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Cultures of Fermentation: Living with Microbes

An Introduction to Supplement 24

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Recent discoveries on the importance of microbes for human biology, health, and culture, the rise of antimicrobial resistance, and developing technological advancements necessitate new dialogues about human relationships with microbes. Long perceptible only through their transformations—from epidemic disease to alcoholic beverages—it is now possible to more fully perceive the diversity of ways in which we influence and are influenced by microbes and to understand that human and microbial cultures are fundamentally intertwined. In the introduction to this supplement, we outline the current state of the art of an "anthropology of microbes" in three subfields of anthropology: biological anthropology, cultural anthropology, and archaeology. Moreover, as a result of dialogues borne out of the symposium associated with this issue, and now reflected in the articles themselves, we discuss the interactions between and within the subfields of anthropology. This supplement is committed to the development of a common language for an emerging anthropology of microbes, and in order to shape genuine transdisciplinarity we argue for the continued necessity of "trading zone" points of intersection—such as the Wenner-Gren Foundation's symposium "Cultures of Fermentation."

Humans have a deep and complex relationship with microbes, but until recently this history has remained largely inaccessible and mostly ignored within anthropology. Broadening views, as well as technological and conceptual advancements, however, have opened up dramatic new opportunities to investigate the microbial communities that have long inhabited human bodies and shaped food systems, both in sickness and in health. Beyond disease, microbes influence human health and behavior through their activity in the microbiome and their diverse roles in food and cuisine. From epidemic disease to alcoholic beverages, microbes are the unseen and often overlooked figures that have profoundly shaped human culture and influenced the course of human history. Long perceptible only through transformations, it is now possible to perceive the myriad ways in which we influence and are influenced by microbes—from cultivation and domestication to eradication, indifference, and neglect—and to understand that human and microbial cultures are deeply and fundamentally intertwined.

In October 2019 the Wenner-Gren Foundation gathered 21 scholars in Sintra, Portugal, for an interdisciplinary symposium titled "Cultures of Fermentation." Here we discussed the long and complex history of human-microbe relationships, the ways microbes manifest in our lives, their role in biopolitics, and the changing scholarship on these invisible actors in our lives. In doing so, we cheerfully exchanged microbial creations, such as "peaso" (or "pea miso"), a food blend borne out of the culinary experimentation of the New Nordic Cuisine discussed by Joshua Evans and Jamie Lorimer (2021), the savory and spicy diversity of fermented products from Korea, Japan, and China, and alpine cheeses made by the hands of one of the organizers. We relished in these microbial concoctions, blissfully ignorant of the substantially changed pandemic lives we would soon be experiencing just a few months later.

During the COVID-19 pandemic, people around the world engaged with these invisible agents in new and unexpected ways. In many contexts, this engagement was one of eradication as sales of disinfectant skyrocketed and we restructured our ways of life to prevent pathogen transmission. For those who had the luxury of time and the means for culinary experimentation, a housebound lockdown often meant a closer connection to microbial species. A boom in home cooking led to shortages on supermarket shelves of, among other things, yeast and flour. At a local store of one of the authors in the United Kingdom, yeast was rationed to 20 grams per person, and in the United States the neighborhood grocer of another author was sold out of yeast for more than three months. As a result, people started their own sourdough cultures or borrowed cultures from friends, family, and neighbors. Sourdoughs, together with Dalgona coffee and garden focaccia, became "quarantine food trends" of 2020 (Li 2020). Similarly, while brewers saw a loss in revenue sales as restaurants and bars closed, and breweries scrambled to get online ordering and delivery services available, sales of home brew equipment rose. As Adam Liaw wrote, "When the world collapsed, we made sourdough. We made sourdough even though we couldn't buy flour. We made sourdough even though all the stores were full of bread. Call it cottagecore, if you like, but

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behind the aesthetic the truth is if you were making sourdough it meant you were one of the luckiest people on Earth—healthy, safe and secure in every respect" (Liaw 2020). When lockdowns lift, the fate of those microbial cultures—cherished during a time of comfort eating, passing time, and fear of staple food shortages—remains to be seen. While a virus is not, strictly speaking, classed as a microbe, it is also an invisible agent, and our shifting relationships with viruses and microbes during the COVID-19 pandemic demonstrate the profound effect that these actors have on us and we have on them.

In this introduction to the "Cultures of Fermentation" symposium supplement, we discuss the current state of the art of research focused on microbes within diverse strands of anthropology and highlight the fundamental but still potential transdisciplinarity of these inquiries. Fermentation is a practice in which complex collectives of humans, animals, plants, fungi, and bacteria meet and thrive and which provides us with a unique vantage point to engage and connect with recent debates in anthropology and beyond. Today, many of the multispecies collectives that have been fermenting together, often in unbroken chains for hundreds of human generations (and millions of microbial generations), are under threat of loss. Many factors have contributed to this microbial crisis, most importantly the increasing industrialization and standardization of farming and food processing (Blanchette 2020; Nestle 2018). The decline of small-scale agriculture in many regions of the world results in the replacement of a multiplicity of peasant life forms with a much less diverse set of industrially bred organisms (Haraway 2015; Wallace 2016). But while there is a broad and diverse movement to save heirloom seeds and heritage livestock breeds (Demeulenaere 2014; Hartigan 2017; Peschard and Randeria 2020; Weiss 2016), the impending loss of the microbial strains integral to small-scale fermentation is only starting to gain attention in academia and civil society. Simultaneously, however, popular interest in boutique or leisure fermentation is growing dramatically, and in many places in the Global North, microbreweries and artisanal cheese makers are unable to satisfy local demand (Asher 2015; Katz 2012; Lorimer 2020; Redzepi and Zilber 2018). Homemade fermented foods are increasingly considered healthy and hip, and they serve to simultaneously ground the fermenter in history and emphasize their individuality. Fermentation is at the core of food traditions around the world, and the study of fermentation crosscuts the social and natural sciences. This symposium sought to foster interdisciplinary conversations integral to understanding human-microbial cultures. By bridging the fields of archaeology, cultural anthropology, biological anthropology, microbiology, and ecology, this issue aims to cultivate an anthropology of microbes.

The Role of Fermentation in Human Evolution

Fermentation is ancient. Long predating humans, and even animals, it traces its origins to the early earth, established before the availability of oxygen in the atmosphere. Fermentation refers to a form of microbial metabolism that converts carbon compounds to energy in the absence of oxygen. As a fundamental biological process, it transforms our foods, drives our microbiome, and composts our waste. But how did humans' particular relationship with fermentation begin? Primates tend to avoid overripe or highly fermented fruits, report Katie Amato et al. (2021). However, avoidance of fermented foods is not complete, and a minority of primate species and populations opportunistically incorporate a range of spontaneously fermented foods into their diets. In contrast, among humans today, nearly all consumed fermented foods are purposely produced through either spontaneous or selective fermentation, and consumption of fermented foods is a generalized trait shared by most humans, albeit with cultural variation. Studies on taste perception and aversion, moreover, suggest that humans are distinct from most other primates in having a strong preference for the sour flavor of acids produced by fermentation (Dunn et al. 2020). Humans clearly have a special relationship with ferments.

On the one hand, like most animals, we have more than a passing intimacy with fermentation in that it is the primary metabolic process of our microbiome, the consortium of microorganisms that live in and on our bodies (Diether and Willing 2019; Flint et al. 2012). At any given time, nearly 40 trillion bacterial cells are busy fermenting within our bodies (Sender, Fuchs, and Milo 2016), and the products of their fermentation nourish our cells, regulate our immune system, and protect our tissues, among other functions. Beyond these autochthonous microbes, however, we also actively seek out additional ferments, particularly through food. The benefits of fermented foods are diverse. As explained by Rob Dunn et al. (2021) and Amato et al. (2021), fermentation facilitates food preservation and storage by limiting the growth of pathogens and spoilage microbes. It also improves the nutritional value of food by synthesizing vitamins, improving digestibility, breaking down toxins, and increasing caloric density. And, when ingested, fermenting microbes act as probiotics and additionally supply prebiotics to the gut microbiome. As such, Dunn argues that fermented foods act as an *extended microbiome*, an externalization and functional expansion of the metabolic processes carried out within our own bodies (Dunn et al. 2020). When fermented foods became a regular component of human diets, however, remains uncertain (Dominy 2015), and it is not clear whether functionalist arguments that human ancestors could metabolize the products of fermented foods (Carrigan et al. 2015; Dominy 2004) are sufficient evidence that they did (Milton 2004).

Although direct archaeological evidence for food fermentation is at present limited to the Holocene, human control of fermentation is almost certainly considerably older. Speth (2017) has argued that protein and fat fermentation may have been nutritionally necessary during the Middle and Upper Paleolithic to supply sufficient B and C vitamins to Neanderthals and modern humans consuming diets dominated by animal products. Amato et al. (2021) argue for an even earlier exploitation of fermented foods during hominin evolution, postulating that fermentation may have expanded the dietary niche of human ancestors in transitional open and variable habitats by making physically and chemically defended underground storage organs (i.e., roots, tubers, bulbs, corms) and fruits more digestible through predigestion. As such, fermentation could have served a similar function as cooking, another Paleolithic technology of uncertain age.

Although archaeological evidence of culinary fermentation is scant for all periods, current global food systems abound with fermented products of all kinds, from kimchi and sauerkraut to mead and pulque to pickled herring and cheese. However, as discussed by Dunn et al. (2021), the origins, diversification, biodiversity, and biogeography of fermented foods have been only marginally studied, and far less than trees or birds, despite their economic and cultural importance. Perhaps this is because the microbial agents are microscopic or because such foods fall within the disciplinary gap between ecology and anthropology. Regardless of the cause, the absence of a research community focusing on the global ecology of fermented foods challenges efforts to build research models for understanding the geographic and cultural variability of these foods and practices. Drawing on successes (and failures) from the field of ecology, Dunn et al. (2021) propose a strategy to systematically study global fermented foods, with the aim to understand the environmental constraints, transmission dynamics, evolutionary pressures, and cultural choices that shape fermented foods and inform their histories.

The ecology and biology of fermented foods can be remarkably complex, but ferments are amenable to study (Wolfe and Dutton 2015), and the study of ferments also enhances our understanding of other human commensal relationships (Mansourian et al. 2018). As we begin to tease apart the routes that microbial species travel through biological and cultural systems, we can begin to imagine how ferments may have first entered into the human diet and how the diversification of this versatile culinary technology has influenced our social and biological history.

The Archaeology of Fermentation

The archaeological record can shed valuable light on the histories of ferments, including their roles in human diets and associated cultural practices, in the study of food and food technology on macro-, micro-, and biomolecular scales. The origins, development, and spread of staple foods used for fermentation, such as rice, wheat, and milk, have been subject to extensive archaeological inquiry, revealing insights into domestication centers, mechanisms of domestication, and the association of these agricultural products with archaeological cultures, as well as facets of trade and migration (e.g., Jones et al. 2016; Larson et al. 2014). However, less attention has been given to the fermented foods themselves and their culinary creation (Sibbesson 2019), with challenges arising in finding evidence of something that is a transformative process, as well as limits to archaeological techniques and interpretations.

While early work in the archaeology of food tended to focus on food acquisition (such as hunting strategies) and food movement (such as the spread of agriculture during the Neolithic), more recent research explores food as cuisine, as a blend of natural resources, technology, cultural practices and knowledge, and material culture (Graff 2020; Hastorf 2016; Twiss 2007, 2012). Graff (2018) argues that this rise of interest in an archaeology of cuisine reflects wider theoretical trends toward understanding social practices and the "archaeology of the everyday." In the past 20 years, alongside these theoretical shifts, the growth of biomolecular approaches in archaeology have contributed to new insights into the archaeology of food and culinary practices through the identification of molecular remnants of food and food preparation. These major methodological and theoretical trends are reflected in the contributions in this supplement, including an exploration of the role of pottery and fermentation in relation to food surplus (Craig 2021), synthesizing and critiquing fermentation with associated material culture in the culinary history of Japan, Korea, and China (Shoda 2021), and drawing on bacterial phylogenetics to assess the role of dairy microbes in the evolution of lactase persistence (Rosenstock, Ebert, and Scheibner 2021).

Developments in biomolecular archaeology have led to new insights into the long antiquity of food fermentation, through the analysis of multiple biomolecular classes from a diversity of archaeological substrates. In rare cases, the foods themselves preserve and can be investigated directly, as was shown by proteomic analysis of microbes present in kefir-like dairy products (Yang et al. 2014) and preserved "sourdough" bread from Bronze Age China (Shevchenko et al. 2014). Ancient dental calculus, tooth tartar preserved on human skeletons, has been shown to preserve milk proteins (Warinner et al. 2014). This has led to new insights into the consumption of this fermentable food, including the detection of horse milk proteins in the dental calculus of individuals from ancient Mongolia, which may indicate early consumption of *airag*, an alcoholic beverage made from fermented horse milk (Wilkin et al. 2020). Organic residue analysis on pottery, a major class of archaeological artifact used for food processing, has enabled new understandings of the adoption and use of particular foodstuffs throughout space and time, such as dairy products (Evershed et al. 2008; Wilkin et al. 2020), fish (Courel et al. 2020; Lucquin et al. 2018), and plants (Hendy et al. 2018; Heron et al. 2016). A large body of research on organic residues has focused on detecting evidence of alcoholic beverages, such as beer and wine (Barnard et al. 2011; Garnier and Valamoti 2016; Guasch-Jané et al. 2006), with a search for "biomarkers" diagnostic of ferments (Guasch-Jané et al. 2004; Isaksson, Karlsson, and Eriksson 2010). However, the robustness of some biomolecular markers for these beverages has been called into question (Drieu et al. 2020). Other examples of fermented foods identified using molecular techniques include evidence of pulque fermentation detected in pottery vessels from Teotihuacan through the identification of a bacterial lipid biomarker (Correa-Ascencio et al. 2014), and evidence of cocoa use 5,300 years ago in southeast Ecuador through the identification of the plant metabolites theobromine, theophylline, and caffeine (Zarrillo et al. 2018). Synthesizing organic residue analysis studies from across northern Eurasia, Craig (2021) argues that there is a link between pottery use and the development of fermentation as a culinary process for coping with food surplus, building on a body of work examining the implications of food surpluses in archaeological contexts (Bogaard 2017).

The analysis of ancient DNA is also revealing the past's microbial landscapes, with studies investigating ancient microbes and microbial communities increasing in number and scope. Initially, efforts were focused on detecting pathogenic species, tracking the development, spread, and prevalence of particular disease-causing microbes. Such efforts have resulted in new understandings of infectious disease, from the Black Death (Spyrou et al. 2019) to Viking-era smallpox (Mühlemann et al. 2020) to the colonial epidemics of the Americas (Vågene et al. 2018). More recently, metagenomic analysis has yielded insights into ancient microbial communities, rather than a single taxon, from a range of substrates but particularly from human-associated microbial communities, such as the oral and gut microbiomes (Shillito et al. 2020; Velsko and Warinner 2017). In future work in this area, it is likely that detection of taxa from microbial communities from outside the human body (e.g., microbes involved in culinary fermentation) will be possible. Here, selection of appropriate archaeological materials, artifacts, and substrates will be key in this detection. Rosenstock, Ebert, and Scheibner (2021) explore the integration of material culture with the biomolecular evidence of ancient fermentation, drawing on insights from molecular biology and bacterial phylogenetics for genomic signatures of fermentation, and explore the role that dairy microbes may have had in the development of lactase persistence.

Beyond biomolecular approaches, archaeological evidence of fermentation can also be found using macro- or microscopic techniques. For example, Arranz-Otaegui et al. (2018) used scanning electron microscopy to examine charred food residues from the Natufian site of Shubayqa 1. By characterizing pore sizes in the charred residue produced by CO_2 from yeasts, they determine that Natufian hunter-gatherers created bread-like products. Using a combination of microfossil analysis (starch and phytolith analysis), as well as the chemical detection of oxalate, Wang et al. (2016) demonstrated evidence for a fermented mix of broomcorn millet, barley, Job's tears (*Coix lacrymajobi*), and tubers from 5,000 years ago in central China.

Zooarchaeological analysis of animal bone is also contributing to the detection of past fermentation. Boethius (2016), in examining fish bones found densely packed in a Mesolithic pit in Sweden, observed taphonomic damage consistent with degradation from acids. This observation, together with the context of the finds, led to the conclusion that such a dense concentration of fish was for fermentation. Attempts have also been made to establish links across experimental archaeology, historical sources, and archaeological evidence in order to reveal the origins of specific culinary practices, such as the production of fermented fish sauce (garum) in ancient Rome (Grainger 2011). In a similar vein, Shoda (2021) explores links between traditions of microbial cultivation, material culture, and secondary products in the archaeology of fermented products in Japan, Korea, and China—examining, for example, the link between salt production and fermentation as well as the role of specific food processing technologies, such as steaming.

Despite these efforts, there still remain substantial challenges to understanding an archaeology of fermentation due to the confounding action of microbes as taphonomic agents (Collins et al. 2002; Gjelstrup Björdal 2012; Kendall et al. 2018). Therefore, efforts to identify and study fermentation resulting from past microbial processes need strategies of distinguishing ancient signals of fermentation from decomposition resulting from postdepositional microbial action. However, as reviewed here, and through the new contributions in this issue, it is clear that the archaeological record has much to offer in revealing the emergence and spread of food traditions, fermentation histories, and human-microbial interactions.

Cultures of Cultures: Sociocultural Anthropology and Fermentation

In recent years, social and cultural anthropologists have shown a growing interest in the multiple ways of how humans mediate their relations with other organisms (Galvin 2018). This has led to the emergence of multispecies ethnography, a genre of writing centered on "how a multitude of organisms' livelihoods shape and are shaped by political, economic, and cultural forces" (Kirksey and Helmreich 2010:545). Building on a long tradition of anthropological engagement with animals (e.g., Bateson 1972; Evans-Pritchard 1940; Ingold 1980; Nagel 1974), anthropologists have started to engage with questions hitherto considered outside the epistemological horizon of the discipline: How do farm animals overdetermine the everyday lives of humans through practices of biosecurity and the idea of "One Health" (Blanchette 2015; Hinchliffe et al. 2016)? What can a mushroom tell us about the production of value in global capitalism (Tsing 2015)? Or, on a more philosophical level, what can animals teach us about politics (Massumi 2014)? Expanding multispecies ethnography to encompass microbes adds another layer of complexity, so much so that one could speak of an emerging multidomain ethnography: it is hard enough to communicate with mammals (Fijn 2011; Govindrajan 2018; Meulemans 2020), birds (Song 2011), fish (Lien 2015; Todd 2014), or insects (Nading 2014; Raffles 2010), but how do you engage with bacteria and yeasts (Brives, Sariola, and Rest 2021; Lyons 2020; Puig de la Bellacasa 2017)?

Ethnographies of microbiologists constitute another important lineage for this symposium (Helmreich 2009; Hird 2009; Nerlich and Hellsten 2009; Sommerlund 2006). Current investigations into microbial worlds (e.g., Benezra, DeStefano, and Gordon 2012; Giraldo Herrera 2018; Helmreich 2015; Kirksey 2019; Lee 2018; Lorimer 2017) show their entanglement with human suffering and thriving. Hannah Landecker's (2016, 2019) exploration of the history of antimicrobial resistance exemplifies how human interventions—long before gene editing—have fundamentally changed microbial life forms. This body of work makes a strong claim for the necessity of a novel form of political theory that considers the role microbes play in society. Today, in the face of a viral pandemic, this is hardly a controversial claim.

Yet, approaching microbes through fermentation offers a way of engagement that is fundamentally different from the long-practiced metaphor of a war against microbes (de Kruif 1926; Latour 1988). Acknowledgment of the importance of bacteria for human metabolism, mental health, and general well-being has rendered the imagination of a neat distinction between "us" and "them" impossible (Rees 2020). Or, as Megan Tracy's (2021) contribution to this issue focusing on how women have become model organisms for dairy cows (and vice versa) succinctly shows: you are not just what you eat, but rather "you are what you eat eats" (Landecker 2011:182). Tracy's discussion of "missing microbes" in industrial dairying exemplifies the problems that the agro-industrial plantation system is creating for all life forms involved. In order to treat bovine mastitis in the face of growing antimicrobial resistance, dairy scientists are looking to treat cows with components of human breast milk. Making visible the circulation of microbes, bodily matter, and metaphors, she concludes that "milk contains not just the cow, but the human, other species, and our moral and ethical landscapes" (Tracy 2021). However, instead of an instantaneous celebration of living with companion species (as a hasty reading of Donna Haraway [2008] might suggest), the contributions collected here open the lived reality of symbiosis to ethnographic investigation.

In the past decades, the exploration of the agentive forces of more-than-human entities has produced some of the most lively interventions in sociocultural anthropology and social theory.[1] Debates about nonhuman agency and its efficacy emerged from engagements with science and technology studies that asked how historians and anthropologists might simultaneously hold to a strongly culturalist vision of how science is made as well as a dedication to a non-anthropocentric attention to the ongoing liveliness of the nonhuman world. During the symposium, time and again we came back to the argument that science and society coproduce each other and cannot be separated (Jasanoff 2004). To many of the participants, Heather Paxson's (2008) idea of microbiopolitics served as a guiding concept to frame their investigations. Its central claim, in Jamie Lorimer's phrasing, is that the way we talk about microbes is an applied science of governing microbes, but it is also inevitably a way of governing people. Here, Paxson extended Michel Foucault's (1978) concept of biopolitics—"what brought life and its mechanisms into the realm of explicit calculations and made knowledge-power an agent of transformation of human life" (143)—to also include microbial life and its mechanisms. So, if biopolitics is the governance of human life by appeal to the biosciences, then microbiopolitics is the governance of human-microbial life by appeal to microbiology. Microbes and the people around them coproduce each other. Along with this coproduction we can observe the transference of ideas and norms from one domain to the other. Take, for instance, the naturalization of wage labor under advanced capitalism. The normalization of the idea that wage labor, which posits that it is human nature to work, has led to the naturalization of microbial processes *as* work and the widespread idea that microbes work when they engage in fermentation (Paxson 2018). Simultaneously, microbial life itself has become a site of potential commodification.

Eben Kirksey (2021) deals with the promise of synthetic biology to generate capital from microbes in his account of student participants of the International Genetically Engineered Machine (iGEM) competition. Following the development of several of their projects, he calls for anthropologists to engage in collaborative speculation with technologists to shape these symbiotic futures together. In a similar vein, Amy Zhang (2021) introduces us to a group of urban "eco-enzyme brewers" in southern China who ferment their household waste in order to reincorporate waste. Contrary to critics who see the practice as just another form of green consumption that fails to challenge the political hegemony, Zhang understands their actions as a form of affirmative biopolitics as developed by Roberto Esposito (2008). Through it and together, they are engaged in building immunity for communities that feel the impact of rapid environmental degradation due to industrialization. Daniel Münster's (2021) contribution, on the other hand, argues that microbes are indifferent to human politics. His article discusses how a fermentation practice among crisis-ridden farmers in southern India promotes a bionativist critique of foreign biologies grounded in a conspiratory resistance to the colonial legacies of the global food system. The ferment's main ingredients are the dung and urine of native cows, and they are used to heal soils degraded from industrial farming. Hand in hand with its strong commitment to organic farming comes an imagination of racial superiority of the "native" Indian cow (*Bos indicus*) over other cows and an endorsement of Hindu nationalism.

As any practitioner will know, time is of the essence in any relation with fermentation microbes. The contributions that engage most directly with time all deal with raw milk cheese. Roberta Raffaetà (2021), in her investigation of cheese making in the summer pastures of the Italian Alps, argues that fermentation participates in the composition of different human, more-than-human, and microbial spacetimes. The summer pastures constitute a topos with conflicting temporal promises: to some they represent a premodern utopia, while others strive to extract and detach their microbial typicality to replicate the health benefits of alpine cheese anywhere. As with Zhang (2021) and Kirksey (2021), she advocates for the messy heterotopia of maintaining complex sets of more-than-human relations. Paxson (2021) wonders about another set of temporal relations in her contribution on the many lives of cheese. Her analysis follows the material transformations and semiotic requalifications of European raw milk cheese as it enters the United States. Through her exploration of the mostly invisible work of importing, she argues for an analysis of global supply chains that takes into account the multiple timescapes and forms of "labor in and of time" (Bear et al. 2015) necessary to preserve the fermentation value of cheese. Matthäus Rest (2021) presents an account of the interdisciplinary research group he works with that is investigating the prehistoric spread of dairying

1. We use this admittedly imprecise phrasing to refer to a number of divergent schools of thought including feminist technoscience, actor-network theory, new materialism, and the ontological turn, among others.

by combining two often-hyped new forms of genomics: ancient DNA and microbiome research. Against strong tendencies in both fields to simplify the human past, he positions Heirloom Microbes as concerned with the everyday reproduction of human-microbe relations through milk that aims to support small-scale dairy producers to protect their microbes from commodification and argues for a global microbial commons.

One central way of explaining the intricate connection between fermentation and value production is through taste. For poorly understood reasons, humans like the taste of fermented foods. As another set of contributions show, taste, belonging, and identity are strongly entangled with fermenting microbes. Evans and Lorimer (2021) explore the nexus of microbial charisma, domestication, human-microbe coevolution, and the deep history of taste. In their account of the miso making practice of haute cuisine chefs in Copenhagen, they claim that charismatic microbes make history and question long-standing beliefs on causality, intentionality, and, ultimately, human exceptionalism. Through the flavor of fermented bamboo shoots from India's Northeast, Dolly Kikon (2021) investigates memory, community, and emerging forms of identities in Delhi. The shared experience of eating bamboo that is considered "smelly" by the city's majority population, she argues, is producing the Northeast as a new trans-ethnic culinary identity. Salla Sariola (2021), in her discussion of sourdough bakers in Finland, sees her interlocutors as actively working on and for a post-antibiotic world. To them, antimicrobial resistance serves not to evoke the metaphor of war against microbes, but sheds light on how microbes are shaped by social practices. Here, antimicrobial resistance is a window that opens up people's relationships not only to the biological mechanisms of microbes but to the entangled levels of the social, political, and economic.

Each of these contributions shows the breadth of social and cultural anthropology's engagement with fermentation and the "always already" political nature of microbes. Taking up Dunn's call for an interdisciplinary and comparative global anthropology of fermentation, we round out this supplement with a photo essay that juxtaposes peasant dairying practice in Mongolia and the Alps. The photographs presented are part of the Dairy Cultures Ethnographic Database (Reichhardt et al. 2021*a*, 2021*b*). This curated online archive is an attempt to open up ethnographic fieldwork on fermentation to a larger audience and to experiment with the possibilities presented by the open data movement in the sciences. In this way they hope to develop new ways of sharing and communicating with the public but also among and between diverse scientific disciplines and communities.

Fermenting Interdisciplinarity to Create an Anthropology of Microbes

In the symposium leading to this supplement, we hoped to achieve an ambitious outcome: "The symposium will foster interdisciplinary conversations integral to understanding human-microbial cultures. By bridging the fields of archaeology, cultural anthropology, biological anthropology, microbiology, and ecology, this symposium will cultivate an anthropology of fermentation" (organizers' statement, October 2019).

There are two key phrases in this excerpt: "interdisciplinary conversations" and "an anthropology of fermentation." Conversations among the participants were to lead ultimately to an outline of what an anthropology of fermentation, or rather, an anthropology of microbes, might look like. There was no expectation that an outline was to be created at the symposium itself, but hope was expressed at its conclusion that such an outline would emerge from the assembled manuscripts and future collaborations among participants. To achieve this, by design and necessity, the conversations had to be interdisciplinary in content and tone.

Conversations of interdisciplinarity arose again and again and feature, explicitly or not, in many contributions in this issue. As organizers, we never actually defined interdisciplinarity for ourselves but yet had the shared perception that having discussions with participants from different subfields of anthropology as well as those from other disciplines were necessarily interdisciplinary. Participants crossed disciplinary boundaries often during the discussions, but were these crossings truly interdisciplinary? Here in this introduction, we believe that a discussion and closer examination of the concept of interdisciplinarity is warranted.

Terms like multidisciplinarity, interdisciplinarity, and even transdisciplinarity, among others, are often used interchangeably. That practice, however, obscures crucial features of how they are actually used by scholars in their research. Multidisciplinarity "draws on knowledge from different disciplines but stays within their boundaries" (Choi and Pak 2006; NSERC 2004; OECD 1998). Van den Besselaar and Heimeriks (2001) explain that in multidisciplinary studies "the subject under study is approached from different angles, using different disciplinary perspectives. However, neither the theoretical perspectives nor the findings of the various disciplines are integrated in the end" (706). This is very much what archaeology looked like in the 1960s and 1970s when that subdiscipline borrowed a wide range of statistical methods as one aspect of the New Archaeology (Aldenderfer 1987:23–27). Archaeologists, the recipients, benefited from the borrowing, but it had little effect on the donors, the statisticians who worked with them. Social anthropologists have also been great borrowers over the past 50 years or so, and these borrowings have certainly enriched anthropological theory and practice.

Social ecologist and environmental anthropologist Michael Dove writes that anthropology, writ large, has a long history of seeking new ideas from many sources in the sciences as well as the humanities (Dove 2006:59). Dove also observes, however, that donor disciplines may not see equal—or any—benefit from being intellectually looted. This does not mean that the results of research that are created by the borrowing fail to be used, but rather, it means that the borrowing per se does little to affect or transform intellectual development in the donor discipline. Dove illustrates this through an analysis of how the ecological anthropology of the 1960s and 1970s, which focused on models of equilibrium borrowed from ecology, was transformed in the

1980s and beyond by models of *disequilibrium*, again borrowed from ecology. Dove asks an important question as he draws his essay to conclusion: "What sort of interdisciplinary borrowing is supportive of the donor (as well as the recipient) discipline and what sort is not?" (Dove 2006:66). Ironically, Dove describes his borrowing as interdisciplinary when in fact it is better described as being multidisciplinary according to the definitions offered above. Nevertheless, the question is of utmost importance, and answering it is critical to deciding just what an anthropology of microbes might look like and what it would take to make it a reality. In other words, when can borrowing be transformative for all those involved in a research endeavor?

Definitions of interdisciplinarity suggest that while borrowing can be important for any research effort, it takes more than that for a project, discipline, or field to become truly interdisciplinary. Choi and Pak (2006:351) and CIHR (2005) suggest that interdisciplinarity "analyzes, synthesizes, and harmonizes links between disciplines into a coordinated and coherent whole." Van den Besselaar and Heimeriks (2001:706) argue that it "creates its own theoretical, conceptual and methodological identity. Consequently, the results of an interdisciplinary study . . . are more coherent and integrated." These authors also note that truly interdisciplinary work tends to be application- or problem-oriented and that the successful creation of larger-scale interdisciplinary research programs or fields, such as biochemistry, is strongly dependent on initial disciplinary coherence that can be translated effectively across the boundaries of the cooperating fields. In other words, borrowing becomes integrated into practice. This emphasis on initial disciplinary coherence helps to explain the failure to build a strong interdisciplinary version of cognitive science (Núñez et al. 2019). There, six disciplines made a concerted effort to develop a new field, but over time existing disciplinary boundaries proved to be insurmountable.

Viewed from this perspective, the challenges of creating an interdisciplinary anthropology of microbes can seem daunting. This, however, does not mean that research in this domain cannot thrive and find theoretical as well as practical application in the subdisciplines of anthropology as well as in microbiology or other fields where the study of microbes is important. At least into the near term, a strong version of multidisciplinary research will be the result of the intellectual ferment generated by the symposium. There are challenges, however, that must be overcome to make this a reality. Philosopher of science Nancy Cartwright (1999) outlines some of them: "How do we best put together different levels and different kinds of knowledge from different fields to solve real world problems, the bulk of which do not fall in any one domain of theory? Within each of the disciplines, pure and applied, we find well developed, detailed methodologies for both judging claims to knowledge and putting them to use. But we have no articulated methodologies for interdisciplinary work" (18). One way to approach this may be to create so-called trading zones. Peter Galison, a historian of science, developed the concept to explain how twentieth-century physicists working from very different theoretical perspectives found novel ways of communicating with one another and solving practical problems. "Two groups can agree on rules of exchange even if they ascribe utterly different significance to the objects being exchanged; they may even disagree on the meaning of the exchange process itself. Nonetheless, the trading partners can hammer out a local coordination" (Galison 1997:783). Trading zones may be one way for incompatible theoretical perspectives to develop workable relationships. The exchange of ideas in a trading zone encourages novel and creative thinking about a problem that all theoretical perspectives share—how to create reliable knowledge about the object of analysis (Aldenderfer 2010).

As such, rather than seeking interdisciplinarity, perhaps a more desirable goal for an anthropology of microbes is to strive toward transdisciplinarity. At times described as a specific form of interdisciplinarity, transdisciplinarity is "an approach that occasions the emergence of new data and new interactions from out of the encounter between disciplines. Transdisciplinarity does not strive for mastery of several disciplines but aims to open all disciplines to that which they share and to that which lies beyond them" (Choi and Pak 2006; First World Congress of Transdisciplinarity 1994). Transdisciplinarity thus encompasses "group research whereby individuals from different disciplines work as a team within a mutually accepted systems organization with an overall set of systems goals" (Choi and Pak 2006; Grossman 1979). The good news about microbes is that we have a very sound understanding of their biological properties—or in other words, there is an initial disciplinary coherence regarding what we know about them that will ultimately help to make an anthropology of microbes a reality. But it will be incumbent for these researchers to avoid jargon, to communicate effectively, and to develop a mutual respect for what each brings to the analysis. We hope that this collaborative endeavor to create an anthropology of microbes will ultimately achieve the goal of transdisciplinary research: to create "a new vision of nature and reality" (Charter of Transdisciplinarity 1994; Choi and Pak 2006).

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