various aspects that can offer valuable insights into the nutritional, cultural, and health dimensions of these practices.

Keywords Fermented fish, Inuit, Asia, Safety, Function

Introduction

The Inuit people, native to the expansive and secluded circumpolar regions of the northern hemisphere (Fig. 1), have nourished themselves across generations with a traditional diet that reflects their profound bond with the natural world. The term Eskimo is widely believed to be derived from a word meaning "those who eat raw meat." [1]. Some Inuit people view this as a derogatory term, and its use is declining. However, their diet is mostly composed of fresh, dried, or fermented animal-based foods

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² Food & Nutrition, Obesity/Diabetes Center, Hoseo University, 165 Sechul-Ri, BaeBang-Yup, Asan-Si, ChungNam-Do 31499, South Korea that have not been heated. This lifestyle is often likened to the dietary habits of the wild carnivorous animals that inhabit these same regions. However, the latter half of the twentieth century witnessed a gradual shift in dietary patterns among the Inuit as Western foods and eating habits began infiltrating these remote landscapes. With this transition came a notable rise in metabolic diseases, raising questions about the health implications of dietary change and the role of traditional fermented foods in supporting well-being.

Asian fermented fish contain 8-30% salt, unlike Iniut fermented fish, which is determined by environmental temperature. Korean fermented fish include 8-13% salt and are stored in the crypt to maintain 13-15 °C, while fermented fish in Southeast Asia contain 20-30% salt. Asian communities have long recognized the nutritional value, preservation benefits, and unique flavors imparted



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Fig. 1 Geographical distribution of Inuit populations in the northern hemisphere. Red area indicated the Inuit. Adapted from: https://www.narod natribuna.info

by fermented fish products. These foods are revered not only for their taste, but also for their role in enhancing gut health, supporting immunity, and providing a source of essential nutrients. We investigate the history of fermented fish consumption and the characteristics of fermented fish in the Inuit and Asian communities. This review aims to provide insights and facilitate understanding of various aspects of fermented fish consumption in these two distinct cultural groups. Some potential aspects that could be explored in this review include the health benefits of fermented fish and how the consumption of fermented fish products impacts the human microbiome.

Fermented fish of the Inuit

Traditional foods of the indigenous people of the arctic

The Inuit are indigenous people of the Arctic regions (sometimes known as Eskimos). They are composed of culturally similar tribes living in the far North and circumventing the northern polar regions of North America, Europe, and Asia [1]. The Inuit are citizens of several countries since they live in Siberia, Alaska, Canada, and Greenland. These remote Far North areas were inaccessible to the outside world until the early 1900s. By the 1950s, the Inuit people were no longer isolated from the outside world, even though they still lived in remote regions of the far North [2]. Agriculture is impossible in the Arctic, so the Inuit are traditionally hunter-gatherers. However, the nomadic way of life of the Inuit has given way to permanent settlements, imported foods that increasingly replace traditional diets, new health challenges, and a diminishing appreciation for long-held traditions [2]. The health benefits of the Inuit diet, as well as the medicinal benefits of traditional foods and remedies, are poorly researched and in critical danger of being forever lost [1].

The Inuit diet has traditionally been rich in fat and protein and very low in carbohydrates. The diet consisted primarily of animal foods, mainly fish, marine and land mammals, and birds. The animal skin, fat, muscle tissue, organs, and eggs were all consumed and eaten raw, cooked, dried, frozen, or fermented [1, 4, 5]. However, in А





D.



Fig. 2 A Contemporary Inuit people dressed in traditional clothing. Downloaded from dreamstime.com. https://www.dreamstime. com/editorial-stock-photo-inuit-eskimo-people-welcoming-forei gners-aboriginal-native-group-waiting-to-welcome-visitors-to-nanor talik-greenland-image73064723. © Teodor Lazarev. B Freshly caught Minke Whale for Sale at a Butcher in Nuuk, Greenland. This is a seasonal delicacy, strictly regulated by a government guota system, that allows the Inuit population to continue its special culinary tradition. Downloaded from www.dreamstime.com ID Number: 80016370 © Luis Leamus|Dreamstime.com. C Fish drying in the sun: Dried fish in Rodebay settlement. Fresh fish rapidly deteriorates unless some way can be found to preserve it. Drying is a method of food preservation that works by removing water from the food, which inhibits the growth of microorganisms. Open air drying using sun and wind has been practiced since ancient times to preserve food Downloaded from www.dreamstime.com ID Number: 33442012 © Checco|Dreamstime.com. **D** Fresh caught fish being prepared

1980, Bang et al. reported that the "Eskimo population" of Alaska and Canada were eating diets rich in "Western foods" and that sugar sales in the region amounted to approximately 175 g per person per day [6]. It was a significant deviation from the traditional diet of the Inuit, which contained no sugar or grains. The "Eskimo Diet" of 1855 consisted of small amounts of food from white traders. However, the overall diet was almost completely carnivorous and provided a daily intake of 377 g of protein, 59 g of carbohydrates, and 162 g of fat. Without Western influences, the "Eskimo" diet contained few plant foods, with only a few seasonal berries, roots, leaves, and seaweed [7].

Traditional fermented food of the indigenous people of the arctic

Traditional fermented foods of the Inuit were composed of marine and terrestrial mammals, fish, and birds (Fig. 2). The most familiar fermented animal meats are walrus, whale, seal, narwhal, Arctic char, trout, and caribou [1, 3, 8]. Very little research has been conducted on Inuit and Eskimo fermented foods, and most of what has been done has focused on food safety concerns. Botulism poisoning is more common in northern Alaska than in other parts of the world. Although it has sometimes occurred in newly introduced foods, it is more frequently occurring in traditional foods that are improperly prepared. Plastic containers have been introduced in modern times but have actually increased the risk of botulism due to a tight seal that results in an anaerobic environment, which encourages the growth of Clostridium botu*linum* [9–12]. Decreasing fermented food preparation in the home may lead to an erosion of knowledge about safe fermented food preparation. Shafer et al. reported a case of botulism poisoning in which a woman fermented a batch of 50 salmon heads (stink heads) in a wooden barrel covered with a canvas cloth [9-12]. Normally, the barrel would have been buried in the ground to maintain a constantly cool temperature. However, she left the barrel sitting open for two weeks. As reported, she recalled having been warned as a child that the sun's rays had a "death meaning" and that fermented foods needed to be kept away from the "killing rays of the sun." She expressed concern that the fermenting fish had gotten too hot while sitting in the sun [9]. The lack of knowledge of proper fermentations will probably only increase. The same study reported a survey revealing that 80% of grandparents and 71% of parents consume traditional fermented foods.

Health and lifestyle trends among the Inuit people

Concurrent with the changing dietary and lifestyle practices of the Inuit populations, there has been a deterioration in the health of the people. In recent years, there have been rather dramatic increases in obesity. From 1992 to 2004, obesity rates increased from 23 to 37% among Inuit adults in Nunavut and Canada [1]. Several cancers have become increasingly common, including lung and nasopharyngeal cancers, and the 2007 cancer mortality rate was 340 per 100,000 people in Nunavut as compared to 166 for the overall Canadian population [13]. Likewise, as the obesity rates have increased, so have diabetes, hypercholesterolemia, and hypertension in the Inuit population [14–16]. Many Inuit people believe consuming the traditional diet is more healthful and desire to do so; however, there are many barriers to reversing the trend toward eating a more Westernized "market diet". Despite the reports of Inuit people claiming that Western foods make them feel "lazy, tired and unfulfilled' and describe Western foods as "sugary, junk foods, and garbage foods," they continue to eat them [15, 17–19]. It is largely due to factors beyond the control of the Inuit people. Starting in the 1950s, the Canadian Inuits were relocated to permanent settlements, much like Indian reservations in the USA, and no longer participated in a nomadic lifestyle, and the sweeping socioeconomic changes were overwhelming [19-22]. While this improved the availability of healthcare and education and was undoubtedly well-intentioned, the unintended consequences were severe. Most of these settlements are remote and isolated, and the people have meager incomes. However, the cost of food is much higher than in most of Canada, and the quality of food is poor, especially fresh fruits and vegetables [19, 20]. Food security is defined as: "when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life". Food insecurity is sevenfold greater in Inuit regions than in Canada as a whole [23]. The Inuit still eat many traditional foods, but it has become a much smaller portion of their diet. That is mainly due to the dependence on motorized boats and vehicles as well as firearms for hunting. Many cannot afford to maintain motorized vehicles or buy fuel, which is also much higher due to the remoteness of the region. They also cannot afford ammunition for the firearms [2]. Therefore, the Inuit are living on a combination of traditional food and low-quality Western food, but the availability of both is often inadequate.

How declines in traditional diets affect the health of the Inuit people.

The Inuit have a history of thousands of years in which they have adapted both genetically [25] and culturally to a hunter-gatherer lifestyle, with diets composed almost entirely of animal foods [26]. However, within a span of only about 50 years, this population has transitioned from people who depended on foods obtained from hunting and gathering to foods primarily purchased at local grocery stores [26]. It has resulted in losing the traditional knowledge and skills required to be self-sufficient in the arctic climate [24]. It has also resulted in a disruption in key nutrients needed to maintain health. The Inuit people who do eat a high percentage of traditional foods (approximately 50% of energy) have significantly higher intakes of energy, protein, micronutrients, fiber, calcium, n-3 polyunsaturated fatty acids, riboflavin, niacin, iron, zinc, copper, magnesium, phosphorus, selenium, vitamins A, B6, B12, C, D, and E and consume less carbohydrate, saturated fat and sodium [15, 27–31]. However, the number of people still eating traditional foods continues to decrease, and simultaneously with this decrease in traditional food consumption is a loss of knowledge of traditional ways of obtaining, preparing, and storing traditional foods [15]. Therefore, as the Inuit people try to adjust to modern and traditional ways, many old ways are being lost, perhaps forever.

Until recently, cardiometabolic diseases such as obesity, type 2 diabetes, hypertension, hypercholesterolemia, and cardiovascular disease were reported to be rare among the Inuit [15, 32]. However, in recent years, the number of diseases has steadily increased. They are believed to be due to the increased consumption of nutrient-depleted diets high in sodium, calories from sugar, and unhealthy fats [33]. The 12.6-year shorter life expectancy in 2001 (compared to the Canadian national average) and the reported increase in hypertension from 9 to 19% in the adult Inuit population of Nunavik, Canada, from 1994 to 2004 [15, 34, 35] are stark reminders of the appalling effects of the dietary and lifestyle changes.

Inuit fermented foods and microbiomes

Most investigations into Inuit fermented foods have focused on food safety issues and potential microbial contamination. One reason for the concern is the lack of similar safeguards to those used in European and Asian foods. Inuit fermentation does not include the addition of salt, any step to pasteurize or sterilize the food, no addition of starter culture, and no direct control of temperature [1]. Despite the apparent lack of control, the Inuit have a long history of primarily safe use of fermented animal foods, and it is generally accepted that consumption of food microorganisms can be crucial to human health [36]. Although Inuit fermented foods are guite unique, both in preparation methods and the type of foods that are fermented, they certainly meet the definition of fermented foods: "foods made through desired microbial growth and enzymatic conversions of food components," established by the International Scientific Association for Probiotics and Prebiotics (ISAPP) in 2021 [37]. The bacteria in Inuit foods also differ from those in most other fermented foods. Fermented walrus and seal meats were found to have high concentrations of *Clostridium* species, and narwhal contained high concentrations of Clostridium and Bacteroidales [38, 39]. The fermented Inuit fish, mostly trout and arctic char but also hakarl (fermented shark), were found to have high bacterial counts of Pseudomonas and Photobacterium [1, 38, 40]. When Campbell et al. [1] tested 47 Inuit food samples using quantitative real-time PCR, the lowest bacterial count was 4×104 per gram on walrus meat, and the highest was on fermented char at 1.6×10^{11} with an average of 2.75×10^{8} per gram. These foods are generally not cooked before fermentation or consumption but are usually eaten raw. Therefore, these Inuit foods contribute many live bacteria to the diet. It is known that bacteria consumed in the diet can reach the gut and contribute to the gut microbiome [41, 42]. In fact, diet-derived transient lactic acid bacteria can account for as much as 0.1% of the gut microbiome in people who consume large amounts of fermented foods containing live lactic acid bacteria [42]. It is known that the gut microbiome is an important mediator of immunity and can offer protection against infectious diseases [43, 44]. However, most research has been conducted on probiotic lactic acid bacteria from European and Asian foods, and the health benefits of fermented Inuit foods and their dominant bacteria have not been studied.

Despite the need for studies evaluating the health effects of Inuit fermented foods, there have been some attempts at researching the effects of the diet on the microbiomes of the Inuit people. However, that has also been somewhat compromised because, by the time the techniques for doing such studies became available, the Inuit people no longer consumed a mostly traditional diet. A 2022 gut metagenomic study of Nunavik youth (age 16-30) used shotgun sequencing data from stool samples to compare the genomes of the Nunavik youth with those of other Canadian non-industrialized and industrialized populations [45]. They found that the Nunavik youth had a more diverse microbiome than the other non-industrialized subjects. Those from an industrialized region had the least microbial diversity in the gut. They could also identify specific bacteria characteristic of a traditional Inuit diet (Table 1) [46–66]. Among the bacterial species were some that are generally considered beneficial and some that are sometimes involved in pathogenic processes when present in an overabundance. Some uniquely characteristic bacteria are likely due to bacteria consumed from traditional fermented foods. Campbell et al. [1] found that the species present in Inuit fermented foods differed from fermented foods, including meats and fish, from other regions. They found that species from the *Clostridium* genus were the primary bacteria in fermented whale and seal meat. Fermented narwhal contained primarily Clostridium and Bacteroidales bacteria. Fermented fish, trout, and arctic char had different microbial profiles dominated by Pseudomonas and *Photobacterium* species [1]. These same species are also common in hakarl and sharks [67]. These common bacteria and many others are very different from the bacteria commonly seen in Western and Asian fermented foods [38]. They are very likely to be major contributors to the diverse and unique microbiomes of the Inuit, who still eat at least some of the traditional fermented foods since fermented foods are generally known to contribute bacterial species to the human microbiome [68, 69]. Even though the microbial content of the Inuit fermented fish foods is unique to the region, clues to their potential health benefits may be obtained by comparison with Asian fermented fish.

Fermented fish and fish sauce in Asia

Fermented fish is also a traditional food in many Asian cultures, and the methods and types of fermented fish can vary significantly across different regions [69]. In contrast to the Inuit fermented fish, most Asian fermented fish is made with salt and sometimes contains rice or rice bran. Korea also has fermented fish called "jeotgal," and jeotgal is made by salting small fresh fish, shrimp, squid, crab, roe, and intestines such as anchovy, shrimp, squid, Alaska pollock, and radish cubes [70]. Fermented fish or fish sauce made from fermented fish is used in various dishes as seasoning in Korea, Thailand, Vietnam, Philippines, and Cambodia. Asian fermented fish is made by cleaning fresh fish, covering all sides of fish with 8–30% salt to reduce harmful bacteria, placing the salted fish in a clean, airtight fermentation container, traditionally ceramic or

Rank	Species	Characteristics of the species and relationship to diet					
1	Collinsella massiliensis	Gram-positive, obligate anaerobic, non-motile, and non-spore-forming bacillus [46]					
2	Prevotella sp AM42 24	A common anaerobic, gram-negative, non-spore-forming bacterium associated with both desirable and undesirable traits [47]					
3	Clostridium innocuum	An anaerobic, gram-positive, spore-forming bacterium that is often benign but also potentially pathogenic [48]					
4	Flavonifractor plautii	A strictly anaerobic, Gram-positive, rod-shaped bacteria belonging to the family of Clostridiales. It is common in the gut and can cause blood infections but may help suppress allergies [49]					
5	Clostridium bolteae	Obligate anaerobic, gram-positive, rod-shaped, spore-forming bacteria [50]. Has been associated with autism [51]					
6	Clostridium leptum	A Clostridium bacteria that seems to be mostly beneficial and exhibits anti-inflammatory properties [52]					
7	Anaerostipes hadrus	A butyrate-producing bacteria isolated from human feces, gram-positive and rod-shaped. Beneficial for a healthy gut [53]					
8	Enorma massiliensis	Gram-stain-positive, non-motile, and rod-shaped organisms first isolated from fecal samples of healthy Chinese subjects [54]					
9	Prevotella sp 885	A common genus of gut bacteria, but this species is associated with chronic kidney disease [55]					
10	Bacteroides uniformis	Bacteroides are common gut bacteria with harmful and beneficial properties, <i>B. uniformis</i> has been shown to have beneficial metabolic effects and to improve exercise performance [56]					
11	Ruthenibacterium lactatiformans	Gut bacteria were found to be elevated in several disease states, such as multiple sclerosis, but no cause and effect was established [57]					
12	Fusicatenibacter saccharivorans	Gram-positive, obligate anaerobe, non-motile, non-spore-forming, spindle-shaped bacteria isolated from human feces [58]					
13	Eggerthella lenta	A common anaerobic, non-sporulating, and Gram-positive bacteria in humans that can sometimes cause serious infections [59]					
14	Anaerobiospirillum thomasii	It is a potential pathogen, an anaerobic spiral bacteria isolated from the feces of cats and dogs and from the diarrheal feces of humans [60]					
15	Anaerotruncus colihominis	Gram-positive, anaerobe, non-spore-forming, rod-shaped bacteria isolated from human feces [61]					
16	Butyrivibrio crossotus	A gut bacteria shown to be elevated in metabolically healthy people [62]					
17	Blautia wexlerae	A potential probiotic bacteria that has been shown to prevent obesity and type 2 diabetes by improving the microbiome [63]					
18	Bacteroides vulgatus	Beneficial bacteria with anti-inflammatory effects are shown to be protective against ulcerative colitis [64]					
19	Blautia obeum	An anaerobic bacteria, possible immune enhancer. Eating dark chocolate enhanced B. obeum and improved mood [65]					
20	Alistipes finegoldii	An anaerobic bacteria often found in healthy gut but also associated with severe infections, but some studies show protective effects against several major diseases [66]					

Table 1 Most important gut microbes for distinguishing the Inuit microbiome from other non-industrialized and industrialized populations according to Abed et al. [45]

wooden container, sealing the container, and leaving the sealed container at room temperature for a few days to several months [71]. In Korea, the container for jeotgal is stored in an underground cave, where storage temperature is maintained at 13-15 °C all year [72].

Fish sauce is made by pressing fermented fish, filtering, pasteurizing, and aging it. Fish sauce is a fundamental ingredient in Asian cooking, often used to add saltiness and depth of flavor to a wide range of dishes, including soups, stir-fries, marinades, and dipping sauces. Different regions and countries may have variations in the production and flavor profile of fish sauce, leading to a diverse range of fish sauces with unique tastes and characteristics. Fermented fish and fish sauce are applied to make kimchi and soups [73]. Interestingly, fermented fish is seldom eaten as a main dish in Asian cuisine; however, the Inuit traditionally eat fermented marine foods as

"stand-alone" foods rather than as a seasoning or soup base [1].

History of fermented fish (jeotgal) in Korea

Like the Inuit, Korea has a long history of preparing fermented fish. The Korean peninsula, specifically the region of Sando, has historically been a stage for the Korean people's activities, and it was there that ancient Koreans began using fermented fish sauce, known as "jeotgal," as a seasoning [74]. In a Chinese dictionary from around the third to fifth centuries B.C., "Liè" was the term for fish-based fermented sauce, whereas "Hai" was used for fermented sauce made from meat. These terms, "Liè," "Zi," and "Hai," appeared in subsequent literature. In the fifth century, the "Jemin Yosul" mentioned two methods of fermenting—one using malt, meju (fermented soybean), alcohol, and salt for fermenting grains, seafood, vegetables, and salt, and the other using fish and meat with salt [75].

In the "Samguk Sagi" during the 8th year of King Shinmun's reign (683 AD), when Kim Heomun's daughter was welcomed as a queen, "Hai" was listed among the tribute items, signifying fermented fish sauce [74, 76]. Throughout the Goryeo and Joseon dynasties, the process of making fermented fish sauce evolved into two main methods: "Jeoryeomhae," where fish and seafood were lightly salted, and "Shikhae," which involved fermenting grains, vegetables, and fish that had been marinated in salt. During the Goryeo era, various records, official documents, and compilations began to shed light on the diverse culinary uses of fermented fish sauce, also presented in ancestral rituals [75, 77].

As the Chosun era unfolded, records related to fermented fish sauce were frequently found in various personal diaries, indicating its relatively widespread use and the wide variety of types. The methods of making fermented fish sauce during the Chosun era can be broader than what is known today.

Microbiota in Asian fermented fish

Aerobic bacteria of fermented fish collected in summer (average 5.87 log CFU/g) are higher than in winter (average 5.05 log CFU/g). Coliforms are not discovered in most samples but are detected in oysters, cutlassfish intestines, and flatfish sauce (ND-2.40 log CFU/g). The fish sauce contains a significant number of bacteria, the majority of which are halophilic, with viable cell counts ranging between 10³ and 10⁵ CFU/g [78]. Lactic acid bacteria are 3-8 log CFU/g in fish sauce and abundant in fermented fish, especially in flatfish sauce. At the genus level, 638 microorganisms were discovered in fish sauce. The fish sauce contains both beneficial and potentially hazardous bacteria. In next-generation sequencing, the most dominant phyla were Firmicutes (62.00%) and Proteobacteria (31.69%) in the fermented fish and fish sauce, which is in contrast to the Pseudomonas and Photobacterium that are predominant in Inuit fermented fish. The Firmicutes phylum contains primarily lactic acid bacteria, which have a beneficial role in the food industry [79]. Fish sauce contains industrially significant lactic acid bacteria, including Leuconostoc, Lactobacillus, Tetragenococcus, Lactococcus, and Weissella [80, 81]. However, some fermented fish and its sauce contain Proteobacteria, part of which is pathogenic [82, 83]. Leuconostocaceae, which showed the largest relative abundance at the family level in fish sauce (34.97%), is especially prominent in long-arm octopus sauce (65.35%). Enterobacteriaceae and Staphylococcus, potentially dangerous bacteria, were detected in Alaska pollock roe sauce. Long-arm octopus sauce contains low salt (about 6-8%),

and Enterobacteriaceae and *Staphylococcus* contain pathogenic bacteria [84]. Diversity analysis demonstrated that raw materials substantially impacted the variability in the microbiota of fish sauce.

Fermented fish and health

Fermented fish and fish sauce involve the fermentation of fish with the help of microorganisms like bacteria and/or yeast [39]. During fermentation, these microorganisms break down the proteins and fats in the fish, leading to the development of unique flavors and textures. Fermenting fish can increase the bioavailability of amino acids, peptides, and n-3 fatty acids, including EPA and DHA [85]. It also contains probiotics that can positively influence gut health by improving the gut microbiota, enhancing digestion, and supporting the immune system. It also contains postbiotics such as bioamines, peptides, and antioxidants, which may have health-promoting properties. Some of these compounds have been associated with anti-inflammatory, antioxidant, and antimicrobial effects. Bioactive peptides produced during fish fermentation may possess antihypertensive effects by inhibiting enzymes involved in blood pressure regulation. It could contribute to cardiovascular health. Fermented food consumption may act through changing gut microbiota, but a 7-day intake of Surströmming, a Swedish fermented fish, does not alter the microbiome of healthy individuals [86]. It may be due to short-term intake of Surströmming. Furthermore, the health benefits of fermented fish can vary based on factors such as the type of fish, fermentation methods, and the specific microorganisms involved. Some fermented fish contain pathogenic microorganism growth, which can be harmful [39].

Traditional beliefs about health benefits of Inuit foods

It is a common belief among the Inuit population that raw, warm meat imparts health benefits and makes a person strong and robust. The Inuit diet is reportedly based on a few basic precepts: humans and animals share a close relationship, the links between the body and soul and life and health, seal blood and Inuit blood are closely related, and dietary choice affects health [88]. The Inuit commonly believe that combining humans and sealing blood in the bloodstream creates an ideally healthy body and soul. [87]. The Inuit believe that the combination of animal and human blood in one's bloodstream creates a healthy human body and soul. Borré [87] described a woman who became ill, blamed it on a deficiency of seal in her diet, and quickly recovered within hours after being given seal meat and blood. It is an experience that was frequently reported by other Inuit as well. Despite the almost total dependence on animal food, the Inuit still have been reported

Table 2	Health	benefits	of fe	ermented	animal	and	fish	foods
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Benefits	Bioactive Compounds	Foods	Fermentation Microorganism(s)	References
Antioxidants	Phenolic compounds,	Dry-cured pork loins	Probiotic Strains of LAB	[91]
Antioxidant Neuroractive	γ-Aminobutyric acid, peptides, CLA ² , Folate	Functional fermented sausages	Bifidobacterium longum	[92]
Anti-inflammatory Potential pathogen	Butyrate	Fermented Whale, Narwal, Seal	Clostridium species	[1, 93]
Anti-bacterial lipid production	Bacteriocins	Fermented Fish	Photobacterium	[1, 94]
Anti-aging in skin	Uncertain	Fermented fish oil	Lactobacillus plantarum and Sac- charomyces cerevisiae	[95, 96]

to have a lower incidence of atherosclerosis than agematched individuals from developed regions, although there is some dispute about how much lower [88]. Nevertheless, there remains a persistent belief among the Inuit population that there is a close physical and spiritual relationship between themselves and the animals that compose most of their diet. This relationship is exemplified in a hunting tradition in which saltwater animals are always considered thirsty and are offered fresh water as they die to show their respect and gratitude toward the seal and their appreciation for the seal, and their bodies become one [89].

Safety of fermented fish

Ensuring the safety of fermented foods, particularly naturally fermented traditional foods, is crucial as there is a possibility of contamination by harmful microorganisms. The fermentation process, which enables the consumption of raw food materials without cooking, may not completely eliminate all potential pathogens. Severe food poisoning has been documented, often linked to uneven salt distribution in lactic acid bacteria (LAB)-fermented fish products and contamination by Proteobacteria and Aspergillus flavus [85]. Although traditional fish fermentation methods typically have inherent safety measures, several factors can impact the final safety and quality of fermented fish products, including processing hygiene, histamine, clostridium, and salmonella poisoning [86]. While fermented fish products are generally considered safe for consumption, various factors can render the product unsafe. These include the use of contaminated, low-grade, or poor-quality raw materials, inadequate storage facilities for raw materials, unhygienic preparation techniques, improper handling involving chemicals, substandard hygienic marketing facilities, lack of standardized packaging practices, and the risk of cross-contamination during marketing, posing a threat to consumers' health and safety. Although extrapolations from Asian and other fermented meats and fish to Inuit fermented fish are imperfect, they may provide clues to their potential health benefits [90], some of which are presented in Table 2.

Future challenges and directions

The future outlook for studying and utilizing traditional Inuit foods is not encouraging. The use of traditional foods has steadily declined [97] as the population has moved into permanent housing and small towns established by governmental authorities. Most publications about fermented fish, which are still occasionally consumed, focus on food poisoning outbreaks due to improper preparation. Suppose the traditional foods and food preparation methods are to be preserved and health benefits scientifically studied. In that case, investigators will require a concerted effort to document the remaining knowledge of the elderly population. Preserving traditional foods would require efforts to commercialize the production of traditional Inuit food since Inuit is no longer an itinerant population moving toward searching for new animal food sources. The preservation of the traditional Inuit food customs will be challenging and, in some respects, impossible. However, the knowledge of this ancient culture should be preserved as much as possible.

Conclusions

Fermentation is a well-established way of preparing many types of food for long-term storage. Fermentation has historically been critical to the Inuit people who live in remote regions above the Arctic Circle and have long periods in which fresh foods are inaccessible. Fermented foods have traditionally been dietary staples for much of the year. Fermented marine products are the most commonly fermented foods of the Inuit, and these foods provide essential dietary nutrients but also contribute to the microbiomes of the Inuit people. Although the bacteria are different from the largely lactic acid bacterial fermentation of most Asian and European fermented foods, they are still important to the development of the unique microbiomes of the Inuit. Food safety remains a serious concern for the preparation of Inuit fermented foods since the Westernization of the Inuit diet has resulted in the loss of knowledge and skills to safely prepare traditional fermented foods. A concerted effort will be required to study and document food preparation methods utilized by traditional Inuit people, or the knowledge of the Inuit ancestors will be forever lost.

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Author contributions

JWD contributed to conceptualization, methodology, writing—draft and review and editing, and project administration. SP contributed to conceptualization and writing—original draft and review and editing.

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