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One health-based strategies to ensure the microbiological safety of milk

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Abstract
Milk from different animal species provides substantial nutritional benefits but may also act as a vehicle for the transmission of pathogenic microorganisms, particularly when adequate hygienic practices are not followed. Contamination may arise from intrinsic factors, such as mastitis, or extrinsic factors, including improper handling and storage conditions. Several foodborne illnesses are associated with classical pathogens, including *Salmonella* spp., *Escherichia coli* O157:H7, *Listeria monocytogenes*, and *Staphylococcus aureus*, which can cause clinical outcomes ranging from food poisoning to severe diseases such as septicemia and meningitis. In addition, non-classical or emerging pathogens, such as *Acinetobacter* spp. and *Brucella* spp., represent increasing public health concerns. The One Health concept advocates an integrated approach involving human, animal, and environmental health to prevent and control these diseases. Measures such as effective pasteurization, animal health monitoring, and the adoption of good agricultural and manufacturing practices are essential to reduce microbiological risks associated with milk consumption. Public awareness initiatives and robust regulatory policies are also critical to ensuring milk safety.

Keywords: Zoonotic pathogens, milk safety, one health, foodborne diseases

Introduction

Milk from different animal species offers distinct health benefits due to variations in their nutritional composition, including high levels of proteins, vitamins, and essential minerals (Meng *et al*., 2021; Arrichello *et al*., 2022) [23, 4]. Milk is among the most widely consumed foods globally, across all age groups and socioeconomic classes, and its production and derivatives play a major role in the global economy. In 2023, worldwide production of milk from cows, buffaloes, goats, and sheep exceeded 900 million tons, with cow's milk accounting for approximately 81% of total production (FAO, 2023; Moraes *et al*., 2025) [10, 26]. Despite its nutritional value, milk may also serve as a vehicle for pathogenic microorganisms, particularly when appropriate hygiene practices are not observed during milking, processing, and storage (Kapoor *et al*., 2023; Farid *et al*., 2025) [16, 12]. Microbial contamination can occur through multiple routes, including the animal's udder-especially in cases of mastitis-as well as from fecal contamination, external surfaces of the udder, and inadequately sanitized equipment used during milk handling and storage (Zastempowska *et al*., 2016; Grace *et al*., 2020) [38, 15].

The relationship between milk and dairy product consumption and the transmission of classical and non-classical foodborne pathogens is of major importance for public health and underscores the need for integrated control strategies that encompass human, animal, and environmental health. This integrated framework is known as One Health, which emphasizes that human health is intrinsically linked to animal health and the surrounding environment (Wiku *et al*., 2022; Pitt & Gunn, 2024) [36, 29]. This work aims to present, in a concise manner, key zoonotic pathogens associated with milk consumption, their relevance within a One Health context, and strategies to mitigate the associated risks.

Pathogens associated with milk consumption

Classical pathogens associated with milk consumption are well recognized for their prevalence and significant impact on public health. *Salmonella* spp., pathogenic strains of *Escherichia coli* (notably *E. coli* O157:H7), *Listeria monocytogenes*, and *Staphylococcus aureus* are frequently implicated in milk- and dairy-related foodborne diseases, causing illnesses that range from mild gastrointestinal symptoms to severe conditions such as septicemia, spontaneous abortion, and meningitis (Zastempowska *et al*., 2016; Gonzales-Barron *et al*., 2017) [38, 14].

Salmonella spp. are commonly associated with foodborne outbreaks linked to the consumption of raw or inadequately pasteurized milk. Non-typhoidal salmonellosis may cause symptoms including fever, severe diarrhea, abdominal pain, headache, fatigue, and prostration, and in severe cases may progress to septicemia, particularly in immunocompromised individuals (Addis & Sisay, 2015; Williams *et al*., 2023) [1, 37].

Another pathogen of major concern is *E. coli* O157:H7, a Shiga toxin-producing strain responsible for numerous severe outbreaks of foodborne illness. Infection may lead to hemorrhagic colitis and hemolytic uremic syndrome (HUS), a potentially fatal condition that disproportionately affects children and older adults (Smith & Fratamico, 2018; Williams *et al*., 2023) [31, 37].

Listeria monocytogenes is also highly relevant in the context of milk consumption. Although listeriosis is relatively uncommon, it is associated with high hospitalization and mortality rates, particularly among pregnant women, older adults, and immunocompromised individuals. Clinical outcomes include spontaneous abortion, meningitis, and septicemia (Disson *et al*., 2021; Kayode & Okoh, 2022) [7, 17].

Staphylococcus aureus represents an additional public health risk, as it is commonly present on the skin and mucous membranes of humans and animals and is frequently detected in milk, especially from animals affected by mastitis. Food poisoning caused by *S. aureus* results from ingestion of preformed enterotoxins and is characterized by symptoms such as nausea, vomiting, and diarrhea. Importantly, both coagulase-positive and coagulase-negative staphylococci are capable of producing enterotoxins (Salamandane *et al*., 2022) [30]. These toxins are heat-stable and may persist in milk even after pasteurization, thereby posing a risk to consumers (Fisher *et al*., 2018) [13].

In addition to classical pathogens, several emerging or non-classical microorganisms have been increasingly associated with milk and dairy products. *Brucella* spp. are particularly relevant in the context of raw milk consumption. These bacteria cause brucellosis, also known as Mediterranean fever, one of the most widespread zoonoses worldwide and a significant public health concern, especially in regions such as South America. Human infection may occur through consumption of raw milk, unpasteurized dairy products, undercooked meat, or through inhalation of contaminated aerosols. Clinical manifestations include fever, myalgia, headache, back and abdominal pain, night sweats, and chills, while severe cases may progress to chronic complications such as arthritis, hepatic disorders, and meningitis (Dadar *et al*., 2020; Khurana *et al*., 2021; Ministério da Saúde, 2025) [6, 18, 24]. In Brazil, brucellosis is recognized as an occupational disease, affecting mainly meat packers, veterinarians, hunters, farmers and livestock producers, and is listed in Portaria nº 1.339/1999 of the Ministry of Health.

Bacteria of the genus *Acinetobacter* have gained increasing attention in recent years. These opportunistic pathogens are often multidrug resistant and have been isolated from milk of contaminated animals. Although traditionally associated with healthcare settings, *Acinetobacter* spp. are now recognized as potentially zoonotic organisms, with evidence suggesting that certain strains may cause gastrointestinal disease following foodborne transmission. The emergence of antimicrobial resistance in these bacteria is particularly concerning, as the inappropriate use of antibiotics in animal production may facilitate the selection of resistant strains capable of affecting both animals and humans (Malta *et al*., 2020; Elbehiry *et al*., 2021; Castillo-Ramírez, 2022; Mohamed *et al*., 2022; Mellace *et al*., 2024) [21, 9, 5, 25, 22].

The transmission of milk-associated pathogens is influenced by multiple factors, including increased consumption of raw milk and unpasteurized dairy products, the formation of biofilms by foodborne pathogens in dairy processing environments, failures in pasteurization processes, and, in some cases, the heat resistance of microbial toxins (Oliver *et al*., 2005; Ali *et al*., 2022) [27, 2].

One Health and One Welfare: risks and mitigation strategies

The concepts of One Health and One Welfare recognize the interconnectedness of human, animal, and environmental health (FAO, 2025) [11]. One Health emphasizes the biological and social links among these domains, while One Welfare expands this framework to include animal, human, and environmental well-being (Pinillos *et al*., 2018; Stephens, 2021; Leeuw *et al*., 2024; Doyle *et al*., 2025; FAO, 2025) [28, 32, 19, 8, 11]. According to the World Organisation for Animal Health (WOAH, 2019) [35], animal welfare encompasses the physical and mental state of an animal throughout its life and at the time of death. Scientific evidence supports a multidimensional approach to animal welfare, recognizing that societal expectations increasingly extend beyond physical health alone to include behavioral and emotional aspects, reflecting both societal expectations and ethical considerations (Alonso *et al*., 2020; Vigors *et al*., 2021; Lemma *et al*., 2022) [3, 33, 20].

Farm animals have specific welfare requirements which, when adequately met, can improve their quality of life, extend their productive lifespan, and enhance their contributions to humans and the environment. Although closely related, animal welfare and animal health are not synonymous: good health cannot be achieved without adequate welfare, yet welfare alone does not guarantee the absence of disease (FAO, 2025) [11].

Contemporary understanding of animal welfare is frequently framed by the “Five Domains” model, which integrates nutritional, environmental, health, and behavioral factors with the animals’ mental and emotional states. Ensuring adequate resources and care across these domains is essential not only for animal welfare but also for the production of safe and high-quality milk (FAO, 2025) [11].

From a One Health perspective, milk safety requires coordinated actions across animal health and welfare, environmental management, and human practices and public policies (Wiku *et al*., 2022; FAO, 2025) [36, 11]. As illustrated in Figure 1, these strategies are interdependent, and interventions at one level directly influence outcomes in the others.

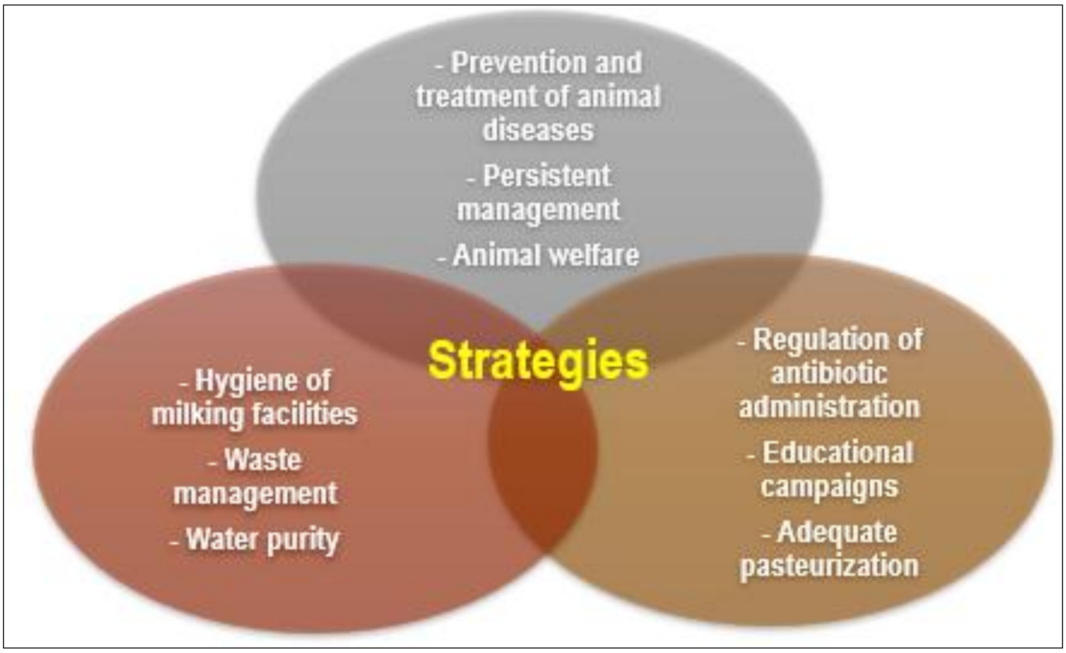

Fig 1: Strategies based on the perspective of the One Health concept to ensure the microbiological safety of milk.

At the animal health and welfare level, preventive herd management and welfare-oriented practices are central risk mitigation strategies. Regular veterinary monitoring, vaccination programs, and early detection and control of diseases such as mastitis and brucellosis reduce pathogen shedding and milk contamination (Wiku *et al*., 2022; FAO, 2025) [36, 11]. Adequate nutrition, housing, thermal comfort, and gentle handling further support immune function and reduce physiological stress, contributing to lower disease incidence and decreased reliance on antimicrobials (WOAH, 2019; Alonso *et al*., 2020; Lemma *et al*., 2022; Vigors *et al*., 2021) [35, 3, 20, 33].

The environmental domain focuses on minimizing microbial contamination from the production environment through hygienic milking facilities, routine cleaning and disinfection of equipment, effective manure and effluent management, and access to clean water. These measures limit pathogen circulation between animals, equipment, and the surrounding environment and reduce environmental dissemination of microorganisms and antimicrobial residues (Wiku *et al*., 2022; FAO, 2025; Zhang *et al*., 2024) [36, 11, 39].

The human and policy-related domain bridges farm-level practices with public health outcomes. Training farm workers in good milking practices, hygiene, and biosecurity reduces cross-contamination during milk handling (FAO, 2025) [11]. At the population level, public policies promoting milk pasteurization, regulating antimicrobial use in animal production, and supporting surveillance and educational campaigns on the risks associated with raw milk consumption are essential to prevent foodborne disease outbreaks and protect consumers (Kapoor *et al*., 2023; Zhang *et al*., 2024; Farid *et al*., 2025) [16, 39, 12].

Conclusion

Milk safety cannot be achieved through isolated interventions. The interconnectedness among the different domains of health highlights the importance of adopting an integrated approach to address issues related to milk consumption and the transmission of foodborne pathogens. Cooperation among human, veterinary, and environmental health sectors is essential for the development of effective public policies and safer production practices. Such integrated actions are fundamental to ensuring milk quality, reducing microbiological risks, and contributing to the prevention of zoonotic and foodborne diseases.

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