1 Microbial Heritage and Cultural Contexts: Introduction

In 2024, the French National Center for Scientific Research (CNRS) warned that Camembert and Brie may be on the brink of extinction. Their imminent demise is due to standardization of their production process over the past half century; through overly drastic selection, the food industry has severely diminished their genetic and microbial diversity (Harmi, 2024). The traditional method for making Camembert was to age the cheese in damp caves, in which the fungi responsible for creating the famous rind exist naturally. This environmental microbiome gave each batch of Camembert its distinctive character. The result of a symbiotic relation: farmers fed the fungi and bacteria with dairy and were rewarded with rindy cheese in various colors and tastes (a little redder, a little bluer, a little greyer, or a little whiter) (Lederman and Sowden, 2024).

In the twentieth century, however, consumers increasingly developed a taste for white rind. To meet their demand, producers started to engineer the process and produce the fungi in a lab. They isolated a specific albino strain that became known as Penicillium Camemberti. This fungus created the perfect white rind for which Camembert and Brie are known. As cheesemakers the world over adopted this strain, it brought the desired consistency to these cheeses. But slowly it endangered their microbial diversity. As a result, over time, Penicillium Camemberti has lost some of its ability to reproduce naturally and scientists have reverted to using asexual reproduction to grow the fungi. A long-term concern is that such an isolated strain is susceptible to a pathogen or a disease that could wipe out the entire fungi population (Lederman and Sowden, 2024). Biological diversity is a natural defense against extinction.

The dire prognosis for the beloved French cheeses illustrates Ricardo Rozzi's decade-old warning that "biocultural homogenization" is the main "global driver of losses of biological and cultural diversity" (2013, p. 9). Along the same line, anthropologist Thomas Hylland Eriksen (2021) has argued that homogenization and standardization as central features of modernity are disastrous for biological and cultural diversity. Others have claimed that as a result, the world is witnessing a sixth extinction in nature (Kolbert, 2014).

1.1 Probiotic Microbiopolitics

In a pungent ethnography of artisanal raw-milk cheese making in the United States, Heather Paxson coined the term "microbiopolitics" to refer to the "creation of categories of microscopic biological agents; the anthropocentric evaluation of such agents; and the elaboration of appropriate human behaviors vis-à-vis microorganisms engaged in infection, inoculation, and digestion" (Paxson, 2008, p. 17). The age of microbiopolitics began with Louis Pasteur's

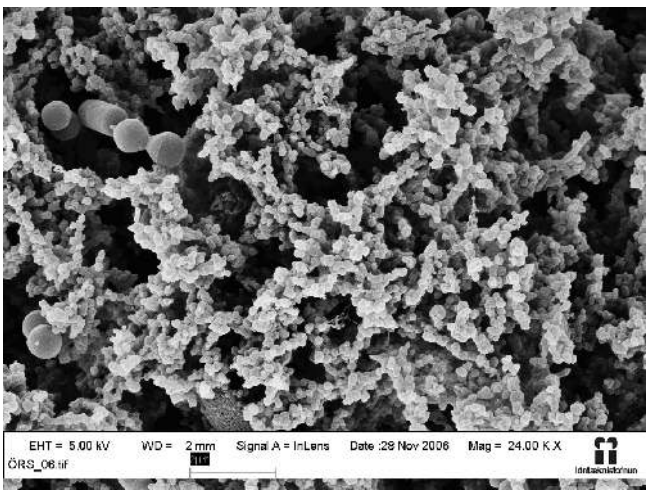

Figure 1 A microscopic view of skyr microbes showing bead-chains of Streptococcus thermophilus and a few sticks of Lactobacillus bulgaricus. Photograph by Jón Matthíasson. Courtesy of Guðmundur Guðmundsson, Rheology and Microstructure of Skyr. M.Sc. thesis, University of Iceland, 2007.

research on fermentation and immunology in the second half of the nineteenth century and the subsequent ascendancy of "Pasteurianism" as an ethical and legal regime in the fields of food production and medicine (Figure 1). Referring to the artisans with whom she worked as "today's post-Pasteurians," Paxson remarks that through their fermentation practices they "seek to rescue indigenous cultures – microbial but also human – from industrial homogeneity" (Paxson, 2008, p. 23).

As people increasingly come to see microbes as allies to be nurtured rather than foes to be exterminated, researchers have sought to describe an emergent post-Pasteurian point of view, from which human–microbial symbiosis is not centered in the "wars on germs" of the twentieth century (cf. Latour, 1993; Otis, 2000; Sinsheimer, 2018). Instead, based in an understanding of ourselves as ecological creatures this perspective brings into focus the beneficial effects of the "human microbiome" (Gilbert et al., 2012; Helmreich, 2014 and 2015; Sangodeyi, 2014; Wahlqvist, 2016). Increasingly, microbes are portrayed as potent and omnipresent actors that have the power not only to harm but also to sustain humanity (Velasquez-Manoff, 2012; Yong, 2016). A paradigm shift is underway: rather than seeing microbes as inherently bad (pathogenic) or good (beneficial), a growing body of research has moved on from a narrow focus on germ theory – that certain diseases are caused by the invasion of the discrete body by foreign microorganisms – to broader ecological understanding of

human–microbial relationships, incorporating socioeconomic, cultural, spatial, and political contexts (Benezra, 2020; Benezra et al., 2012; Ironstone, 2019; Tracy and Howes-Mischel, 2018; Paxson, 2008, 2014a and 2019; Sarmiento, 2020).

At the same time, increasing scientific knowledge of the role of microbes in promoting human health and wellness has given rise to new expectations and values that are increasingly commodified and contested (Blaser, 2014; Bloomfield, 2016; Chuong et al., 2017; Greenhough et al., 2020; Hawkins and O'Doherty, 2011; Lorimer, 2016; Rhodes et al., 2013; Wolf-Meyer, 2017). This might be described as a probiotic turn in the social imagination as well as in the food and health industries. Rising interest among the public in gut health is mirrored in the growth of the global probiotics market; market analysts estimate its value somewhere between 80 and 90 billion US dollars in 2024 and forecast between 100 percent and 200 percent growth in market size over the next five to seven years (Probiotics Market Size, 2024). That market includes probiotic foods and beverages, on the one hand, and dietary supplements, on the other (Figure 2).

Directly ingesting microbes through supplements is a novelty, to be sure. Consuming probiotic foods and drinks, on the other hand, is certainly not novel. Fermentation is an ancient and widespread method for transforming and conserving food. Since the agricultural revolution over ten thousand years ago, the

Figure 2 MS Dairy skyr commercial. Courtesy of MS Iceland Dairies.

fermentation of foods and beverages has been essential to people's diets in most societies (El Sheikha and Hu, 2020; Katz, 2011 and 2012; Ray and Joshi, 2014; Tamang et al., 2020). From sauerkraut to sourdough, from kimchi to miso, from beer to kombucha, from yogurt to cheese, many traditional foods and drinks in societies across Europe and worldwide are produced through fermentation by live cultures. The live cultures involved comprise diverse species of bacteria, fungi, and other microorganisms that co-habit the earth with human and non-human animals and plants. Indeed, traditional fermented foods and drinks are prime examples of biocultural heritage, ecosystems that result from long-term social and biological relationships between humans, other animals, plants, soils, and microbes (Lorimer, 2016 and 2020; Lyons, 2020). These relationships have shaped human health, memory, practices, and traditional knowledge. Taken together, fermented foods may thus be described as "a key reservoir of microbial diversity in the human diet" (Hernández-Velázquez et al., 2024).

1.2 Original Skyr

One such fermented food is skyr, a thick and sour dairy product. Outside of Iceland, it is often referred to as a thick yogurt but technically it is an acid-curd cheese. Skyr played a large role in sustaining the Icelandic population from the era of settlement in the 800–900s CE and up to the present day. Until the twentieth century, most people in Iceland lived from subsistence farming with grass as the major crop and dairying a major occupation. Animal products provided the bulk of people's daily food, with dairy accounting for an important proportion (Gísladóttir, 1999; Júlíusson, 2013). Most of that dairy took the form of skyr, for skyr making was a way to preserve the 90 percent that remains of fresh milk after the cream has been skimmed off and churned into butter. Skyr is produced by heating skimmed milk, then cooling it again before adding live fermentative microbial cultures, which effectively make the skyr by curdling the milk. Traditionally, the fermentative cultures came from a pinch of skyr from the previous batch, deliberately conserved for this purpose. After culturing and coagulating, skyr is strained to remove the watery whey, making the final product creamy and rich in texture.

Skyr might be defined as an ecosystem created and sustained by relations between Streptococcus and Lactobacillus bacteria, various yeast species (Valsdóttir et al., 2011; Valsdóttir and Sveinsson, 2011), mammals such as cows, sheep, or goats, their pastures and soils, as well as the humans who tend to them and eat them. The live cultures of skyr provide an excellent case study of symbiosis between microbial cultures and human cultures through their respective histories. Indeed, the long-term resilience and adaptation of the skyr

Figure 3 Through the centuries in Iceland, humans, animals and microbes lived in symbiosis in turf houses, contributing to a diverse skyr microbiome. Photograph by Hannes Pálsson. Courtesy of the National Museum of Iceland.

microbiome, along with its natural and cultural selection over time, fostered great microbial diversity. As a result, skyr microbes make up a unique part of ecological diversity in Iceland (Figure 3).

In a twist that is reminiscent of the development and fate of Brie and Camembert, however, standardization, hygiene regulation, and technological innovations in skyr production have greatly impoverished its microbial diversity over the past one hundred years. The formerly diverse microbiome of traditional skyr in Iceland has been reduced to a single strain of one single microbial species, cloned for large-scale industrial production in a multinational biochemical factory. The story of skyr, like that of its French cousins, is thus the story of missing microbes in modern industrial and postindustrial societies. That story recounts a crucial dimension of the loss of biodiversity in our era as microbes are the dominant form of life on the planet: microbes make up two-thirds of life on earth and, indeed, more than half the cells of the human body (Yong, 2016). Ironically, the single strain cloned for industrial production has been trademarked as "Original Icelandic Skyr Cultures" in the European dairy market and as "Heirloom Icelandic Skyr Cultures" in the US dairy market.

1.3 Heirlooms and Monocultures

There is good reason to take a step back and consider the implications. The term "heirloom" in "heirloom cultures" is inspired by concepts like "heirloom seeds" and "heirloom tomatoes." By the middle of the twentieth century, agriculture in North America, and to a growing extent elsewhere, turned "away from a broader array of crops based on open pollination towards a narrow range of hybrid crops" (Jordan, 2007, p. 28). Large-scale industrial production resorted where possible to mechanical harvesting, but as Carolyn de la Peña remarks in an essay on "the mechanized tomato," "no existing varieties could withstand the violence of mechanical cutting, separating, sorting, and loading" (de la Peña, 2013, p. 35). Since flavor was not a characteristic that influenced mechanical compatibility, it became no more than an afterthought in the breeding of the perfect tomato. Instead, industrial-scale agriculture bred for consistency, durability, longevity, visual appearance, and transport across distances without significant damage. As a result, while transportation allowed access to produce out of season, the varieties available to consumers decreased dramatically.

Meanwhile, older varieties – over 3,000 of them – were still grown at small scale in "the backyards of tomato fanatics and solitary seed savers," as Jennifer A. Jordan notes in her investigation of "The Heirloom Tomato as Cultural Object" (Jordan, 2007, p. 21). The term "heirloom" began to be used to describe these varieties in the 1980s and 1990s: varieties that predate the rise of industrial agriculture, can be pollen fertilized, and have a history of their own. The "heirloom tomato" found its way back to the dining table through farmers' markets and community-supported agriculture in North America and Europe. In the context of organic farming and an appeal for traditional, natural foods over industrial foods and monocultures, it eventually staged a seasonal return to restaurants and grocery stores. Unlike typical grocery store tomatoes bred for uniformity and durability, heirlooms come in a wide range of colors and have rich, complex flavors (Jordan, 2007; Joseph et al., 2017).

By the turn of the twenty-first century, heirloom tomatoes and seeds had popularized the term "heirloom" among foodies. It was a short step, then, to describe fermentation cultures as heirlooms to emphasize their lineage, resilience, and the artistry involved in maintaining them over time. With implicit reference to conceptions of biocultural heritage, the term "heirloom cultures" has thus over the past quarter-century come to describe the traditional agents in the fermentation of skyr, yogurt, kefir, and other fermented dairy products. Its use signals the affirmation of heritage values such as authenticity and presence.

The revival of microbial heritage, or heirloom cultures, coincides with the rise of the Slow Food movement in the 1990s and 2000s, a growing interest in

Figure 4 Skyr was traditionally stored in wooden barrels where microbes soured and preserved skyr for the winter season. Photograph by Hans Kuhn. Courtesy of the National Museum of Iceland.

traditional food preparation since the turn of the century, and rising awareness of gut health in the past decade. Typically, the term heirloom cultures describes fermentation cultures preserved over generations, cherished for their flavors, fermentation characteristics, and probiotic qualities. Just as heirloom seeds are kept for their distinctive traits, heirloom cultures are maintained for their time-tested characteristics that cannot easily be replicated with mass-produced starters. Each culture can carry specific strains of bacteria and yeast that give foods distinctive textures and flavors, which commercial, mass-produced starters often lack (Figure 4). A preference for heirloom cultures can also signal a commitment to microbial diversity over the monocultural values of scale and productivity. The dairy industry's trademarking of "Heirloom Skyr Cultures" thus appears to appropriate a commitment to biocultural diversity for the purposes of branding a commercial dairy product produced with standardized, monoculture strains selected for consistency, shelf-stability, and efficiency. One might describe this move as a capture of language, or perhaps as ironic branding, designed to suggest time-depth and artisanal authenticity, even in their absence.

1.4 Lactobacillus, Sour Milk, and Superfood

In 1904, a young Bulgarian physician named Stamen Grigoroff began his work to isolate the microorganisms that played the key role in fermenting sour milk. Grigoroff worked with samples taken from his native village Studen Izvor, whose inhabitants were known throughout Bulgaria for good health and

longevity. Grigoroff discovered three different microorganisms in Bulgarian sour milk ("Kissélo-mléko"), which he named *Bacille A*, *Microcoque B*, and *Streptobacille C.* It was *Bacille A*, he found, that causes milk to curdle, transforming it into yogurt; it soon came to be called *Lactic acid bacillus* or *Lactobacillus*. The particular strain of Lactobacillus that Grigoroff discovered was later named Bacillus Bulgaricus in his honor. *Microcoque B* came to be known as *Streptococcus thermophilus*. Grigoroff isolated these three species and was able to ferment milk with each one, with vastly different outcomes in taste and texture. When he mixed his three samples of fermented milk together, however, the three species resumed their symbiosis, and the outcome once again resembled the original Bulgarian sour milk with which the experiment began (Grigoroff, 1905; Nancheva, 2019; Stoilova, 2015).

At the Pasteur Institute in Paris, the Russian biologist Elie Metchnikoff had already built a reputation for his research into the biology of aging as well as of gut microbiota. He invited Grigoroff to Paris to speak to his colleagues about his discoveries. A couple of years later, Metchnikoff built on Grigoroff's findings in his hypothesis that regular consumption of yogurt and other fermented milk could positively influence the intestinal micro-flora and promote good health and longevity. Metchnikoff took particular interest in the longevity of Bulgarian villagers and attributed it to the large quantity of lactic acid bacteria that they consumed in their daily bowl of yogurt. Moreover, Metchnikoff conducted several experiments along with his lab assistants and found that not all *Lactic acid bacillus* were created equal. Bulgarian bacilli, he found, were most beneficial to the intestinal micro-flora (Stoilova, 2015).

In 1905, Metchnikoff gave a public lecture in Paris in which he argued that harmful intestinal bacteria contribute to aging and that eating yogurt and other fermented dairy helps to cultivate beneficial bacteria to counteract "intestinal putrefaction" and its effects on the body. His lecture made headlines on both sides of the Atlantic and sparked an international "yogurt mania." Not only did the production and consumption of Bulgarian-style yogurt spread across the European and North-American continents; pharmacies also sold "Bulgarian cultures in the form of tablets, powders, and boullions – precursors of today's probiotics" (Vikhanski, 2016).

Metchnikoff published his findings in two influential volumes: *Scientifically Sour Milk: Its Influence in Arresting Intestinal Putrefaction* (1996[1907]) and *The Prolongation of Life: Optimistic Studies* (2004[1908]). The latter was translated into English in 1908, the same year as he was awarded the Nobel Prize for his research into immunology, aging, and microorganisms. His work kicked off a new era in microbiology as scientists set out to explore the relationship between microbiota and intestinal health. It also provided

a scientific rationale to the belief that regular consumption of yogurt promotes good health and combats aging (Yotova, 2018). A superfood was born.

Some few years after the publication of Metchnikoff's books, knowledge of the benefits of sour milk had reached Icelandic shores. Gísli Guðmundsson was the first Icelandic microbiologist, educated at various European universities from 1910 to 1913. Upon returning to Iceland, one of his first projects was a study of the microbiology of skyr. He published the results in 1914 in *Búnaðarritið* ("Journal of Agriculture"), where he accounts for the various bacteria and fungi discovered in traditional skyr. Having summarized Metchnikoff's work on fermented dairy, Guðmundsson focused in particular on his findings about the health benefits of *Streptococcus thermophilus*. Relying on the observations of Metchnikoff and Grigoroff, he also posed the question which is healthier: freshly made skyr or older skyr. Guðmundsson concluded that freshly made skyr might be healthier due to the diminishing effect of skyr cultures over time. His principal argument rests on a comparison with the eating habits of Bulgarians: they make and consume their yogurt daily, which explains their good health and longevity. It bears noting in this context that Guðmundsson was working with timescales that belonged to Icelandic peasant society, not to shelf-life in our days of "best before" stamps: by "older" he referred to more than six months old; skyr was "new" until it reached that respectable age. In his article from 1914, Guðmundsson moreover reports success in isolating clear skyr cultures that closely resembled Bulgarian yogurt cultures. He even managed to mix the two together to make "sour milk": Icelandic-Bulgarian microbial cooperation at its finest. Guðmundsson also noted that people all over the world make products similar to skyr. The most well-known, he wrote, is "the Bulgarian skyr," a.k.a. yogurt; other skyr-like foods, he adds, from other parts of the world include kefir, matzoon, and kumis. Seeing as in recent years, skyr is often labeled Icelandic-style yogurt in global dairy markets, Guðmundsson's enumeration of skyr-like products from other regions, including "Bulgarian-style skyr," may serve to remind us of the global diversity of fermented dairies and their traditional microbiomes.

In the first decades of the twentieth century, Bulgaria and its healthy, long-lived inhabitants were ubiquitous in the marketing of this exoticized superfood in Europe and the United States. As a result, Bulgarian yogurt became synonymous with all yogurt-like products. It ceased to matter very much whether any given yogurt was produced in Bulgaria. Instead, what came to matter was the general association between Bulgarianness, good health, and longevity, all neatly packaged in a cup of yogurt – without regard to where it was actually produced or packaged.