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Authors

Marco, Maria L
Smid, Eddy J

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Editorial overview: Food biotechnology: Exploration and exploitation of microbial resources to address the need for sustainable production of safe, healthy and nutritious food

Maria L Marco and Eddy J Smid



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Maria L Marco



Eddy J Smid



Maria L Marco received her BS from the Pennsylvania State University in microbiology (1995) and PhD from the University of California, Berkeley in plant-microbe interactions (2002). She then worked as a post-doc and project scientist at NIZO food research, The Netherlands, investigating probiotic *Lactobacillus* and novel properties of other lactic acid bacteria (LAB). In 2008, Dr . Marco started her appointment in the Department of Food Science & Technology at the University of California, Davis where she is currently an associate professor. Her

Food production and processing have never been more technologically advanced and integrated and at the same time under such extreme pressures to feed the expanding world population. The Food and Agriculture Organization of the United Nations (FAO) has called for radical changes to food systems to support human populations while also prioritizing approaches that preserve natural resources and minimize impacts on climate [1]. The number of people on Earth is expected to grow to almost 10 billion by 2050, a change that could increase agricultural demand by 50%. Therefore, it is essential to creatively and intensively pursue research and policies that contribute to achieving this goal.

A deeper understanding of microorganisms is essential for any approach in food and agriculture that promotes human health and protects the environment at the same time. Microbes can be beneficial, and at times, essential in food production systems. Food preservation by fermentation is an ancient practice and currently receives a broad interest from consumers and producers because of the links between fermented food consumption and good health. Many foods and beverages ultimately become fuel for the intestinal microbiota which are pivotal players in bodily function. Conversely, other microbes are a significant threat to public health and global food security. The global burden of food-borne disease was estimated at 33 million "disability adjusted life years" in 2010 and crop losses due to plant pathogens range in the hundreds of billions of dollars per year [1].

This Food Biotechnology special issue emphasizes microorganisms in foods and the digestive tract. Several articles draw upon recent advancements resulting from systems biology and ecological approaches. Other articles have a more narrow focus on how individual groups of food and gut associated microbes and their cellular components provide new and deeper views and how this knowledge can be used for the advancement of food biotechnology processes.

Genomics approaches for improving food safety and fermentation

Technological and computational advances in DNA sequencing continue to be a significant force in microbiology research. *Allard et al.* summarize how whole genome sequencing (WGS) and related methods have transformed efforts to improve food safety by the Food and Drug Administration and other federal agencies in the USA. Genetic data on foodborne pathogens can be shared between state and federal laboratories and with the public during outbreak investigations and for identification of risks (antibiotic resistance, virulence factors) associated with individual strains. Because of WGS, foodborne illness outbreaks can be studied in 'real-time' resulting in faster response times to restrict expansion and identify probable contamination sources. These efforts are now being globalized to construct a more integrated microbial food safety network world-wide. Because of the technological advancements of WGS and metagenomics in recent years, the microbial food safety landscape is changed forever.

research focuses on LAB in food systems and the mammalian digestive tract. The broad objective of her work is to identify the attributes of microbes that can be used to guide improvements in food production to benefit human health.

Eddy J Smid received his PhD degree (1991) in Microbiology at the University of Groningen, The Netherlands. After his graduation, Smid took up a scientist position at ATO-DLO, Wageningen, The Netherlands to conduct research in the field of Food Microbiology. In 2000, he moved to NIZO food research to lead a group on fermentation research. In 2010, Smid joined the Wageningen University where he was appointed in 2014 as full Professor with a personal chair in Food Microbiology at the Laboratory of Food Microbiology. His current research programme focuses on the microbial ecology of complex food fermentations with the objective to steer and control the functionality of fermented food products and food ingredients. Biodiversity mining, population dynamics and adaptive evolution strategies are being applied to achieve the desired culture properties which produce fermented food products with novel functionalities.

Genomics approaches are also being applied to investigate the composition and ecology of food fermentations. Fermented dairy foods are intricate ecosystems that are the result of exposing milk to variations in environmental conditions and microbes. In their paper, [Macori and Cotter](#) provide an overview of different fermented dairy products. The complexity of these foods is remarkable, considering that they are all produced from milk and few other ingredients. The range of the microbial interactions and population dynamics in dairy is increasingly appreciated from the study of individual strains to the dairy ecosystem in its entirety.

The compositional complexity of microbial communities in fermented food products is also reflected in the diversity of bacteriophages found on these products. [Gonçalves de Melo *et al.*](#) describe the down-side and the beneficial aspects of bacteriophage presence in food fermentation processes. On the one hand, they describe new strategies to ‘vaccinate’ CRISPR-containing industrial bacteria with the objective to increase their resistance towards lytic phage attack. On the other hand, they describe the use of distinct phages to control proliferation of pathogenic bacteria in our food production chains.

Similar efforts are underway for understanding vinegar fermentations. [Lu *et al.*](#) describe how the production of traditional cereal vinegars is performed in multiple stages, requiring numerous fungal and bacterial species, and includes solid-state or semi-solid state fermentations. Although vinegar processing methods have been refined and optimized over the centuries, a mechanistic view of the microbial communities required for this process has only recently started to be elucidated. Acetic acid bacteria (AAB) are among those microorganisms that play a key role in vinegar production. In this issue, [De Roos and De Vuyst](#) emphasize our current understanding of these bacteria in various fermented foods like lambic beer, water kefir, kombucha, and cocoa. These bacteria can be a challenge to cultivate and study in the laboratory however efforts are underway to develop starter cultures to improve control of over food and beverage fermentation processes.

Microbial transformations of foods and beverages

Several papers published in this issue explore characteristics of bacteria and yeast that contribute to food fermentations. [Di Cagno *et al.*](#) discuss the adaptations of lactic acid bacteria (LAB) to terrestrial plants and the roles of these bacteria in the fermentation of plant tissues. They creatively described LAB metabolism during growth on plants as a ‘labyrinth’ of enzymatic processes. The authors illustrate numerous facets of how LAB transform plant-associated compounds resulting in the removal of toxic or anti-nutritional compounds or improvements to digestibility. LAB can also produce bioactive compounds such as the neurotransmitter gamma-amino butyric acid (GABA) and improve the bioavailability of phenolic metabolites.

The contribution made by [Hittinger *et al.*](#) emphasizes the discovery of the enormous diversity in yeast species found on spontaneous fermented food products and how these non-conventional yeast species can be used for innovations in food fermentations that reach beyond the use and optimization of conventional *Saccharomyces cerevisiae*. [Gallone *et al.*](#) zoom in on the phenotypic and genetic diversity of the domesticated, beer brewing yeast species *S. cerevisiae* and *Saccharomyces pastorianus*. They show the different evolutionary routes taken by each of the two species and how experimental evolution in conjunction with marker-assisted breeding and other techniques form the basis for biotechnology-driven evolution of industrial beer yeasts.

Microbial cell products and pathways

Biotechnological applications frequently involve specific metabolites and proteins made by microorganisms. These cell products can be synthesized by a limited number of microbes for normal physiologic function but often result in uses that are broad in scope. An example of this was provided by [Chikindas *et al.*](#) who reviewed advances to our understanding of bacteriocins produced by Gram-positive bacteria. Bacteriocins are classically understood as antimicrobial peptides. This function has been applied for food preservation. However, as Chikindas and co-authors point out, defense is just one activity of bacteriocins. Other roles include quorum sensing and acting as effectors on other microbes and host cells. These capacities could be used in medicine and food preservation.

Bacterial membrane vesicles (MVs) constitute another example of a product uniquely linked to microbial activity. [Liu *et al.*](#) describe food biotechnology related applications of bacterial MVs based on their natural functions and properties. They refer to MVs as agents for shaping starter culture communities, as substitutes for probiotics, as delivery vehicles for nutritional compounds to the human host and as bioactive agents in various other applications.

Biotechnological advancements are not limited to understanding extracellular products. [Thorsing *et al.*](#) convey the latest discoveries in small RNA (sRNA) biology in major foodborne pathogens with special emphasis on the regulatory functions of these molecules in adaptation to host-specific niches. The established role of non-coding RNAs as regulators of bacterial gene expression linked to important cellular processes such as stress response, virulence, and metabolism underlines the importance of knowledge of sRNA biology for food microbiology.

The capacity of microorganisms to produce metabolites other than those predicted for normal cellular pathways was presented by [Notebaart *et al.*](#) Side activities of enzymes result in an underground metabolism that can support adaptations to new environments and bypass genetic defects. Outcomes of such enzymatic promiscuity can also lead to both undesired toxic compounds and novel bioactive products. Notebaart and co-authors describe how underground activities have been discovered using both experimental and computational approaches and how systems biology is integrating these efforts. This knowledge should lead to unique opportunities to harness microbes for biotechnological applications that either augment or restrain their metabolic potential.

Probiotics and gut microbiology

Lastly, several articles emphasize the actions and ecology of microorganisms in the human digestive tract. Although strain-specificity has long been regarded as a hallmark of probiotic function, [Sanders *et al.*](#) provide a provocative view that certain general properties of *Lactobacillus* and

Bifidobacterium, the most commonly applied probiotic genera, can result in health benefits. These Gram-positive bacteria have numerous traits in common (e.g. production of lactate) or have attributes that are shared among species (e.g. surface-layer proteins). Such cell products might be responsible for the core mechanisms of probiotic function. If so, probiotics can be grouped into categories according to the health benefits that those cell products and metabolites confer. Strains that have not been tested in human efficacy trials might still meet the minimum definition of the term 'probiotic'.

The urgency and opportunities for developing deeper, mechanistic knowledge on probiotics was shared by [Lebeer *et al.*](#) Their paper provides examples of mechanistic studies on probiotics tracing the specific molecules produced by probiotics and the corresponding responses by the host and gut microbiota. The continued development of systems biology and genetic tools combined with the use of animal models has the field poised to address molecular interactions between probiotics and their hosts that result in local and systemic responses which support human health.

[Heeney *et al.*](#) provided a comprehensive summary of recent, untargeted metataxonomic studies which found that lactobacilli are frequently, although not exclusively, associated with the gut microbiomes of healthy individuals. Certain species of *Lactobacillus* are commonly found among the gut microbiota of humans and animals as well as other sites on the body. Interpreting the significance of these bacteria in limiting gastrointestinal illness and altering metabolic, immune, neural, and developmental processes could provide routes to identify novel probiotic strains and understand their mechanisms of action in the digestive tract.

Lastly, [Walter *et al.*](#) expanded the discussion to address one of the more frequently mentioned goals of probiotics applications to modify the gut microbiome. By understanding and applying established theories on invasion ecology, constraints to establishing populations of probiotic bacteria as stable members of the gut microbiome come better into view. Such engraftment might increase probiotic efficacy and can be used to re-establish essential metabolic and physiologic capacities to the gut.

Concluding remarks

The contributions and opinions described in this special issue of Current Opinion in Biotechnology show the broad scope of the field of food biotechnology and bring together the diverse activities that are currently being explored to improve safety, nutritional value, and health impact of food products as well as sustainability of food production.

Reference

1. [FAO: The Future of Food and Agriculture – Trends and Challenges. Rome; 2017. ISBN 978-92-5-109551-5.](#)