# Zoonosis in the Food Chain

27

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## ABSTRACT

This book chapter examines the complex relationship between the worldwide food supply chain and the transmission of diseases, with a particular emphasis on zoonotic pathogens. During the latter part of the 20th century, there was a significant growth in global interdependence due to the movement of people and goods across borders. This resulted in a higher risk of the worldwide spread of biological threats. Globally, outbreaks of foodborne diseases have extensive social and economic consequences, impacting food consumption patterns and behavior. The chapter explores foodborne pathogens, classifying diseases caused by bacteria, viruses, and parasites. The chapter delineates the origins of zoonotic infections, with particular emphasis on manure, animal feed, and milk as noteworthy contributors. Manure presents a significant hazard of contaminating crops and pastures. Animal feed can act as a reservoir for zoonotic infections. The popularity of consuming raw milk is increasing; however, it poses health hazards due to the presence of potentially harmful microbes. Proposed are mitigation measures to effectively manage zoonotic illnesses within the food chain. These measures encompass international cooperation, monitoring, and timely identification; embracing a holistic approach to health; advocating for public awareness; enforcing strict protocols to prevent the spread of disease on farms, implementing responsible antibiotic usage; ensuring cleanliness and sanitation in food production; enforcing stringent food safety regulations; and implementing effective strategies for wildlife management. To Conclude, the chapter highlights the urgent requirement for a comprehensive and cooperative strategy to reduce the dangers linked to zoonotic pathogens in the worldwide food supply network. It stresses the significance of international collaboration, research, and proactive actions to guarantee the safety and welfare of both animals and humans.

**Keywords:** Zoonotic pathogens, Foodborne diseases, Global food supply, Biosecurity, Mitigation strategies, One Health approach, Antibiotic control, Manure contamination, Food safety, International collaboration

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## 1. INTRODUCTION

### GLOBAL FOOD SUPPLY AND DISEASE SPREAD

During the latter half of the 20th century, the globalized political economy witnessed a notable social, political, and economic interdependence rise (Cork and Checkley 2011). The swift cross-border movement of individuals, goods, and other commodities primarily drove this phenomenon. One of the outcomes resulting from the escalation of trade, travel, and migration is the increasing potential for the widespread transmission of biological and other dangers across different countries (Smith and Kelly 2008). The increasing interconnectedness of global populations has facilitated the rapid spread of novel and emerging diseases, making their containment and management challenging. The rise of global trade commodities and the emergence of transnational corporations (TNCs) have coincided with a surge in foodborne illnesses across national borders (King et al. 2004).

Worldwide foodborne disease outbreaks have significant social and economic consequences, influencing food and behavioral patterns (Quested et al. 2010). Over the last few decades, industrialized nations' foodborne disease reporting systems have improved a lot. Food safety awareness has increased due to improved pathogen detection and the ability to trace diseases to specific food products (Wilcock et al. 2004). Furthermore, novel infections have emerged that align with the evolving food supply, a rise in the population of individuals with increased vulnerability to foodborne illnesses, and a more comprehensive range of food preparation methods and dietary preferences. The circumstances mentioned above have presented several difficulties for veterinarians, and organizations focusing on public health (Lusk and McCluskey 2018). In addition to these modifications, the global economy has enabled rapid transportation of consumable food items, hence augmenting the likelihood of novel populations being subjected to foodborne infections commonly found in remote regions of the globe (Gargiulo et al. 2022). Biosecurity and pathogens should be checked on the farm where food production starts (Youssef et al. 2021).

From production to packaging, food can be contaminated before it reaches consumers. Advanced food processing facilities are vast and consolidated compared to modest family-run operations that supply food locally. Consolidation of the food-producing sector has been driven by economic forces in many countries (Cardwell et al. 2016).

The increasing prevalence of middle-class households in numerous nations has led to a growing preference for takeaway food (Burgoine et al. 2014). There is a correlation between this phenomenon and a rise in foodborne illnesses, particularly in fast-food establishments and restaurants that exhibit inadequate food handling practices and hygiene. Certain countries are experiencing a rise in the elderly population due to decreasing birth and death rates. Consequently, a significant portion of this demographic has pre-existing medical conditions. Advancements in medical treatments have contributed to the increased life expectancy of infants, pregnant women, individuals with compromised immune systems, and aging populations. Healthcare professionals should be knowledgeable about the potential risks related to feedstuffs and adhere to safe meal preparation methods (Kelly and Marshak 2009).

## 2. FOOD PATHOGENS

### 2.1. BACTERIAL DISEASES

Foodborne pathogens refer to microorganisms that have the potential to induce illness when ingested along with food. The predominant causative agents in question are bacteria, although they may also encompass viral, parasitic, and fungal entities. Locality, food preparation, poor hygiene, limited access to clean water, and lack of community education are primary epidemiological factors (Allard et al. 2018). The following are several often-observed bacterial foodborne diseases (Table 1).

*L. monocytogenes* is a Gram-positive facultative pathogen that can cause severe problems in pregnant women, infants, the elderly, and immune-compromised individuals. The disease is categorized into high, medium, and low-risk foods. Non-pathogenic *E.coli* is categorized into serotypes according to the presence of virulence genes (Wilcox 2018). Vero toxic *E. coli* (VTEC) is a bacterial group that can lead to multiple human diseases, such as gastroenteritis, dysentery, urinary tract infections, sepsis, pneumonia, and meningitis (Karmali et al., 2003). Salmonella, a Gram-negative bacterium, is frequently present in the gastrointestinal tracts of reptiles, birds, wildlife, farm animals, and humans. *Salmonella enterica* serovar *Choleraesuis, Salmonella dublin, Choleraesuis,* and *Arizonae* are frequently implicated in foodborne salmonella outbreaks in Europe (Dos Santos et al. 2019).

**Table 1:** Various bacteria, their contamination sources, and associated symptoms.

| Bacteria | Source of Contamination | Symptoms | References |
|---|---|---|---|
| *Escherichia* (*E.*) *coli* (many variants) | Meats and vegetables washed in contaminated water | Gastroenteritis, significant systemic signs | (Orth et al. 2008) |
| *Campylobacter spp.* | Contaminated meats | Gastroenteritis, fever, and other systemic signs | (Hermans et al. 2012) |
| *Brucella spp.* | Milk and milk products from infected ruminants | Undulant fever, body and headaches which may become chronic | (El-Diasty et al. 2018) |
| *Vibrio spp.* | Contaminated water and food, shellfish and salads | Gastroenteritis, fever, vomiting | (Baker-Austin et al. 2018) |
| *Salmonella spp.* | Meats and vegetables rinsed in contaminated water | Gastroenteritis, fever, and other systemic signs | (Hurley et al. 2014) |
| *Listeria monocytogenes* | Contaminated shellfish, chilled meats, and salads | Gastroenteritis with other systemic signs | (Stavru et al. 2011) |
| *Staphylococcus aureus* | Food contaminated with toxin | Gastroenteritis may have other systemic signs | (Haag et al. 2019) |
| *Shigella* | Contaminated food; primates and humans the key hosts | Gastroenteritis with blood in feces | (Jennison and Verma 2004) |
| *Mycobacterium avium paratuberculosis* | Contaminated milk | Bowel disease and Crohn's disease | (Kennedy and Benedictus 2001) |
| *Bacillus cereus* | Reheated food, especially rice | Gastroenteritis | (Bottone 2010) |
| *Yersinia enterocolitica* | Contaminated meats | Gastroenteritis with other systemic signs | (Galindo et al. 2011) |
| *Clostridium perfringens* | Insufficiently cooked meat or reheated food | Gastroenteritis with other systemic signs | (Freedman et al. 2016) |
| *Leptospira – various serovars* | Humans are typically infected through direct contact with infected animals' urine or contaminated food or water consumption | Variable including diarrhea, fever, vomiting, myalgia, abdominal pain, and jaundice | (Zuerner et al. 2009) |
| *Mycobacterium bovis* | Contaminated milk | Lymph gland enlargement and localized or systemic signs | (Phillips et al. 2003) |
| *Clostridium difficile* | Contaminated ground beef, pork or turkey | Mild gastrointestinal signs associated with toxin | (Vonberg et al. 2008) |
| *Yersinia pseudotuberculosis* | Contaminated meat and vegetation | Gastroenteritis, appendicitis and systemic signs | (Galindo et al. 2011) |
| *Coxiella burnetii* | Contaminated milk products | Fever, systemic signs such as nausea, headache, and myalgia | (Kazar 2005) |

Campylobacter spp. is a significant cause of human foodborne illness, accounting for 14.2% of reported cases from 1998 to 2002 in the United States (Bhunia 2018). The primary reservoirs for Campylobacter spp. include leporids, birds, ovine, canines, bovines, poultry, and domestic pets. Risk assessments have been employed to identify the origin of human infections, and it has been found that contaminated chicken meat is the primary source of foodborne *Campylobacter jejuni* infection. *Yersinia enterocolitica* is a zoonotic ailment caused by *Coxiella burnetii*, which is frequently present in the gastrointestinal tract of both healthy and diseased birds and mammals. It causes approximately 87,000 cases of gastroenteritis each year (Riahi et al. 2021). Yersinia is categorized into five groups according to their pathogenicity, ecological factors, and geographical distribution. Although the disease typically resolves on its own, there have been rare instances where septicemia and mortality have been documented. The prevention of Yersinia necessitates the purification of dairy products and thorough gastronomic of meat, particularly pork (Tauxe 2019).

Q fever, also known as "query fever," is a globally prevalent zoonotic disease caused by *Coxiella burnetii* (Angelakis and Raoult, 2010). The primary mode of infection in humans is through the inhalation of aerosols that contain dried placenta, secretions, and feces from infected livestock. Q fever primarily affects individuals in occupational fields such as farming, abattoir work, veterinary practice, and laboratory work (Clark et al. 2018).

Common symptoms of brucellosis include profuse sweating, splenomegaly, cough, and pleuritic chest pain. Gastrointestinal symptoms encompass reduced appetite, nausea, vomiting, diarrhea, and constipation (Dadar et al. 2019). Symptoms typically last for a duration of 2 to 4 weeks and resolve without the need for intervention. Brucella spp., such as *B. melitensis*, pose a food security concern in Mediterranean areas (Aliyev et al. 2022). Standardized animal health and public health programs are more prevalent in certain countries (Antunes et al. 2020).

## 2.2. VIRAL DISEASES

Foodborne viral diseases can have long-lasting persistence in the environment, facilitating transmission to susceptible hosts (Velebit et al. 2019). The primary modes of transmission for the most prevalent human viruses are through water contamination, consumption of contaminated drinking water, ingestion of shellfish, and consumption of fresh fruits and vegetables. Zoonotic viruses may be transmitted through meat that is infected or contaminated. In the United States, the majority (66.6%) of foodborne illnesses are caused by viruses, while *Salmonella* and *Campylobacter* account for 9.7% and 14.2%, respectively (Fleet et al. 2000). Some human viral pathogens which are recently discovered, may have originated from animals, and there is still limited understanding of the epidemiology of these viruses. The presence of water and foodborne viruses, such as Enteroviruses, Adenoviruses, Hepatitis Ab, Hepatitis E, Astroviruses, Rotaviruses, and Norwalk-like viruses (noroviruses), may result in the development of gastroenteritis and systemic symptoms (Table 2).

Enteroviruses constitute a collection of viruses that are commonly disseminated by water sources that have been contaminated, as well as through the ingestion of food that has been tainted. The microbes can induce gastroenteritis, a condition marked by inflammation of the gastrointestinal tract that manifests through symptoms such as diarrhea, vomiting, and abdominal pain. Moreover, Enteroviruses can induce systemic symptoms, consequently impacting several organs and systems inside the human body. Adenoviruses, akin to Enteroviruses, have the potential to be transferred via water that has been contaminated, hence leading to the manifestation of gastroenteritis. In certain instances, patients may also manifest respiratory symptoms, such as wheezing or respiratory infection, alongside gastrointestinal problems. This virus can be transmitted by ingesting water and food that has been infected, with a specific focus on crustaceans. This pathological state gives rise to hepatic inflammation, resulting in the clinical

manifestation known as hepatitis. The manifestation of the illness may occur without jaundice, a condition distinguished by the coloring of the skin and eyes. The primary mode of transmission for Hepatitis E is through the ingestion of contaminated food, with a particular emphasis on the intake of raw pig and deer meat. Hepatitis E induces a clinical presentation resembling Hepatitis A, though with a notable absence of jaundice in many cases (Koopmans et al. 2002).
Astroviruses spread via ingesting water and food that has been infected, with a particular emphasis on crustaceans. The incidence of gastroenteritis is attributed to the causal agents, which manifest symptoms such as diarrhea accompanied by mucus, vomiting, and a reduced appetite, sometimes referred to as anorexia. Rotaviruses possess the ability to be transmitted via water and food that have been polluted. Noroviruses are commonly linked to gastroenteritis, especially in young infants, and present with vomiting symptoms and diarrhea episodes. The subject of discussion pertains to Norwalk-like viruses, which are alternatively referred to as noroviruses. Noroviruses are mainly spread via ingesting contaminated water and food. These are widely recognized for their inclination to induce gastroenteritis outbreaks in settings characterized by limited space or high population density, such as cruise ships and healthcare institutions.

**Table 2:** Various Viruses, their contamination sources, and associated symptoms

| Virus | Transmission Route | Symptoms | References |
|---|---|---|---|
| Enteroviruses | Contaminated water | Gastroenteritis and systemic signs | (Sinclair and Omar 2022) |
| Norwalk-like viruses (noroviruses) | Contaminated water and food, including shellfish | Gastroenteritis with vomiting, diarrhea, and abdominal pain | (Marks et al., 2000) |
| Hepatitis A-B | Contaminated water and food | Hepatitis with or without jaundice | (Maddrey 2000) |
| Astroviruses | Contaminated water and food, including shellfish | Gastroenteritis with watery diarrhea, vomiting and anorexia | (Kurtz and Lee 2007) |
| Hepatitis E | Contaminated food, including pork and venison | Hepatitis, often without jaundice | (Krawczynski et al. 2000) |
| Rotaviruses | Contaminated water and food | Gastroenteritis with vomiting and diarrhea | (Cook et al. 2004) |
| Adenoviruses | Contaminated water | Gastroenteritis may have respiratory signs | (Lynch III and Kajon 2021) |

The infection elicits symptoms characterized by severe emesis, episodes of diarrhea, and abdominal discomfort (Iturriza-Gomara and O'Brien, 2016).

## 2.3. PARASITIC DISEASES

Including over three hundred species of parasitic helminth and more than seventy species of protozoans, parasitic diseases transmitted through food pose a significant threat to human health (Torgerson et al. 2014). Parasites have had a symbiotic relationship with humans, and they are typically transmitted through food and water. The mode of environmental transmission plays a crucial role in the epidemiology of numerous protozoa and helminths, making the epidemiology of parasitic diseases complex (Chávez-Ruvalcaba et al. 2021). Important environmental factors include appropriate humidity, temperature, food and water availability, and favorable soil and vegetation. The capacity of parasites to generate multiple infectious stages and their environmental resilience pose a significant threat to human health and regulatory agencies. Geographic variations in the prevalence of parasites in the food supply are influenced by the consumption of fresh or undercooked foods (Torgerson et al. 2015).
Human or animal excreta frequently contaminates freshwater sources with protozoa. In addition, they are present on fruits and vegetables rinsed in contaminated water (Fayer et al. 2004). Some protozoa are also transmissible via direct contact with or consumption of fresh meat. The clinical pathology of human

protozoan diseases is influenced by several variables, such as the level of exposure, parasite virulence, host immunity, and the presence of concurrent infections caused by bacteria, viruses, and other protozoa (Omarova et al. 2018). As a large proportion of the population has been unprotected to Toxoplasma cysts, but only a minority exhibit obvious symptoms of contamination, the clinical presentation of these individuals differs considerably. Foodborne infections such as Giardiasis, Cryptosporidiosis, Cyclosporiasis, Sarcocystosis, and Amebiasis can cause severe gastrointestinal complications. Giardia cysts are found in surface water and the feces of fauna, whereas *Cryptosporidium parvum* is typically found in cider, unpasteurized milk, and contaminated wastewater (Fletcher et al. 2012). *C. cayetensis* is endemic in a variety of developing countries and is transmitted via the fecal-oral route. Sarcocystis is a significant human pathogen, observed predominantly in Asia with few reported cases. *Entamoeba* (*E.*) *histolytica* is a significant agent in the etiology of gastroenteritis pathogens in tropical and subtropical regions, as well as a notable human pathogen (Mortimer and Chadee 2010). *E. histolytica* is another important source of mortality in humans, affecting approximately 50 million people worldwide. Annually, between 40,000 to 100,000 fatalities are attributed to this infection's complications. It is recommended to cook completely wild game meat and pork. Trichinellosis and Diphtheria are just a few of the health, social, and economic concerns of parasites. Trichinellosis is a parasitic infection caused by the consumption of raw or undercooked flesh containing the larvae of Trichinella and its related species. Commonly, both wild carnivores and domestic dogs are infected. Meat can be cooked properly or frozen at -15°C or lower for at least 20 days to prevent contamination (Zhou et al. 2008).

The cestodes capable of infecting humans encompass *Taenia solium, Taenia saginata, Diphyllobothrium latum, Hymenolepis nana, Echinococcus granulosus, and Echinococcus multilocularis*. The global distribution of *T. saginata* encompasses several regions, yet there is a notable disparity in the prevalence of human infection, with poorer countries exhibiting greater rates (Dorny et al. 2009).

The canine parasite *Diphyllobothrium latum* can infect both humans and animals through its transmission via crustaceans and freshwater fish (Amissah-Reynolds et al. 2016). The parasite is transmitted to humans through the consumption of raw fish, but it frequently does not cause any symptoms in humans or other primary hosts. The hydatid cyst caused by *Echinococcus spp*., is a parasitic organism that primarily infects canines. However, it can also infect humans and other animals that inadvertently consume tapeworm eggs present in the feces of the host. Cysticercosis is caused by two primary cestodes: *E. granulosus*, which leads to the development of "cystic" ailment, and *E. multilocularis*, which bases "alveolar" ailment (Chhabra and Singla 2009). The estimated occurrence of *D. latum* infection in the United States is no more than 0.5%. However, recent epidemics have been linked to the accessibility of fresh salmon and the consumption of raw fish (Fried and Abruzzi 2010). Flukes exhibit a life cycle that necessitates the involvement of one or two intermediate hosts. Foodborne trematodes infection pose a growing public health concern in Southeast Asia and the Western Pacific region. Human fascioliasis is a significant emerging disease primarily transmitted through the ingestion of infectious forms found in plants, particularly watercress. Fish borne Zoonotic Trematodes (FZT) can pose significant health risks to humans, particularly when transmitted through the consumption of raw or undercooked fish that have been cultivated on fish farms (Toledo et al. 2012).

To prevent human infection, it is imperative to implement effective educational initiatives, conduct thorough testing of beef and pork products, adhere to proper cooking techniques, and promote hygiene habits.

## 3. SOURCE OF ZOONOTIC PATHOGENS

The common sources of zoonotic pathogens have been shown in Fig. 1.

### 3.1. MANURE

Manure, a mixture of livestock excreta and bedding materials, is a significant source of contamination for crops and pastures. Diseases that are connected with organisms that can be contracted through manure primarily spread through the fecal-oral pathway and present as gastrointestinal illnesses. More than 100 zoonotic pathogens have been documented to impact humans by entering the food chain (Khan et al. 2020). Despite the considerable array of zoonotic pathogens that possess the capacity to induce illness in human beings, the overwhelming majority of diseases can be attributed to a limited number of species. Manure can contaminate water sources accessed by humans through leaching, runoff, and thawing snow. This contaminated water contains pathogenic microorganisms, which can lead to human morbidity (Chen et al. 2018). Control measures can be implemented at various stages of animal and plant production to prevent zoonotic infections transmitted through feces (Ghasemzadeh and Namazi 2015). These measures should reduce the pathogen burden within the host animal, which can reduce productivity. Preventing environmental contamination mitigates the potential for reinfection of livestock and human diseases resulting from the transmission of plant or waterborne pathogens. Fertilizer management systems,

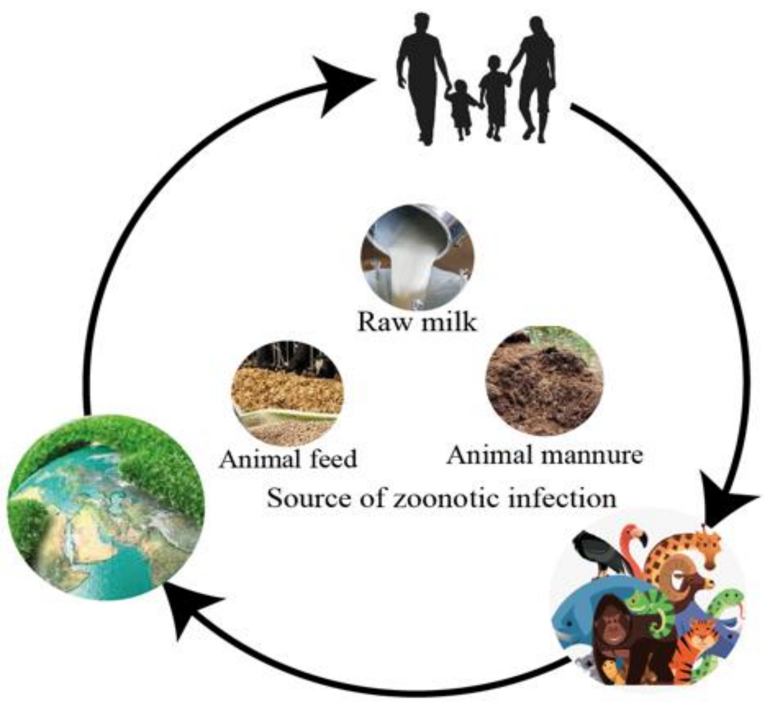


**Fig. 1:** Common sources of zoonotic pathogens.

including composting and various treatment methods such as physical, chemical, and biological approaches, have the potential to mitigate environmental pollution. Applying appropriate irrigation and soil management techniques can mitigate the potential for contamination in fruit and vegetable crops. Food processors should adopt risk mitigation measures to minimize the likelihood of fecal contamination in their products (Bosch et al. 2018).

### 3.2. ANIMAL FEED

The feed industry plays a crucial role in the agricultural supply chain and sustainability by providing essential ingredients, including forage, grains, meals, fats, oils, minerals, vitamins, and by-products, sourced from developing countries. However, it also possesses the capacity to isolate, intensify, and recycle zoonotic pathogens, while redistributing significant amounts of heavy metals and other potentially harmful substances. (Martinez et al. 2009). Feed production in developed countries is estimated to be around 420 million tons annually, indicating significant growth and complexity in the industry.

Feed ingredient contamination poses a greater risk compared to other risks, and animal feedstuff serves as a notable reservoir of zoonotic etiologies, including Salmonella spp., which can endure in arid conditions. Oilseeds, animal feed, cooked plants, and feed mills are common sources of this substance (Gaggìa et al. 2010). The heat treatment employed in animal protein feeds effectively eliminates the organism, but subsequent meals become contaminated following the heating process. *Salmonella* can persist on greasy surfaces and floors, become airborne in factory dust, and subsequently contaminate flour during the cooling process. *E. coli* O157:H7 and *Salmonella* are frequently present in compound feed mills (Davis et al. 2003).Feed decontamination is a significant issue in the European Union (EU) due to the requirement that all feed must undergo testing for *Salmonella* and be confirmed negative before being transported to farms (Okojie and Isah 2014). The feed industry in Europe does not consider the presence of *Salmonella* in feed to pose a substantial risk to human health. The EU has implemented a ban on the use of subtherapeutic antibiotics in animal feed, reflecting the complexity surrounding the use of antibiotics in this context. The administration of residual drugs in animal feed can come up with the emergence of drug resistance and a decline in antibiotic-susceptible pathogens (Heinzerling 2012). In North America, the utilization of antibiotics in livestock production is primarily motivated by economic advantages and improved operational effectiveness. The cessation of using antibiotics as growth promoters may result in increased antibiotic usage for treating animals, which could lead to a higher incidence of clinical conditions in livestock and poultry.

### 3.3. MILK

The consumption of unprocessed, unpasteurized milk has increased significantly. Raw milk's growing prevalence can be attributed to its improved nutritional value, enhanced flavor, potential health welfare, rising petition for inherent and raw foodstuffs, and the desire for personal autonomy. However, it is essential to recognize that additional extensive scientific evidence is necessary to support these claims completely (Angulo et al. 2009). Milk and dairy products are essential to a healthy diet, but consuming them unpasteurized can pose health risks due to potentially hazardous microorganisms. People continue to consume raw milk despite the well-documented presence of numerous microorganisms, some of which have been linked to human illness. In the context of allowing the sale of raw milk, it is essential to establish safeguards against the potential risks associated with raw milk consumption and its derivatives. Establishing regulatory standards, such as microbiological criteria, for unprocessed milk intended for human consumption is one method for addressing this issue. Additionally, implementation of whole milk labeling requirements could be considered (Papademas and Bintsis 2010).

Furthermore, it is possible to enhance hygienic practices during the milking process and implement educational programs targeting both producers and consumers. Implementing on-farm pre- and post-harvest control techniques is crucial for effectively reducing microbial contamination in raw milk, which in turn contributes to overall pathogen control (Oliveira et al. 2011). The International Dairy Foods Association and the National Federation of Dairy Producers endorse a legal requirement for all establishments producing raw or unpasteurized dairy products for human consumption to be registered with the United States Food and Drug Administration (FDA). Furthermore, these facilities must adhere to food safety regulations, similar to other establishments engaged in the production of dairy products.

Liability is a significant aspect that merits attention from both raw milk manufacturers and consumers. Dairy manufacturers must possess comprehensive knowledge regarding the potential risks and legal responsibilities associated with the distribution of raw milk to consumers. Customers getting un-processed milk must acknowledge the vital hazards and limited legal protections in case of illness caused by consuming contaminated raw milk infection. Until comprehensive investigations are carried out, the most effective approach to mitigate the risk of foodborne illnesses related to raw milk is to refrain from consuming un-processed milk and dairy harvests through un-processed milk.
Through consistent measures, the safety and purity of dairy products are ensured from the farm to the processing plant. Transforming low-quality un-processed milk into a higher-quality milk product is likely simpler. Dairy producers must implement production practices to reduce mastitis and microbial contamination in bulk milk to meet stringent raw milk quality standards (Lemma et al. 2018). Reducing raw milk contamination, implementing effective management practices, and establishing mastitis control strategies can aid dairy producers in achieving significant objectives. This. It is essential to recognize that using these techniques does not eliminate the possibility of pathogens in raw milk and the associated dangers of milk-borne illnesses (Zeinhom and Abdel-Latef 2014).

## 4. MITIGATION STRATEGIES

The effective management of zoonotic diseases on a global scale necessitates a high degree of international collaboration. Promoting international collaboration in disease surveillance and response endeavors mitigates cross-border transmission and enhances the effectiveness of coordinated outbreak responses (Jebara 2004).
Within the food chain context, diverse tactics for mitigating zoonotic diseases exist, which encompass a range of interventions designed to impede the transfer of infectious ailments from animals to people. The significance of surveillance and timely detection in identifying possible threats at an early stage must be considered. This includes implementing a complete surveillance system aimed at monitoring zoonotic illnesses in animals and installing reporting procedures that facilitate the identification of unusual disease patterns in both animal and human populations. The allocation of resources towards research and testing facilities plays a crucial role in expediting the detection of emerging zoonotic infections, thereby enabling a proactive approach to addressing these threats.
Adopting a One Health approach is essential to successfully treat zoonotic illnesses inside the food chain (Rossow et al. 2020). The facilitation of collaboration between the human health, veterinary, and environmental sectors is crucial in fostering the development of complete solutions. The exchange of information and collaboration across pertinent authorities and groups enhances a cohesive and efficient response (Webster et al. 2016). Education and public knowledge play a vital role in mitigating zoonotic dangers. Raising consumer awareness of zoonotic diseases and the importance of proper food handling and cooking techniques can contribute to mitigating disease transmission. Furthermore, increasing awareness among healthcare workers expedites the process of identifying and reporting suspected cases of zoonotic diseases (Monath et al. 2010).
To avoid introducing and spreading infectious pathogens, farms, and animal production facilities must adopt and enforce rigorous biosecurity protocols. It is imperative to limit access exclusively to individuals who have been granted authorization while ensuring regular animal health monitoring. The prompt implementation of isolating and treating unwell animals further diminishes the probability of disease spread (Collins and Wall 2004).
Antibiotic control practices are essential in mitigating zoonotic diseases within the food chain. Promoting safe antibiotic usage in animals is crucial in mitigating the transmission of antibiotic-resistant

microorganisms to humans. In contrast, promoting non-antibiotic interventions, such as probiotics and vaccines, safeguards animal health by mitigating the emergence and proliferation of antibiotic resistance (Gwenzi et al. 2022).

Ensuring stringent levels of cleanliness and sanitation are upheld throughout the food production process is of utmost importance. This entails implementing rigorous hygienic measures during the processing and handling of animal products to mitigate the risk of contamination. The use of routine cleaning and sanitation practices for equipment and facilities in slaughterhouses, processing plants, and vehicles further mitigates the potential for cross-contamination (Lam et al. 2013). The implementation of rigorous food safety rules is crucial to mitigate the risk of zoonotic infections. Implementing routine inspections and audits in food production facilities significantly ensures compliance with safety regulations. The implementation of traceability systems for monitoring the provenance of food products facilitates prompt recalls in the event of outbreaks, effectively mitigating the transmission of zoonotic illnesses.

Preventing zoonotic illnesses necessitates implementing effective wildlife management strategies, given that numerous viruses have their origins in wildlife populations. Implementing policies aimed at managing and controlling zoonotic diseases in wildlife and monitoring and regulating wildlife trade and migration can contribute to the mitigation of disease transmission to human populations (Shiferaw et al. 2017).

## CONCLUSION

The allocation of resources toward research and innovation is pivotal in advancing efficient solutions for preventing and controlling zoonotic diseases. The comprehension of the ecological aspects and transmission routes of zoonotic diseases plays a crucial role in formulating and implementing precise therapies. Furthermore, assisting in advancing novel diagnostic instruments, vaccines, and treatments enhances our ability to address zoonotic illnesses efficiently, safeguarding the well-being of animals and humans across the entire food production process.

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