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A 100-Year Review: Microbiology and safety of milk handling[1]

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ABSTRACT

Microbes that may be present in milk can include pathogens, spoilage organisms, organisms that may be conditionally beneficial (e.g., lactic acid bacteria), and those that have not been linked to either beneficial or detrimental effects on product quality or human health. Although milk can contain a full range of organisms classified as microbes (i.e., bacteria, viruses, fungi, and protozoans), with few exceptions (e.g., phages that affect fermentations, fungal spoilage organisms, and, to a lesser extent, the protozoan pathogens *Cryptosporidium* and *Giardia*) dairy microbiology to date has focused predominantly on bacteria. Between 1917 and 2017, our understanding of the microbes present in milk and the tools available for studying those microbes have changed dramatically. Improved microbiological tools have enabled enhanced detection of known microbes in milk and dairy products and have facilitated better identification of pathogens and spoilage organisms that were not known or well recognized in the early 20th century. Starting before 1917, gradual introduction and refinement of pasteurization methods throughout the United States and many other parts of the world have improved the safety and quality of milk and dairy products. In parallel to pasteurization, others strategies for reducing microbial contamination throughout the dairy chain (e.g., improved dairy herd health, raw milk tests, clean-in-place technologies) also played an important role in improving microbial milk quality and safety. Despite tremendous advances in reducing microbial food safety hazards and spoilage issues, the dairy industry still faces important challenges, including but not limited to the need for improved science-based strategies for safety of raw milk cheeses, control of postprocessing contamination, and control of sporeforming pathogens and spoilage organisms.

Key words: dairy food safety, cheese safety, pasteurization

INTRODUCTION

The first issue of the *Journal of Dairy Science* (**JDS**) in 1917 comprised 5 articles, including 1 article on the microbiology of milk authored by Cornell scientists R. S. Breed and W. A. Stocking (Breed and Stocking, 1917). The article reported both agar-based and direct microscopic bacterial counts for "market milk" collected in New York. This article ended with the noteworthy conclusion, "Research men, using technique which differs much in details, may be depended upon to secure much more consistent agar plate counts from ordinary samples of market milk than laboratory assistants working rapidly and using the routine methods of analysis recommended for the purpose." Although we, the authors of the review presented here, are indeed located in Stocking Hall, which was named after the author of the first JDS microbiology paper, today research women and men are using different rapid detection methods and molecular biology tools, including whole-genome sequencing, to ensure the safety and quality of milk throughout the world.

Between 1917 and 2017, our understanding of the microbiology of raw milk and dairy products has undergone tremendous advances (see Appendix Table A1), in no small part because of the development and use of new microbiological techniques and methods, including development of improved selective and differential bacteriological media and development of molecular biology tools (e.g., PCR). In parallel, development and implementation of improved technologies and systems to control microbial food safety hazards and spoilage organisms have significantly improved dairy product quality and reduced public health hazards associated with dairy products to a level that would have been unimaginable in 1917, as illustrated by the modern availability of HTST pasteurized fluid milk with shelf lives of >21 d.

MICROBIOLOGY AND SAFETY OF MILK HANDLING FROM 1917 TO 2017

Transition to Pasteurization

The widespread implementation of pasteurization for raw milk has improved public health by preventing the

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spread of foodborne diseases across the United States. However, pasteurization was initially controversial and slow to be adopted as a common practice. In 1864, Louis Pasteur discovered that gradually heating wine, and then rapidly cooling it, prevented abnormal wine fermentation due to spoilage microorganisms; this process came to be known as pasteurization. Although Pasteur himself did not apply this principle to milk, implementation of milk pasteurization started considerably before 1917. As early as 1873, the American pediatrician Abraham Jacobi advocated boiling cow milk in bottles before feeding it to infants (Jacobi, 1873; Holsinger et al., 1997). Later, in 1886, the German chemist Franz von Soxhlet devised an apparatus for in-home, in-bottle milk sterilization for infants; this procedure involved boiling milk for 40 min (Andrews and Fuchs, 1944). By 1893, under the advice of Jacobi and others, philanthropist Nathan Straus opened milk depots in New York City, providing sterilized milk to infants of impoverished families (North, 1921; Steele, 2000). Despite an observed effect of sterilization on reducing infant mortality rates and growing support for in-home pasteurization of cow milk for infant consumption, implementation of widespread commercial pasteurization faced strong opposition (North, 1921; Andrews and Fuchs, 1944). Many public health officials and doctors in the United States opposed widespread commercial pasteurization of milk, fearing it would provide only a stopgap measure that might create a false sense of security for the processor while distracting farmers from the need to increase on-farm sanitary measures (North, 1921; Andrews and Fuchs, 1944). In addition, although some recognized pasteurization as a useful method for reducing milk spoilage, they remained concerned about its ability to effectively inactivate milkborne pathogenic microorganisms (Andrews and Fuchs, 1944). Nevertheless, in 1907, the first commercial-scale apparatus for pasteurizing milk by the holding method was installed in New York City (Andrews and Fuchs, 1944). A pivotal shift occurred in January 1908, when the US Public Health Service (**USPHS**) and Marine Hospital Service published *Milk and its Relation to the Public Health*, which revealed that the consumption of raw milk was dangerous and was often the cause of tuberculosis, typhoid fever, diphtheria, scarlet fever, and intestinal disorders of babies. In this document, US Surgeon General Walter Wyman famously wrote, "Pasteurization prevents much sickness and saves many lives" (Wyman, 1908). This report prompted states to respond to public health concerns surrounding diseases associated with raw milk. In July 1908, Chicago became the first American city to pass an ordinance requiring the pasteurization of all cow milk entering the city, except for that from tuberculin-tested cows (Czaplicki, 2007). This ordinance was originally intended only as a temporary measure to control the spread of bovine tuberculosis; simultaneously, farmers were expected to bring their herds into compliance with tuberculin testing (Czaplicki, 2007). However, many cities followed suit, releasing similar ordinances regarding pasteurization (Andrews and Fuchs, 1944). As a result, commercial milk processing facilities were constructed throughout the United States to meet compliance needs, thus rapidly spreading the practice of pasteurization (Andrews and Fuchs, 1944). Once pasteurized milk was introduced to the public, pasteurized milk and milk products rapidly penetrated the market. According to Smith-Howard (2013), by 1916, 80 to 90% of the milk sold in Chicago, Boston, Philadelphia, and New York was pasteurized.

To assist in the prevention of milkborne diseases, in 1924 the USPHS published the *Standard Milk Ordinance for Alabama Municipalities*, later referred to as the first Standard Milk Ordinance; this document included standards for pasteurization (USPHS/FDA, 2016). Subsequently, Frank et al. (1927) reported on outcomes from the implementation of the Standard Milk Ordinance in 14 Alabama towns. Significant improvements were described in raw milk quality and USPHS milk sanitation ratings for both farms and processing facilities that were pasteurizing milk. Consequently, in 1926 a slightly modified version of the Standard Milk Ordinance was published (Frank et al., 1927). In 1927, the USPHS released an accompanying code to provide a uniform interpretation of the ordinance and to offer administrative and technical details regarding satisfactory compliance (USPHS/FDA, 2016). The ordinance and accompanying code were the precursors of the current US Grade A Pasteurized Milk Ordinance (**PMO**; USPHS/FDA, 2016).

As scientific research in the areas of milk production, processing, nutrition, and public health progressed and was shared with the public through publications such as JDS, the controversy surrounding pasteurization diminished to a point where it became more broadly accepted in the late 1930s (Steele, 2000). The practice of pasteurization achieved regulatory authority in 1947, when Michigan became the first state to implement a statewide milk pasteurization law, which compelled further expansion of pasteurization from cities to rural areas. Hence, 1947 represented a major landmark in dairy food safety. Since then, all other states have adopted similar requirements, signifying recognition of the importance of pasteurization in ensuring dairy food safety. Although some states still allow the intrastate sale of raw milk, interstate sale of raw milk and raw