Chapter

Emerging Infectious Food System Related Zoonotic Foodborne Disease – A Threat to Global Food Safety and Nutrition Security

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Abstract

The zoonotic potential of foodborne infections, as well as their capacity to secrete toxins that cause a threat to global food safety and nutrition security and is enough to highlight the gravity of the problem. Feeding the estimated world population of 8.4–8.7 billion, 9.4–10.2 billion, and 11 billion people by 2030, 2050, and 2100, respectively, will require significant increases in crop and animal production, which will increase the agricultural use of antibiotics, water and pesticides and fertilisers, and contact between humans, wild and domestic animals, all of which will have implications for the emergence and spread of infectious agents. Hence, Infectious foodborne zoonotic illnesses are spreading at an unprecedented rate over the world. The evidence that animals are carriers of foodborne diseases is examined in this chapter. The processes through which infectious foodborne zoonosis impacts the global food and nutrition security, as well as how human infectious illnesses may affect food production and distribution are synthesised. The need for agricultural and disease management and policy activities, as well as a review of recent research on novel detection and control techniques in addressing the public health threat posed by foodborne Zoonotic illness, is also addressed.

Keywords: food safety, nutrition, foodborne infectious diseases, zoonosis, one health, emerging zoonotic disease, climate change, food system, animal health

1. Introduction

Agrifood systems cover the various dynamic and interconnected phases of agricultural production, processing, distribution, and consumption, with each phase including a variety of processes, value chains, numerous players, and their interactions [1]. In order to combat poverty, defend human rights, and restore ecosystems, the UN 2030 Agenda for Sustainable Development emphasises the importance of resilient agricultural methods and sustainable food production systems. A key component of such a system is food safety [1].

Foodborne zoonosis is an infectious disease brought on by consuming contaminated animal products. As a result, many bacteria, parasites and viruses that infect humans are present in vertebrate animals and are being spread through food on a regular basis. Foodborne bacterial infections have emerged long time ago and not related to environmental changes but other things related with food production and conservation. Environmental changes can be the cause of the appearance of new pathogens (emerging) coupled with increasing human susceptibility to sickness. The fight against foodborne bacterial diseases faces new challenges as a result of the constantly evolving human consumption patterns, the globalisation of the food industry, and climate change. Hence, infectious illnesses are emerging at an unprecedented rate, with serious consequences for the global economy and public health [2]. As a result, the social and economic aspects are of great importance. The social and environmental circumstances that contribute to the onset of illnesses, as well as management techniques that might lower the risk of emergence or recurrence, are of special interest [3, 4]. Malnutrition, defined as an insufficient intake of one or more nutrients, continues to be a major cause of disease globally [5]. Together, the extraordinary rate of infectious disease incidence and the need to feed the world population sustainably are two of the most daunting environmental and public health concerns of the twenty-first century [6], and they interact in complicated ways [4]. Access to safe, adequate, and nutritious food is an unquestionable human right [7, 8] and is critical for good health. A safe food supply benefits a country's economy, trade, and tourism, as well as food and nutrition security and sustainable development [9].

Emerging zoonotic diseases are those that are novel to human populations or that existed previously but are currently quickly growing in incidence or geographic range [10]. Fortunately, most of these infections are not fatal, and they do not spread widely. Some new illnesses, on the other hand, are having a significant influence. Ebola, HIV/AIDS, and, most recently, COVID-19 are well-known examples of new zoonoses that are especially harmful to human health and the economy [10]. Zoonoses have the potential to produce worldwide pandemics; historically, large-scale zoonotic epidemics resulting in high numbers of deaths caused major economic, political, and societal upheaval [11, 12]. People's interactions, both as merchants and consumers; the sale of live animals; food goods, especially ready-to-eat meals; and wild and peridomestic animals are all key risk factors for developing infectious illnesses [11]. These illnesses can be transmitted from animals to people if there is a barrier that permits infections to cross species, such as on a farm or at a market. Recent coronavirus (CoV) and avian influenza virus (AIV) outbreaks have convincingly proven that these emerging animal-borne zoonotic illnesses might constitute a hazard to human health [11, 13].

In the EU each year there are more than 200,000 cases of Campylobacteriosis and more than 50,000 of Salmonellosis. According to EFSA [14] report, "campylobacteriosis and salmonellosis were respectively the first and second most reported zoonoses in humans in 2020. Yersiniosis was the third most reported zoonosis in humans, with 10-foldless cases reported than salmonellosis, followed by Shiga toxin-producing *Escherichia coli* (STEC) and *Listeria monocytogenes* infections. Illnesses caused by *L. monocytogenes* and West Nile virus infections were the most severe zoonotic diseases with the highest case fatality". In India, animal products are responsible for around 70% of foodborne diseases [15]. The three types of foodborne diseases are intoxification (a toxin produced by pathogens that cause foodborne illness), infection (ingestion of pathogen-containing food), and toxicoinfections (production of toxins during growth in the human gut) [16–18]. Human-animal infections can be spread by direct touch, indirect environmental contact, and/or food intake [19]. Approximately 60% of human illnesses are caused by animals, and approximately 75% of emerging human infectious diseases are passed from vertebrates to humans [20].

Many viruses that cause human illness after being transferred through food are naturally found in vertebrate animals [21]. Humans are exposed to pathogenic bacteria through three different food sources: meat (beef, mutton, and pork), dairy (milk, cheese, yoghurt, and ice cream), and eggs [22]. Environmental difficulties have resulted in the emergence of foodborne bacterial pathogens and increased human vulnerability to illness [23]. Due to rapidly changing human consumption habits, food market globalisation, and climate change, the battle against foodborne bacterial infections confronts new problems [16, 24]. The purpose of this chapter focuses:

I. The evidence that animals are carriers of foodborne diseases

II. The ways through which infectious foodborne zoonoses undermine global food and nutrition security.

III. The impact of human infectious illnesses on food production and distribution.

IV. The importance of agricultural and disease-related interventions, as well as political actions.

V. A review of recent research on innovative detection and control approaches for foodborne zoonotic illnesses, which constitute a public health danger.

2. Why diseases emerge and the wicked problem

Zoonoses transferred from animal hosts to humans have evolved in food systems as a result of a lack of food safety monitoring and enforcement [25]. In regulated production systems and wildlife trafficking, improper animal storage, filthy environments, and poor handling of animal products have been identified as pathways for viral strain mutation and interspecies transmission [12, 26–28]. Viruses such as the new coronavirus have found an opportunity to spread into pandemics, aided by human-to-human transmission due to urbanisation, increased ease of local and worldwide transit, and growing antibiotic resistance [29, 30].

King [31] assessed the convergence of conditions contributing to the global rise of foodborne illnesses. The variety of global food safety issues and their causes describes disease onset as a perfect microbial storm, according to the convergence model of variables influencing the establishment of infectious illnesses [32]. **Table 1** depict the numerous elements that impact the complex host-pathogen-environment interactions that can result in the formation or recurrence of infectious illnesses [32, 34]. Zoonoses arise through a complicated process. A variety of external causes or drivers generate the circumstances for a disease to expand and adapt to a new habitat. The primary motivators include environmental, political, economic, and social pressures at the local, national, regional, and global levels. Hotspots for zoonotic diseases are areas where these characteristics are most densely aggregated, common, and where the likelihood of a disease outbreak is greatest [35].

Genetic and biological factors	Physical environmental factors	Ecological factors	Social, political, and economic factors
• Microbial adaptation and change	• Climate and weather	• Changing ecosystems	• International travel and commerce
• Human susceptibility to infection	• Economic development and land use	• Human demographics and behaviour	• Poverty and social inequity
			• War and famine
			• Lack of political will
			• Intent to harm

Source: King [31], Choffnes et al. [33].

Table 1.
Factors influencing the emergence or Reemergence of infectious diseases.

Several environmental elements, including but not limited to the following [33], are particularly important for the establishment and transmission of foodborne infections:

- **Intensive farming methods.** Raising and moving big herds of cattle, flocks of birds, or shoals of fish or shellfish in close quarters in the quest of efficiency creates perfect circumstances for the onset and spread of illness [36].

- **Increased interactions between humans, domestic animals, and wildlife**. Increased interaction between humans, animals, and their associated microorganisms, sometimes induced by habitat degradation, changing land-use patterns, and killing of animals for food or the food trade, further increases the possibility for disease transmission across animal species or between humans and animals [37].

- **Environmental "commons" such as water**. Contamination of shared resources disperses and raises the danger of pathogen and chemical contaminant emergence, and it can spread across farms, regions, states, and countries.

Jones et al. [3] stated that significant emerging viral illnesses such as HIV/AIDS and severe acute respiratory syndrome (SARS) are classified as foodborne pathogens since their entrance into humans and subsequent transmission is intimately tied to food availability. This includes a huge variety of viruses that have spread from wild or cattle populations to individuals who seek bushmeat (HIV/AIDS) or kill and process exotic and domesticated animals in wet markets [38]. The killing and percutaneous and mucosal contact with blood and body fluids of non-human primates hunted in Sub-Saharan Africa are most likely linked to the spread of HIV and Ebola hemorrhagic fever.

King [31] introduced the concept of the "wicked problem," and demonstrated why the hunt for safe food in a globalised world matches this criterion. According to King, [31], wickedness refers to the inability of such issues to be treated by normal techniques to maintaining food safety, which are based on medical education and training concepts that aim to describe a problem, make a diagnosis, and prescribe a remedy. The researcher promotes the One Health concept, which acknowledges the interconnection of humans, animals, and the environment and stresses illness prevention as a means of solving these difficult and emerging problems [33].

3. Animals: carriers of foodborne diseases

Zoonotic infections can be spread both by Animal Sources Food (ASF) and by non-ASF that get infected during the manufacturing process [39]. One study found that over 60% of emerging human infectious diseases are zoonotic, with the majority (72%) of these being of wild animal origin [3], while another estimate suggested that 75% of emerging pathogens were zoonotic [40], putting ASF consumers at risk [41]. While estimates vary, most new viruses are thought to originate in animals. Many new epizootic and zoonotic viral infections contain single-stranded RNA viruses like coronaviruses, which can cause serious infections in both animals and humans [11]. 1445 novel RNA viruses have recently been identified in Invertebrates while over 200 previously undiscovered viruses have been discovered in vertebrates [42, 43]. Food-producing animals (e.g., cattle, chickens, pigs, and turkeys) are the primary reservoirs for several foodborne infections, including *Campylobacter spp., Salmonella enterica* or non-Typhi serotypes, *E. coli* Shiga toxin-producing strains, and *L. monocytogenes* [44]. *Salmonella* is found in both domestic and wild animals, including cats, dogs, amphibians, reptiles, and rodents [44].

Poultry is thought to be the primary source of *Campylobacter* species transfer to humans [45], owing to their higher body temperature. Handling, processing, and consumption of chicken meat can account for 20–30% of human campylobacteriosis infections, whereas the chicken reservoir as a whole accounts for 50–80% [46]. Campylobacteriosis has also been related to cattle dogs, pigs, and piglets [44, 45]. In addition to the concerns already mentioned, contact with pets is another potential source of human illness [47].

Cattle and other ruminants are assumed to be the principal reservoirs of Shiga toxin-producing E. coli (STEC) [44]. *L. monocytogenes* has been recovered from cattle, sheep, goats, and poultry, primarily on their skin, although several studies have shown that this bacterium is also found in muscle, albeit at low levels [48]. Crustaceans, shellfish, molluscs, and related goods, cheese, meat and meat products, pork and related products, vegetables, juices, and related items such as mixed salads and soft cheese are all food carriers for *L. monocytogenes* [48].

4. Changing food system and foodborne zoonotic diseases

Rohr et al. [4] and Tilman et al. [49] reported that deficiency of nutrients is expected to worsen as climate change occurs. According to the United Nations, the world population will expand by over 4 billion to more than 11 billion people by 2100 [50]. Achieving the United Nations Sustainable Development Goal of eliminating hunger for the world's rising population would necessitate a significant increase in food supply, as well as significant changes in agricultural production and distribution systems, infrastructure, and social protection programs [4, 51, 52]. Historically, increased wealth has been correlated with higher food consumption in general and animal-based food consumption in particular, both of which further increase food demand and the need for agricultural expansion or intensification [4, 53]. Recent studies have shown that agricultural production may need to double or triple by 2100 in order to keep up with the global economy and keep pace with projected population growth and demand for food [4, 51, 52, 54]. Agriculture currently uses more than two-thirds of the world's freshwater and occupies about half of the world's land area [55]. Despite ongoing advancements in agricultural efficiency, a reevaluation of these estimates will be necessary. In order to meet these needs with current agricultural production systems, it may be necessary to replace more than 109 hectares of natural ecosystems with agricultural production. According to estimates by Foley et al. [51], Tilman et al. [49], and Rohr et al. [4], this rise in agriculture might also result in an estimated 2-fold increase in irrigation, a 2.7-fold increase in fertiliser, and a 10-fold increase in pesticide usage.

There are various ways in which the problems of feeding more than 11 billion people and controlling infectious illnesses are related [4]. First, tropical developing countries are experiencing disproportionate agricultural expansion and intensification [51] in which infectious diseases account for 75% of deaths [56] and the risk of disease emergence is highest, and where disease surveillance and access to health care, particularly for those infections associated with extreme poverty, are most restricted [3]. Second, historically significant habitat change, pollution with animal waste, and greater use of agricultural inputs like pesticides and antibiotic growth promoters have all occurred in conjunction with agricultural expansion and intensification [4]. Aside from their direct detrimental effects on human health [57], agricultural biochemical inputs are known to have an indirect driving force in the emergence of wildlife diseases [4, 58], which are significant sources of emerging human infections [3, 30], as well as direct effects on human infectious diseases. The improvement of diet, however, has demonstrable advantages in reducing the prevalence of many infectious illnesses at the individual and population levels [5, 59].

4.1 Food system transition and animal health

In order to achieve crucial global goals at the junction of human and planetary well-being, there is widespread agreement that food systems must be transformed [51, 60]. Therefore, in order to cultivate agrifood systems that are resilient, sustainable, and equitable in the face of economic, social, and environmental challenges, there are growing efforts underway to transform agrifood systems so that the expanding global population has access to food that is nourishing, safe, and affordable [1]. Giving everyone access to more nutrient-dense meals is vital, and hence, future food systems must offer a wide variety of reasonably priced foods to enable everyone to have access to diets of high nutritional quality. To ensure that the circumstances that have made it possible for people to survive on the planet and the present Earth's ecosystems to flourish continue, a significant reduction in the ecological footprint of the livestock sector is required [60].

4.2 Animal husbandry intensification and veterinary drugs abuses

The cost of cattle products has grown as a result of the Westernisation of diets and the rise in demand for nutritional diversity in many emerging nations [61]. Animal production has increased, gaining from agricultural industry's economies of scale [62]. The genetic variety of cattle breeds has been decreased as productivity has been increased to preserve competitiveness in livestock production systems. Antimicrobial resistance in people has been reported to rise when antibiotics are overused in livestock production to promote growth and maintain herd health [25]. Agribusiness uses a larger portion of the world's antibiotic and anthelmintic production than human medicine to prevent catastrophic disease-related losses and enhance animal growth. The majority of antibiotics are given in non-therapeutic doses because there is no known disease [63, 64]. Although estimates are lacking for the majority of the nations in the world, in the United States, animals receive about nine times as many antibiotics as people do, and of those given to animals, more than 12 times as many are used for non-therapeutic purposes than for therapeutic ones [63]. Given that it appears to encourage microbial resistance to these medications, some of which are also used in human medicine, the widespread use of antibiotics and antiparasitics (such as anthelmintics) in industrialised agriculture and aquaculture could have significant effects on infectious diseases affecting humans [63]. For instance, antibiotic-resistant strains of *Salmonella, Campylobacter*, and *E. coli* are that are harmful to humans are mostly found in cattle [63]. There is proof that bacteria with antibiotic resistance genes acquired from aquaculture can spread to human systems and cause epidemics [4]. According to Rohr et al. [4] anthelmintic resistance is common among parasitic worms that infest animals and is significantly associated with human parasite worms. It is likely that current antibiotics and anthelmintics will lose some of their effectiveness due to developed resistance as animal and aquaculture production increases to meet rising food needs [64]. This will make treating infectious diseases in domestic animals and humans more challenging. There are now worries that insufficient antibiotic usage in cattle would create antimicrobial resistance, harming human health and undermining human antimicrobial therapy.

4.3 Climate change and food borne zoonotic disease

Food value chains have a detrimental influence on the environment since they require energy, raw materials, and modify how land is used [65]. The frequency, severity, and unpredictability of extreme events linked to climate change are increasing. In addition to negatively influencing agricultural productivity and yield and upsetting supply systems, such catastrophes also have an influence on food safety [1]. Increased temperatures have a serious impact on various biological and chemical contaminants in food by changing their virulence, occurrence, and distribution [1]. Other factors include the alternation of severe drought periods and heavy rains, soil quality degradation, rising sea levels, and ocean acidification. Due to this, more people are at risk of contracting foodborne illnesses. Additionally, the increased globalisation of the food supply chains makes it easier for foodborne dangers to spread along the route, creating potential for local outbreaks of foodborne illness to become international outbreaks [1].

It is predictable that climate change would hasten the spread of vector-borne illnesses (such those carried by flies), including those that are food-borne pathogens [65]. On the other hand, the adverse higher temperatures might stress fisheries and livestock, increasing their susceptibility to diseases and causing diseased animals to moult more frequently [9]. (**Figure 1**). More frequent flooding and rain events will enable the spread of infections and chemical risks through runoff in agricultural regions, leaving cropland vulnerable [9, 66]. The deterioration of water quality for drinking and agriculture has also been connected to these catastrophes. On the other side, unfavourable higher temperatures can have an impact on fisheries and cattle health. In addition to infections and increased animal disease shedding, livestock are also susceptible to dietary shortages and animal disease outbreaks (**Figure 1**) [9]. As a result, these occurrences will increase the danger to food safety [67]. For instance,

Figure 1.
A child walks past goats that died from hunger and thirst outside Dollow, Somalia, on April 14, 2022. Sally Hayden/SOPA images/LightRocket/Getty. Source: Global Health NOW Johns Hopkins Bloomberg School of Public Health Issue No. 2085 June 9, 2022.

deforestation brings about the introduction of new animal species that are carriers of disease vectors and are generally hazardous to human health [30, 68]. Long-term climate change also presents difficulties for the resurgence of infectious illnesses that have been eradicated due to shifting ecological habitats [69]. The loss of biodiversity and climate change have increased the new risks posed by these illnesses.

E. coli, a bacteria that causes gastroenteritis, is virulent, and its virulence is strongly connected with both temperature and precipitation. Due to the introduction of novel pathogens and vectors into temperate zones as well as temperature-related changes in contamination levels, climate change also results in a rise in foodborne illnesses [25, 70]. Rapid urbanisation, intensification of animal production, modernisation of food marketing systems, and changes in food consumption patterns have caused ecosystem degradation [21]. New zoonotic infections are emerging as a result of some of these conditions, while endemic zoonoses are reemerging as a result of others [41]. Eutrophication and acidification of water bodies are two additional environmental effects that modify aquatic ecosystems and their ecological resilience [71]. As a result, these occurrences will increase the danger to food safety [67].

5. Emerging infectious foodborne zoonotic disease

The most recent and dramatic example of the possible establishment of zoonoses in human populations is the suspected emergence of the SARS-CoV2 virus from an unknown animal source in or near the Wuhan Seafood Market in late 2019 [41]. The COVID-19 pandemic, if proven true, will be one of the most prominent instances of zoonotic spillover in recent memory, following the relatively recent emergence of the severe acute respiratory syndrome (SARS), Middle East respiratory syndrome (MERS), Nipah virus, swine flu, and highly pathogenic avian influenza (H5N1) [72].

The origin and spread of COVIDs from their origins in an unofficial wet market clearly demonstrate that comparable foodborne dangers might be enhanced by such attitudes [41]. Its cascading effects and disruption of local food systems in Low- and Medium-Income Countries (LMICs) highlight how difficult it is to prevent and manage the spread of such pathogens internationally [73].

5.1 *Campylobacter spp*

Campylobacter spp. is the world's most common source of zoonotic enteric infections and a contributor to foodborne diseases. Human campylobacter infections are mostly spread via the food chain [74]. *Campylobacter (C.) jejuni*, one of the *Campylobacter spp.*, is the most common cause of bacterial food-borne gastroenteritis globally with more than 96 million cases annually [75, 76]. The lower digestive tract of many animals often harbours these bacteria asymptomatically. *Campylobacter jejuni*, however, when infects people, it can lead to significant illness states [77, 78]. Consuming inadequately cooked chicken meat is the main way for the bacteria to spread to humans. Usually in healthy people, *C. jejuni* infections can last up to 2 weeks and are self-limiting, but problems are more common in kids, the elderly, or those with impaired immune systems [76].

5.2 Salmonellosis

One of the most often reported foodborne zoonoses is salmonellosis [79, 80]. From farm to fork, the causative agent, Salmonella can be transferred to people, mainly through contaminated food with an animal origin [81]. Globally, Salmonella spp. is thought to be responsible for 155,000 fatalities and 93.8 million instances of acute gastroenteritis [82, 83]. According to the Centers for Disease Control and Prevention (CDC), Salmonella spp. results in 1.2 million illnesses, 23,000 hospitalizations, and 450 fatalities annually in the United States, costing an estimated $400 million in direct medical expenditures that would otherwise be incurred [80]. While Salmonella spp. caused 43% of foodborne outbreaks in the United States in 2018 [81, 82], they were responsible for 24.4% of all foodborne outbreaks in Europe in 2016 [79, 80].

5.3 *Listeria*

The bacterium listeria is typically found in soil, surface water, plants, and food. It is spread by a wide range of animals. Along with people, *Listeria* can also be found in at least 42 other types of wild and domesticated mammals and 17 different types of birds, including domestic and wild poultry. *Listeria* have been found in oysters, fish, crabs, ticks, and flies [33]. Infected animals can shed the pathogen through their faeces, milk, and uterine secretions, which is how most infections are contracted [84]. The relatively uncommon but hazardous disease listeriosis, which has a mortality rate of about 20% in humans, can be brought on by listeria infection [33]. According to Scallan et al. [85]'s estimate, *Listeria monocytogenes* causes 255 fatalities, 1455 hospitalizations, and an average of 1591 incidents of domestically acquired foodborne disease per year in the United States [85]. For instance, the world's greatest epidemic of listeriosis occurred in South Africa between 2018 and 2019, resulting in more than 1000 laboratory-confirmed cases and more than 200 fatalities among those who caught the disease after consuming contaminated food [10, 86]. Listeria is highly suited to conditions of food preparation and storage. At low refrigeration temperatures, it can proliferate and cause lingering infections on food processing equipment [87]. After being cleaned and sanitised, *L. monocytogenes* can develop in biofilms that shield them from environmental stress [87].

5.4 *Escherichia coli*

E. coli is a vast and varied genus of bacteria that may be found in the environment and in a range of animals, including humans, as commensal organisms [88]. *E. coli* that produces the shiga toxin (STEC) is one of the most infamous foodborne pathogens. Hemolytic uremic syndrome (HUS), a hazardous consequence marked by copious bleeding that can result in kidney failure and death, develops in 5–10% of infections caused by STEC, and it can cause mild to severe diarrhoea [89]. According to estimates by Scallan et al. [85], STEC strain O157:H7 results in 63,000 infections, 2100 hospitalizations, and 20 fatalities annually. The digestive system of cattle is the primary reservoir for this zoonotic infection.

5.5 *Brucella spp*

The bacterium genus Brucella is the source of the zoonotic illness known as brucellosis. By ingesting contaminated food items, coming into close contact with sick animals, or inhaling aerosols, the germs can be transferred from animals to people. The illness is widespread and has several names, including undulant fever, Mediterranean fever, Malta fever, and remitting stomach fever mostly transmitted to humans by raw milk or close contact with sick animals. Human infections cause a fluctuating temperature, joint discomfort, and weakness [90].

5.6 Cryptosporidiosis

Cryptosporidiosis is a diarrheal disease mostly severs on young animals and children and immunocompromised adults. Among 44 species 21 are reported with human infection but *C. hominis* and *C. parvum* are most frequently found in intestinal infections with symptoms of watery diarrhoea, pain, abdominal cramps, vomiting, nausea, dehydration, fever, and weight loss are most symptoms associated with cryptosporidiosis [91]. The food sources include shellfish, uncooked beef, pork, and chicken.

5.7 *Mycobacterium bovis*

Raw milk is the main channel of *M. bovis* transmission from cattle to people. The signs and symptoms of *Mycobacterium tuberculosis* are same in humans. Africa is thought to have the largest incidence of zoonotic tuberculosis (TB), due to the prevalence in cattle and the absence of pasteurisation in the majority of milk drank there [92].

5.8 *Toxoplasma gondii*

Toxoplasma gondii is one of the most pervasive zoonoses. Humans get the disease through consuming cysts in raw meat or by coming into touch with food and water contaminated by the sporulated oocysts of cats, the disease's ultimate host. Although toxoplasmosis is often asymptomatic, foetuses, the elderly, and those with impaired immune systems are especially vulnerable. [41, 93].

5.9 *Taenia solium*

The parasitic zoonoses *Theridion solium* use pigs as their intermediate host. Consuming pork that is not fully cooked causes tapeworm (taeniosis) infection at its most advanced stage. Following faecal-oral transmission in humans, neurocysticercosis, a prominent cause of epilepsy in endemic places, can result from an aberrant intermediate-stage infection [41, 93].

5.10 Fish borne trematodes

Fish muscles contain *metecercaiae*, which when ingested by humans can lead to cholangitis, pancreatitis, and chronic liver disease in some people [21].

5.11 *Paragonimus spp*

This zoonotic parasite infects humans when they consume raw or undercooked seafood. Flukes that are still developing go to the lungs, where they cause inflammation-related pulmonary symptoms. The parasite is particularly common in Asia, where eating raw shellfish is a cultural habit that supports the parasite's life cycle [94].

5.12 *Trichinellosis*

Trichinellosis is a dangerous and occasionally deadly human illness that is caused by parasitic nematodes of the genus *Trichinella*. *Trichinella* larvae are transmitted to humans through the consumption of inadequately prepared meat. It has traditionally been linked to the intake of pig meat [95]. According to Rostami et al. [96], wild boar meat is presently the second most significant source of human trichinellosis and has been linked to several human outbreaks in Europe. Trichinellosis severity mostly relies on the quantity of larvae consumed (the infectious dosage), how frequently contaminated meat is consumed [97].

5.13 Hepatitis E virus

According to Hoofnagle et al. [98] Hepatitis E virus (HEV) the responsible agent, has been genetically linked to humans as well as a number of other animal species [99, 100]. Pigs and maybe other animal species serve as HEV reservoirs, and hepatitis E is now regarded as a zoonotic disease [99]. Concerns about zoonotic diseases and food safety have been raised by occasional and cumulative instances of acute hepatitis E being linked to direct contact with diseased animals and eating of tainted animal meat and meat products [100]. HEV genotypes 1 (G1) and 2 (G2) were estimated to cause 20 million yearly infections in 2005 [101, 102]. HEV typically results in an acute, self-limiting infection that goes away in a few weeks, but in some people (such as those with compromised immune systems), these infections can become chronic, lead to acute liver failure known as fulminant hepatitis, or have extrahepatic manifestations, which can be fatal [101].

5.14 Monkeypox virus

While clinically less severe than smallpox, monkeypox is a viral zoonosis with symptoms that are comparable to those experienced by historical smallpox victims. Primarily occurring in central and western Africa, monkeypox is increasingly common in cities and frequently found close to tropical rainforests. Direct contact with blood, bodily fluids, or skin or mucosal lesions of infected animals can result in animal-to-human transmission (zoonosis) [103]. Numerous animals in Africa, including rope squirrels, tree squirrels, Gambian opossums, dormice, numerous monkey species, and others, have shown signs of infection with the monkeypox virus. A potential risk factor is consuming raw meat and other animal products from infected animals [103]. According to a WHO estimate, the monkeypox epidemic in 2022 is on the verge of becoming a global public health emergency (PHEIC) with more than 6000 cases reported in 58 countries. More than 80% of the cases in the ongoing outbreak in 2022 are in Europe.

5.15 Nipah virus

The spread of the Nipah virus (NiV) in Malaysia and Bangladesh is a particularly lethal illustration of the various channels via which zoonotic diseases are transmitted and how these channels are connected to the food chain [33]. Flying foxes of the genus *Pteropus* serve as the paramyxovirus's primary reservoir in animals [104]. Nipah virus was initially identified as the result of a Malaysian outbreak in 1999, but it is now more frequently linked to Bangladesh and the surrounding regions of India, where multiple outbreaks over the past decade have led to more than 250 cases and nearly 200 fatalities, according to Luby et al. [105]. According to Epstein et al. [106] and Choffnes et al. [33], the Malaysian outbreak, which has killed more than 100 people and infected about 40% of those who have been identified, was initially linked to close contact with infected pigs. However, it has since been determined that infected bats that reside in forested areas close to large-scale commercial pig farms were likely the source of the outbreak.

5.16 Influenza

Avian influenza viruses (AIV) are classified as types A, B, C, or D based on genetic variations and are members of the *Orthomyxoviridae* family [107]. The influenza A virus is naturally found in birds, where it can spread to people and cause zoonotic diseases [108]. Direct contact with infected birds, eating raw or undercooked chicken products, and human-to-human transmission are all risk factors for human infections [109]. Growing international trade (including live bird markets) and wild bird movement are factors in the development of the illness [107]. According to Libera et al. [107], a human infection can present as a mild upper respiratory tract infection that causes fever, headache, and cough in addition to conjunctivitis and digestive issues. However, acute respiratory distress, multiple organ failure, shock, and severe pneumonia can develop quickly [110]. Viruses generated from HPAI A (H5N1) and LPAI A (H7N9) infections are responsible for the most deadly illnesses in humans [111].

The influenza A virus (IAV), generally known as the swine flu virus, is what causes swine flu (SIV). Hemagglutinin (HA) and neuraminidase (NA), two proteins, are used to categorise IAVs into 18H and 11 N subtypes [110]. The (H1N1) pdm09 novel triple reassortant virus, one of the IAVs, produced a pandemic in the human population in 2009 [107]. IAVs may infect both pigs and people. In both people and pigs, symptoms include respiratory system (sneezing, coughing, and trouble breathing), fever, tiredness, and reduced appetite [112].

5.17 Severe acute respiratory syndrome (SARS)

The coronavirus known as SARS-CoV, which causes SARS, was originally discovered in China in February 2003 and presumably originated in bats [10]. It then likely moved to other species (mainly civet cats), and finally to people. This pneumonia-like sickness spread to more than a dozen nations in North America, South America, Europe, and Asia. Horseshoe bats have been shown to have a coronavirus that resembles SARS, indicating that bats are natural reservoirs [10]. Since 2004 there have been no cases documented [113].

5.18 Ebola

According to Knipe et al. [114], the Ebola virus disease (EVD) is one of the deadliest viral infections that may afflict both people and monkeys. The *Rhabdoviridae* and *Paramyxoviridae* families of viruses, which also contain the Ebola virus (EV), are members of the order *Mononegavirales*. This pandemic illness is marked by hemorrhagic symptoms that can cause shock, organ failure, and mortality [115]. It also causes fever, intense weariness, and joint discomfort. It spreads to people by skin-to-skin contact or body fluids exuded by infected animals including fruit bats, chimps, and monkeys. A major source of oral Ebola virus transmission, particularly in African nations, is eating raw contaminated meat like bat or chimpanzee [116].

Hunters who opportunistically shot and processed sick gorilla and chimpanzee carcasses for meat consumption spread the disease in Central Africa [10, 117]. While there is a danger associated with eating game meat without following minimal hygienic requirements, it is not the only factor. Secondary epidemiological cycles are involved in the largest Ebola outbreaks in West Africa and the eastern DRC at present, highlighting the fact that human conditions and actions, not unintentional transmission effects, are the main determinant in zoonoses' spread [10].

5.19 Lassa fever

This foodborne zoonosis, Lassa fever, was found and named after a town in Nigeria and causes significant health and food safety issues in Africa. *Mastomys natalensis*, a common type of rat, transmits the lassa virus, which is excreted in faeces and urine. Human infection results through ingesting contaminated food and drink or from coming into direct touch with infected items and open skin sores. Inhaling airborne particles from actions like sweeping or touching the rodent while it is being prepared for consumption are other ways in which contamination might occur. Contact with an infected person's body fluids can result in human-to-human transmission. For instance, 58 million people in West Africa are at risk, with 100,000 to 300,000 suspected cases of Lassa fever and 5000 suspected fatalities per year [118].

6. Infectious foodborne zoonoses and impact mechanisms on global food safety and nutrition security

Recent years have seen the development of sophisticated and efficient methods for foodborne zoonotic agents to transmit diseases from animals to people [119]. Poverty and food instability have been the root causes of epidemics like Ebola and HIV, and rising demand for wildlife for commerce and consumption has increased human-wildlife interaction [120]. Mechanism through which foodborne zoonoses impact global system food safety and nutrition security have to be examined.

6.1 Food losses and waste

Over 14% of food produced worldwide is lost before it leaves the field, and 17% of food that is available to customers is wasted in stores and homes [121, 122]. According to Tilman et al. [49], in the past 25 years alone, outbreaks of foot-and-mouth disease and the influenza A virus (H5N1) have killed more than 1.2 million chickens and 6 million animals in China and Great Britain, respectively. Mad cow disease has also resulted in the slaughter of 11 million cattle globally. The highly infectious avian influenza virus strain has also been discovered in overcrowded chicken farms in Thailand and Vietnam [123]. Vietnam and Thailand paid about $45 million and $135 million, respectively, to contain the epidemic. Food supplies were devastated by the epidemic. In order to control the epidemic, over 18% of the entire chicken population in Vietnam and 15% of the total poultry population in Thailand were slaughtered in 2004 [124]. Similar situations have happened in aquaculture, particularly in impoverished nations with poor hygiene.

6.2 Reduction in optimal nutrition/dietary intake

Development in agriculture may directly enhance nutrition, and nutrition can influence infectious disease susceptibility and progression via a number of pathways [125]. By raising the body's requirement for nutrients when sick reduced food intake, malabsorption, and metabolic losses of nutrients, infection can lead to malnutrition [126]. Fear of contracting a foodborne disease can deter consumers from purchasing or consuming ASPs in both high- and low-income contexts [127–129]. Due to a lack of alternatives, consumers in nations where the aforementioned foods are unavailable either increase their risk of developing food-borne diseases by consuming the foods or they raise their risk of malnutrition by excluding nutritious foods from their diets [130]. For instance, after the avian influenza epidemic in Egypt in 2006, a surge in human stunting was seen as a result of the decreased poultry availability (and less dietary variety) brought on by the widespread slaughter of poultry to suppress the outbreak [131]. As malnourished people become more prone to infections, such dynamics can result in a vicious cycle of undernutrition and illness [130]. Because many parasite illnesses exert direct demands on host nutrition, undernutrition can result when food is scarce [132]. Even eating disorders like geophagy (the desire to eat earth), bulimia, and anorexia can be brought on by certain parasites, such as helminths [133]. Persistence infections frequently need quick and efficient tissue healing, which is also expensive.

6.3 Human infectious illnesses impact food production and distribution

The economic and agricultural growth required to feed the expanding human population can also be impacted by human infectious illnesses [4]. Zoonotic illnesses pose a hazard to human health and well-being, animal health and production, and consumer health [134]. According to estimates by Grace et al. [135], zoonotic illnesses and diseases that have recently originated from animals account for more than a quarter of the disability-adjusted life years (DALYs) lost to infectious diseases in low-income nations like sub-Saharan Africa. Areas with higher historical tsetse-fly abundance, the vector of the parasite (*Trypanosoma brucei*) that causes African sleeping sickness in humans and cattle, experienced greater lags in the adoption of animal husbandry practices that hindered agricultural development and prosperity in Africa long before and after Europeans colonised [4, 136]. In rural subsistence communities, any source of ill health can significantly impact people's productivity, yields and agricultural output [137]. For instance, since 1997, the human immunodeficiency virus/AIDS has reduced the average life expectancy in sub-Saharan Africa by 5 years. Some low-income populations appear to be stuck in the poverty-disease cycle, and as a result, they may need significant health system financing to support the crucial agricultural and economic growth that will help break the pattern [137, 138].

7. Food system approaches to control of foodborne zoonotic diseases

The main goal of food systems is to provide safe and nourishing food for people, with the ultimate goals being nutrition and fitness. Food safety refers to the circumstances and procedures applied to the food system in order to prevent foodborne disease and minimise serious health risks [130]. Pathogen prevention and control methods are not always easy. However, Sahoo et al. [139] state that the following crucial steps must be put into place in farms and processing facilities since they can be effective in lowering the risk of infection: (1) Clean management procedures and separating sick animals from healthy ones, (2) safety measures at both the farm and processing levels, (3) well-planned precautions, such as animal testing, full-size homes, and wild animals vaccination, (4) cooling after animal slaughter, (5) animal health training, (6) Use of antibiotics and phytonutrient-rich feed, (7) modern food processing techniques, (8) adequate kitchen cleaning, cooking, and sanitization procedures, (9) avoiding cross-contamination and ingestion of raw or undercooked animal products, and (10) routine product inspection, monitoring, and sampling.

7.1 Man-Imal: from animal to man one health strategies

In a globalised, industrialised society with an increasing number of stakeholders and regulations, production chains are becoming more and more complex. Based on the "One World, One Health" concept promoted by the WHO, FAO and OIE, the '*man-imal*' (From Animal to Man) seek to engage multidisciplinary approach in "Analysing and Managing Health and Food Risks" as being anchored by "Oniris" a French institution. Hence, the success of One Health (formerly One Medicine) initiatives will provide the foundation for advancements in food safety, public health, and welfare in the future decades. The key tenet of this concept is that there is a close relationship and interdependence between the environment and both human and animal health [107]. One Health is an all-encompassing or comprehensive approach where the assumption is that welfare and wellbeing are founded on human, animal, and environmental health and that integration and exchange of information on animal and human health is the key to effective health systems [140]. For tackling complicated health issues, One Health represents a rapidly expanding variety of synergistic disciplines, including food safety, public health, health economics, ecological health, social science, and animal health [141]. To manage food safety and comprehend the factors that contribute to the formation and persistence of hazards to people, animals, and the environment, one health is required [142].

Consistent surveillance for zoonotic illnesses should combine animal, human, and environmental markers, offering a useful tool for early detection of zoonotic infections [11]. Scientific assessment techniques, such as mathematical models, should first elucidate the interactions between animals, humans, and the environment before evaluating the impact of various policy alternatives [11]. Inadequate efforts have been made to prevent and manage zoonotic illnesses at their source, reflecting our incomplete knowledge of the underlying mechanisms of transmission in the animal reservoir. To effectively monitor and infer disease trends in animal reservoirs, present surveillance and model assessment should be upgraded [11]. It is crucial to approach them from a risk perspective in order to prioritise surveillance and interventions in the areas where the risks are greatest [143, 144]. In comparison to more stringent strategies like market shutdown, implementing the One Health strategy would be more sustainable in reducing the possibility of future zoonotic epidemics.

7.2 Biosecurity and biosafety strategies

In order to adequately analyse the zoonotic dangers, Naguib et al. [11] advocated a scientifically based risk-assessment framework that included field surveillance and risk assessment. In order to comprehend the real frequency of risks and the areas where the danger for disease onset is greatest, long-term, extensive surveillance is crucial. Along the value chains, food goods, the environment, customers, vendors, and vendors themselves would all be sampled and interviewed [11]. Rapid risk assessment seeks to investigate the environmental and zoonotic background, as well as the transmission potential of the present and upcoming zoonotic outbreaks, with the use of this all-encompassing surveillance system [11]. Emergency response in high-risk locations and routine treatments in low- to medium-risk areas would be used to leverage risk-based hierarchical controls [11].

7.3 Sustainable slaughterhouse and wet market management

Cross-species spread of infectious illnesses has been connected to inappropriate animal storage, crowding, poor hygiene, incorrect faeces disposal, and improper carcass disposal in wet markets [25]. Wet marketplaces that deal locally in cattle products have been made into epicentres of infectious diseases due to the lax implementation of food safety regulations. Aiyar and Pingali [25] define a wet market as an open food market. Traditionally, the primary qualities of wet market is a location that sells live animals in the open. Pigs, fish, reptiles, and poultry may be part of the collection of animals traded [33]. To reduce the risks to public health from endemic diseases as well as emerging diseases, markets must gradually improve with better food safety, hygiene standards, less animal crowding, and regular inspections from reputable officials with the authority to sample and condemn products [11].

7.4 Individualised animal treatment

The ideal course of action is to postpone and, avoid the appearance and subsequent spread of resistant bacteria or resistance genes, according to the case study of Antimicrobial Resistance (AMR). The widespread use of antimicrobial agents in veterinary medicine to treat both food animals and companion animals cannot be utilised to make up for substandard animal care and raising conditions [142]. Preventative medicine needs to be improved, including better biosecurity, reinforcement of animal health and welfare within production systems, improved access to infection-prevention vaccines, and an increase in animal breeding programmes that focus on robustness and resilience [142]. The creation of an efficient surveillance system, as well as extensive education and training of several system actors within the Animal Source Foods (ASF) system, are likely necessary to achieve sustainable antimicrobial usage.

7.5 Agricultural disease management synergy and policy monitoring activities

Integrating food safety objectives for disease prevention with trade-related food safety guidelines will support commerce and sustain competitiveness One such regulation that may be utilised to assist nations in achieving the twin objectives of equitable trade and improved health through food-safety investments is the Codex Alimentarius, an international convention for food safety [25]. Local stakeholders must be actively involved in the standards' implementation as well as active surveillance for containment to be successful [145]. Only if knowledge is shared transparently and local actors are given the means to address disease hazards can disease transmission be contained [25]. In the one-health, health, and food systems groups, improving interdepartmental collaboration can shorten the time it takes to identify diseases and execute containment measures [30, 146]. A "One Health" approach to food safety is one that aims to provide "optimal health for humans, animals, and the environment via the combined effort of different disciplines working locally, regionally, and internationally" [147]. If such an approach were used to address food safety, it might have the potential to combine the knowledge and resources from a variety of health domains, such as those in the fields of plant pathology, human and veterinary medicine, and ecology and wildlife and aquatic health [33]. By tracing and disrupting the pathways that lead to food contamination, these transdisciplinary synergies could provide crucial insights into the sources, reservoirs, and factors that underlie the emergence of infectious diseases and prevent the negative health effects associated with the emergence and spread of novel, emerging, or reemerging food-borne diseases [33].

Governments and funding organisations have moved quickly to support COVID-19-related research due to the race to understand the pathophysiology and epidemiology of the disease [148]. Such global finance and cooperation were not always obvious. SARS and H5N1 avian influenza, two foodborne zoonosis that first appeared in China, previously failed to garner the attention of the international community [41], limiting opportunities to improve disease surveillance systems that could provide risk assessments for the preparation and consumption of animal-sourced food [119]. Integrated animal, livestock, and human disease surveillance-response may help avoid future zoonoses outbreaks even if more research is needed to determine the zoonotic origin of COVID-19 [149]. Overall, consumers are becoming more aware of the wider public health implications of present food systems, despite the fact that there are still significant obstacles to overcome with regard to the reorientation of market incentives and food safety standards [72]. Future foodborne zoonoses treatments focused at informal markets may receive more support from national and international governments as a result of this increasing knowledge, which may improve policymakers' willingness to restructure global food systems to better safeguard public health [41]. As the incidence of events like foodborne zoonotic diseases and food safety are increasingly linked to globalised food systems, policymakers must focus on planning and prioritising response [139].

7.6 Food safety conservation measure

Experts in food safety should support research into preserving the genetic variety of cattle and other food production animals through creation of vaccines and veterinary services for livestock [25]. These measures can lessen the risk of escalating antimicrobial resistance as well as the vulnerability of animals to zoonotic infections [29, 150]. Increasing conservation activities will lessen exposure to animals that act as harmful disease vectors by reducing demand for wildlife and/or encouraging afforestation [28]. These initiatives will be critical to reducing the spread of zoonotic illnesses with a high risk but low likelihood [25].

7.7 Life Cycle Thinking (LCT)

A crucial idea in accomplishing the shift to a more ecologically sustainable food system is Life Cycle Thinking (LCT) [151]. Along the life cycle of complex food systems, it enables the evaluation of inputs, outputs, and potential environmental implications. LCT is defined as "moving beyond the conventional focus on production locations and manufacturing methods to encompass environmental, social, and economic aspects of a product across its whole life cycle" according to the UNEP/SETAC Life Cycle Initiative [152]. LCA is the most preferred and frequently used tool to evaluate and address the environmental sustainability of food systems when dealing with current global challenges, such as ensuring food safety and environmental sustainability of food systems under conditions of climate change [65]. The primary environmental loads may be identified via LCA, allowing for more effective definition and implementation of reform initiatives. LCA must switch from its global viewpoint to RA's narrow, site-specific focus. These days, site-dependent characterisation variables [153], national databases [154, 155], and grid cell-based inventories [156] can all be used to do. These Worldwide programmes and activities are driven by this global problem, which is already included in the portfolio of policy objectives [65].

8. Review of recent research of novel detection and control techniques in addressing the public health threat posed by foodborne zoonotic illness

Food safety laboratories can find new infections and detect pathogen deviations through routine testing, monitoring, and participation in epidemiological

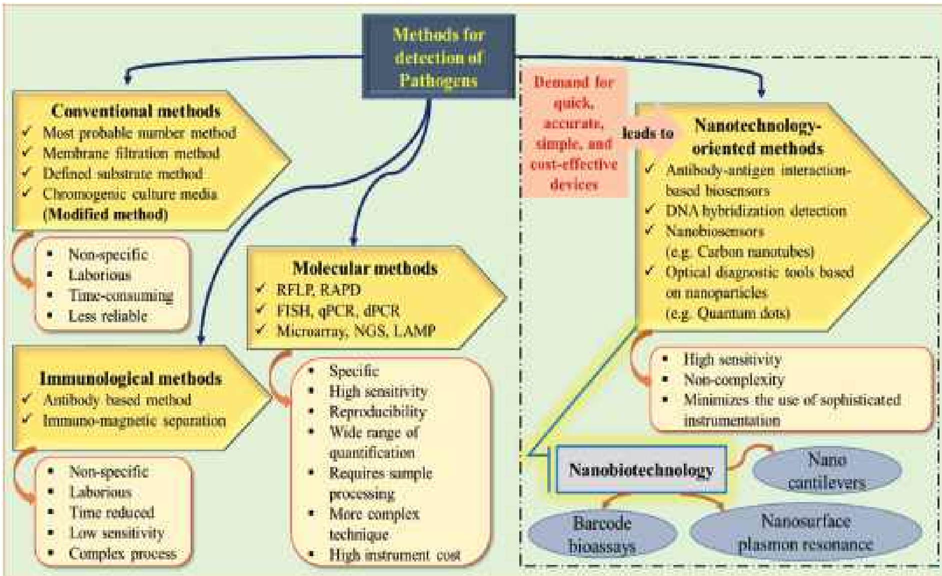

Figure 2.
Standard and novel techniques for the detection and control of foodborne zoonotic pathogens. Source: Shanker et al. [157], Sahoo et al. [139].

investigations. Controlling foodborne outbreaks requires quick identification of the infection pathway and focused detection of the causing organisms. The source may be looked into using the several detection techniques shown in **Figure 2** [139]. Bacteriophages, or "phages" for short, are a possible replacement for conventional methods of food safety preservation [82], particularly given their effectiveness against bacteria that are resistant to antibiotics [158]. Phage-based food treatments reduce the loads of spoilage microorganisms in fruits, dairy products, poultry, and red meats as well as dangerous bacteria such *L. monocytogenes, Salmonella*, and *C. jejuni* [159].

Molecular-based assays such as next-generation sequencing (NGS), quantitative and digital polymerase chain reaction (qPCR and dPCR), immunomagnetic separation assays, florescence in situ hybridization (FISH), DNA microarrays, direct epifluorescence filter techniques, latex agglutination tests, and flow cytometry are more sensitive than traditional culture methods for the rapid detection of pathogens [17]. Whole-genome sequencing (WGS), an analytical technique used to determine an organism's complete genomic sequence, foodborne pathogen routine monitoring and surveillance, tracing contamination sources, demarcating transmission routes in the farm-to-fork continuum, and incorporating genomic data into microbiological risk assessment, is a widely used application of NGS [160].

Cutting-edge genomic technologies are opening up fascinating new possibilities for zoonotic pathogen surveillance in a variety of contexts and ecosystems. Using taxonomically informative genes, such as the 16S rRNA gene, next-generation sequencing systems enable the metabarcoding of complex bacterial communities [161]. As a molecular marker for bacterial identification, including for pathogens with clinical significance, 16S rRNA sequence data are particularly helpful [162]. While second-generation sequencing platforms, such as Illumina MiSeq and NextSeq, which are frequently used for bacterial metabarcoding experiments, offer high per-base accuracy and sequencing throughput, the resulting data are only relatively short (300 bp) reads, which frequently allow for the analysis of specific subregions of the 16S rRNA gene's full-length (1550 bp) sequence [163].

The Oxford Nanopore Technologies (ONT) MinION sequencer, on the other hand, is a third-generation single-molecule sequencing device that can sequence unusually lengthy DNA fragments (i.e., hundreds to millions of bases in length) [164]. Because of this, the MinION can sequence the complete 16S rRNA gene, which has a length of 1550 base pairs, offering two to five times the coverage of the 16S rRNA gene compared to second-generation sequencing data. A higher number of phylogenetically relevant characteristics are included in full-length 16S sequencing data, which improves downstream bacterial taxonomy identification [161]. This strategy is crucial because, according to Byrd et al. [165], bacterial pathogenicity is often seen as a species- or strain-level phenomena.

On-site cost-effective quick analytical detection techniques are a new challenge compared to traditional approaches, claimed Sahoo et al. [139]. Potential exists for combining chemical engineering, biosensors, microfluids, and nanotechnology [166]. Large surface areas of nanomaterials make it possible for various biomolecules and reaction sites to engage with a target species [139]. This characteristic allows for the creation of sensitive nanobiosensors with faster reaction times for precise detection, in conjunction with the superior optical and electrical capabilities of nanomaterials [167]. In order to create a piezoelectric biosensor for "real-time" detection of the foodborne pathogen *E. coli* O157:H7, the electrical characteristics of the Au NPs were taken advantage of [168]. *E. coli* and *Campylobacter* have been removed from poultry products using nanoparticles [169]. Using magnetic nanoparticle-based immunomagnetic separation and real-time PCR, *Listeria monocytogenes* was found in milk samples [157]. For the quick detection of *Salmonella enteritidis*, two nanoparticle-based fluorescent barcoded DNA assays were developed. Using a portable device and a nanosensor, researchers found cytochrome b genes in animal diets [170].

9. Conclusions

The zoonotic spread of foodborne illness is presently a danger to the complex and dynamic global food system. Food losses and waste, a decline in optimal nutrition and dietary intake, and the effects of infectious diseases on human health on the production and distribution of food are all signs of their impact on global food safety and nutrition security. It is crucial to control foodborne zoonotic diseases using a variety of food system approaches, including Man-imal One Health Strategies, Biosecurity and Biosafety Strategies, Sustainable Slaughterhouse and Wet Market Management, Individualised Animal Treatment, Agricultural Disease Management Synergy and Policy Monitoring Activities, Food Safety Conservation Measure, and Life Cycle Thinking (LCT).

With the advancement of chemical engineering, biosensors, microfluids, and nanotechnology, more sensitive molecular-based assays for the rapid detection of pathogens have been developed. These include next-generation sequencing (NGS), quantitative and digital polymerase chain reaction (qPCR and dPCR), immunomagnetic separation assays, fluorescence in situ hybridization (FISH), DNA microarrays, direct epifluorescence filter techniques, latex agglutination tests, A collaborative, coordinated, multidisciplinary, responsible, cross-sectoral approach including ministries and institutions involved in commerce, health, and agriculture at regional, national, and international levels is needed for prompt identification and treatment to new infectious pathogens.

Conflict of interest

The authors declare no conflict of interest.

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References

[1] FAO. Thinking About the Future of Food Safety—A Foresight Report. Rome; 2022. DOI: 10.4060/cb8667en

[2] Fanzo JC. Fixing Dinner Fix the Planet? Johns Hopkins University Press; 2021. DOI: 10.1353/book.83887

[3] Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, et al. Global trends in emerging infectious diseases. Nature. 2008;**451**(7181):990-993

[4] Rohr JR, Barrett CB, Civitello DJ, Craft ME, Delius B, DeLeo GA, et al. Emerging human infectious diseases and the links to global food production. Nature Sustainability. 2019;**2**:445-456 10.1038/s41893-019-0293-3

[5] Roberts L. Nigeria's invisible crisis. Science. 2017;**356**:18-23

[6] Naylor R. The Evolving Sphere of Food Security. Oxford Univ. Press; 2014

[7] FAO and WHO. The Rome Declaration on Nutrition. Second International Conference on Nutrition. Rome: Food and Agriculture Organization of the United Nations; 2014

[8] United Nations. Transforming Our World: The 2030 Agenda for Sustainable Development (a/RES/70/1). New York, NY; 2015. https://sustainabledevelopment.un.org/content/documents/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

[9] FAO. Climate change: Unpacking the burden on food safety. Food Safety and Quality Series. 2020;**8**:176 https://www.fao.org/documents/card/en/c/ca8185en/

[10] UNEP and ILRI. Preventing the Next Pandemic: Zoonotic Diseases and How to Break the Chain of Transmission. Nairobi, Kenya: United Nations Environment Programme and International Livestock Research Institute; 2020

[11] Naguib MM, Li R, Ling J, Grace D, Nguyen-Viet H, Johanna F. Lindahl live and wet markets: Food access versus the risk of disease emergence. Trends in Microbiology. 2021;**29**(7). DOI: 10.1016/j.tim.2021.02.007

[12] Kruse H, Kirkemo A-M, Handeland K. Wildlife as source of zoonotic infections. Emerging Infectious Diseases. 2004;**10**(12):2067-2072

[13] Webster RG. Wet markets—A continuing source of severe acute respiratory syndrome and influenza? Lancet. 2004;**363**:234-236

[14] EFSA European Food Safety Authority. The European Union one health 2020 zoonoses report European Centre for disease prevention and control. EFSA Journal. 2021;**19**(12):6971 https://efsa.onlinelibrary.wiley.com/doi/epdf/10.2903/j.efsa.2021.6971

[15] Brucellosis PM. A highly infectious foodborne zoonotic disease of public health concern Madridge. Journal of Food Science and Technology. 2018;**S1**(1):1-3. DOI: 10.18689/mjft-2577-4182-S1-101

[16] Abebe E, Gugsa G, Ahmed M. Review on major food-borne zoonotic bacterial pathogens. Journal of Tropical Medicine. 2020. DOI: 10.1155/2020/4674235

[17] Dhama KS, Rajagunalan SC, et al. Food-borne pathogens of animal

origin-diagnosis, prevention, control and their zoonotic significance: A review. Pakistan Journal of Biological Sciences. 2013;**16**(20):1076-1085

[18] Addis M, Sisay D. A review on major food borne bacterial illnesses. Journal of Tropical Diseases. 2015;**3**(4):1-7

[19] Chlebicz A, Śliżewska K. Campylobacteriosis, salmonellosis, yersiniosis, and listeriosis as zoonotic foodborne diseases: A review. International Journal of Environmental Research and Public Health. 2018;**15**(5):1-28

[20] Bidaisee S, Macpherson CNL. Zoonoses and one health: A review of the literature. Journal of Parasitology. 2014;**2014**

[21] Carrique-Mas JJ, Bryant J. A review of foodborne bacterial and parasitic zoonoses in Vietnam. EcoHealth. 2013;**10**(4):465-489

[22] Abunna F, Abriham T, Gizaw F, et al. Staphylococcus: Isolation, identification and antimicrobial resistance in dairy cattle farms, municipal abattoir and personnel in and around Asella, Ethiopia. Journal of Veterinary Science & Technology. 2016;**7**(6):1-7

[23] Hemalata VB, Virupakshaiah DBM. Isolation and identification of food borne pathogens from spoiled food samples. International Journal of Current Microbiology and Applied Sciences. 2016;**5**(6):1017-1025

[24] Argaw S, Addis M. A review on staphylococcal food poisoning. Food Science and Quality Management. 2015;**40**:59-71

[25] Aiyar A, Pingali P. Pandemics and food systems-towards a proactive food safety approach to disease prevention & management. Food Security. 2020;**12**(4):749-756. DOI: 10.1007/s12571-020-01074-3

[26] Destoumieux-Garzón D, Mavingui P, Boëtsch G, Boissier J, Darriet F, Duboz P, et al. The one health concept: 10 years old and a long road ahead. Frontiers in Veterinary Science. 2018;**5**(14)

[27] Han BA, Kramer AM, Drake JM. Global patterns of zoonotic disease in mammals. Trends in Parasitology. 2016;**32**(7):565-577. DOI: 10.1016/j.pt.2016.04.007

[28] Hassell JM, Begon M, Ward MJ, Fèvre EM. Urbanization and disease emergence: Dynamics at the wildlife—Live-stock—Human Interface. Trends in Ecology & Evolution. 2017;**32**(1):55-67. DOI: 10.1016/j.tree.2016.09.012

[29] Holmes AH, Moore LSP, Sundsfjord A, Steinbakk M, Regmi S, Karkey A, et al. Understanding the mechanisms and drivers of antimicrobial resistance. The Lancet. 2016;**387**(10014):176-187. DOI: 10.1016/S0140-6736(15)00473-0

[30] Morse SS, Mazet JAK, Woolhouse M, Parrish CR, Carroll D, Karesh WB, et al. Prediction and prevention of the next pandemic zoonosis. The Lancet. 2012;**380**(9857):1956-1965. DOI: 10.1016/S0140-6736(12)61684-5

[31] King L. What is One Health and Why Is It Relevant to Food Safety? Presentation Given at the, Public Workshop Improving Food Safety Through One Health, Forum on Microbial Threats. Washington, DC: Institute of Medicine; 2011

[32] IOM (Institute of Medicine). Microbial Threats to Health: Emergence, Detection, and Response. Washington, DC: The National Academies Press; 2003

[33] Choffnes Eileen R, Relman DA, Olsen LA, Hutton R, Mack A. Improving Food Safety Through a One Health Approach: Workshop Summary. Rapporteurs; Forum on Microbial Threats; Board on Global Health. Washington, DC: Institute of Medicine; 2012 Available from The National Academies Press at http://www.nap.edu/catalog.php?record_id=13423

[34] IOM (Institute of Medicine). Emerging Infections: Microbial Threats to Health in the United States. Washington, DC: National Academy Press; 1992

[35] IOM (Institute of Medicine) and NRC (National Research Council). Sustaining Global Surveillance and Response to Emerging Zoonotic Diseases. Washington, DC: The National Academies Press; 2009

[36] King LJ. Emerging zoonoes and pathogens of public health concern. Revue Scientifique et Technique de l'OIE. 2004;**23**(2):429-433

[37] Pike BL, Saylors KE, Fair JN, LeBreton M, Tamoufe U, Djoko CF, et al. The origination and prevention of pandemics. Emerging Infections. 2010;**50**(12):1636-1640

[38] Rasko DA, Webster DR, Sahl JW, Bashir A, Boisen N, Scheutz F, et al. Origins of the *E. coli* strain causing an outbreak of hemolytic-uremic syndrome in Germany. New England Journal of Medicine. 2011;**365**(8):709-717

[39] Abebe E, Gugsa G, Ahmed M. Review on major food-borne zoonotic bacterial pathogens. Journal of Tropical Medicine. 2020;**2020**

[40] Taylor LH, Latham SM, Woolhouse MEJ. Risk factors for human disease emergence. Philosophical Transactions of the Royal Society of London B. 2001;**356**:983-989

[41] GAIN (Global Alliance for Improved Nutrition). Assessing Food Safety Interventions Relevant to Foodborne Zoonoses in Low- and Middle-Income Countries. A USAID EatSafe Project Report 2020

[42] Shi M et al. The evolutionary history of vertebrate RNA viruses. Nature. 2018;**556**:197-202

[43] Shi M et al. Redefining the invertebrate RNA virosphere. Nature. 2016;**540**:539-543

[44] Heredia N, Santos G. Animals as sources of food-borne pathogens: A review. Animal. Nutrition. 2018;**4**:250-255. DOI: 10.1016/j.aninu.2018.04.006

[45] Kaakoush NO, Casta~no-Rodríguez N, Mitchell HM, Mana SM. Global epidemiology of Campylobacter infection. Clinical Microbiology Reviews. 2015;**28**:687-720

[46] EFSA. Scientific opinion on quantification of the risk posed by broiler meat to human campylobacteriosis in the EU. EFSA Journal. 2010;**8**:1437-1526

[47] Silva J, Leite D, Fernandes M, Mena C, Gibb PA, Teixeira P. Campylobacter spp. as a foodborne pathogen: A review. Frontiers in Microbiology. 2011;**2**:1-12

[48] Buchanan RL, Gorris LGM, Hayman MM, Jackson TC, Whiting RC. A review of *Listeria monocytogenes*: An update on outbreaks, virulence, dose-response, ecology, and risk assessments. Food Control. 2017;**75**:1-13

[49] Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S. Agricultural

sustainability and intensive production practices. Nature. 2002;**418**:671-677

[50] United Nations, World Population Prospects: 2017. Revision: http://esa.un.org/unpd/wpp/

[51] Foley JA et al. Solutions for a cultivated planet. Nature. 2011;**478**:337-342

[52] Elechi JOG, Nwiyi IU, Adamu CS. Global food system transformation for resilience. In: Ribeiro-Barros AI, Tevera D, Goulao LF, Tivana LD, editors. Food Systems Resilience. London, UK: IntechOpen Limited; 2022. DOI: 10.5772/intechopen.102749

[53] Godfray HCJ, Garnett T. Food security and sustainable intensification. Philosophical Transactions of the Royal Society of London B. 2014;**369**:20120273

[54] FAO. How to Feed the World: Global Agriculture Towards 2050. FAO; 2009 www.fao.org/fileadmin/templates/wsfs/docs/Issues_papers/HLEF2050_Global_Agriculture.pdf

[55] FAO. World Agriculture Towards 2030/2050: 2012 Revision ESA Working Paper. FAO; 2012

[56] Lozano R et al. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: A systematic analysis for the global burden of disease study. 2010. The Lancet. 2013;**380**:2095-2128

[57] Sheahan M, Barrett CB, Goldvale C. Human health and pesticide use in sub-Saharan Africa. Agricultural Economics. 2017;**48**:27-41

[58] Dobson A, Foufopoulos J. Emerging infectious pathogens of wildlife. Philosophical Transactions of the Royal Society of London B. 2001;**356**:1001-1012

[59] Evenson RE, Gollin D. Assessing the impact of the green revolution, 1960 to 2000. Science. 2003;**300**:758-762

[60] Mario H, Mason-D'Croz D, Thornton PK, Fanzo J, Rushton J, Godde C, et al. Livestock and sustainable food systems: status, trends, and priority actions. In: Food Systems Summit Brief. United Nations Food Systems Summit 2021. Scientific Group; 2021. https://sc-fss2021.org/

[61] Pingali P. Westernization of Asian diets and the transformationof food systems: Implications for research and policy. Food Policy. 2007;**32**(3):281-298. DOI: 10.1016/j.foodpol.2006.08.001

[62] Duffy M. Economies of size in production agriculture. Journal of Hunger & Environmental Nutrition. 2009;**4**(3-4):375-392

[63] Gorbach SL. Antimicrobial use in animal feed—Time to stop. The New England Journal of Medicine. 2001;**345**:1202-1203

[64] Van Boeckel TP et al. Reducing antimicrobial use in food animals. Science. 2017;**357**:1350-1352

[65] Feliciano RJ, Guzm'an-Luna P, Bou'e G, Mauricio-Iglesias M, Hospido A, Membr'e J-M. Strategies to mitigate food safety risk while minimizing environmental impacts in the era of climate change. Trends in Food Science & Technology. 2022. DOI: 10.1016/j.tifs.2022.02.027

[66] WHO. Food Safety, Climate Change and the Role of WHO. 2019. https://www.who.int/publications/i/item/food-safety-climate-change-and-the-role-of-who

[67] IPCC. In: Pachauri RK, Meyer LA, editors. Climate Change 2014: Synthesis Report. Contribution

of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (Core Writing Team). 2015. https://www.ipcc.ch/report/ar5/syr/

[68] Jones BA, Grace D, Kock R, Alonso S, Rushton J, Said MY, et al. Zoonosis emergence linked to agricultural intensification and environmental change. Proceedings of the National Academy of Sciences. 2013;**110**(21):8399-8404

[69] Gould EA, Higgs S. Impact of climate change and other factors on emerging arbovirus diseases. Transactions of the Royal Society of Tropical Medicine and Hygiene. 2009;**103**(2):109-121. DOI: 10.1016/j.trstmh.2008.07.025

[70] Grace D, Mahuku G, Hoffmann V, Atherstone C, et al. International agricultural research to reduce food risks: Case studies on aflatoxins. Food Security. 2015;**7**(3):569-582. DOI: 10.1007/s12571-015-0469-2

[71] Li A, Kroeze C, Kahil T, Ma L, Strokal M. Water pollution from food production: Lessons for optimistic and optimal solutions. Current Opinion in Environmental Sustainability. 2019;**40**:88-94. DOI: 10.1016/j.cosust.2019.09.007

[72] Thomas LF, Patterson G, Coyne L, Rushton J. Countering the double-whammy of zoonotic diseases. Rural 21. 2020

[73] Béné C. Resilience of local food systems and links to food security—A review of some important concepts in the context of COVID-19 and other shocks. Food Security. 2020:1-18

[74] Hafez HM, Attia YA. Challenges to the poultry industry: Current perspectives and strategic future after the COVID-19 outbreak. Frontiers in Veterinary Science. 2020;**7**:516. DOI: 10.3389/fvets.2020.00516

[75] Kirk MD, Pires SM, Black RE, Caipo M, Crump JA, Devleesschauwer B, et al. World Health Organization estimates of the global and regional disease burden of 22 foodborne bacterial, protozoal, and viral diseases, 2010: A data synthesis. PLoS Medicine. 2015;**12**:e1001921

[76] Sharafutdinov I, Tegtmeyer N, Müsken M, Backert S. *Campylobacter jejuni* serine protease HtrA induces paracellular transmigration of microbiota across polarized intestinal epithelial cells. Biomolecules. 2022;**12**:521. DOI: 10.3390/biom12040521

[77] Burnham PM, Hendrixson DR. *Campylobacter jejuni*: Collective components promoting a successful enteric lifestyle. Nature Reviews Microbiology. 2018;**16**:551-565

[78] Heimesaat MM, Backert S, Alter T, Bereswill S. Human campylobacteriosis-a serious infectious threat in a one health perspective. Current Topics in Microbiology and Immunology. 2021;**431**:1-23

[79] European Food Safety Authority (EFSA). The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2017. EFSA Journal. 2018;**16**:5500

[80] Center for Disease Control and Prevention (CDC). National Enteric Disease Surveillance: Salmonella Annual Summary. 2019. https://www.cdc.gov/nationalsurveillance/salmonella-surveillance.html

[81] Mezal EH, Sabol A, Khan MA, Ali N, Stefanova R, Khan AA. Isolation

and molecular characterization of Salmonella entericaserovar enteritidis from poultry house and clinical samples during 2010. Food Microbiology. 2014;**38**:67-74

[82] Rivera D, Moreno-Switt AI, Denes TG, Hudson LK, Peters TL, Samir R, et al. Novel Salmonella phage, vB_Sen_STGO-35-1, characterization and evaluation in chicken meat. Microorganisms. 2022;**10**:606. DOI: 10.3390/microorganisms10030606

[83] Majowicz SE, Musto J, Scallan E, Angulo FJ, Kirk M, O'Brien SJ, et al. The global burden of nontyphoidal Salmonella gastroenteritis. Clinical Infectious Diseases. 2010;**50**:882-889

[84] Jemmi T, Stephan R. *Listeria monocytogenes*: Food-borne pathogen and hygiene indicator. Revue Scientifique et Technique de l'OIE. 2006;**25**(2):571-580

[85] Scallan E, Hoekstra RM, Angulo FJ, Tauxe RV, Widdowson MA, Roy SL, et al. Foodborne illness acquired in the United States—Major pathogens. Emerging Infectious Diseases. 2011;**17**(1):7-15

[86] South Africa, National Institute for Communicable Diseases [SANICD]. An Update on the Outbreak of *Listeria monocytogenes*. South Africa: NICD; 2019 http://www.nicd.ac.za/wp-content/uploads/2018/08/An-update-on-the-outbreak-of-Listeria-monocytogenes-South-Africa.pdf

[87] Ghandhi M, Chikindas ML. Listeria: A foodborne pathogen that knows how to survive. International Journal of Food Microbiology. 2007;**113**:1-15

[88] Garcia A, Fox JG, Besser TE. Zoonotic enterohemorrhagic *Eschericia coli*: A one health perspective. ILAR Journal. 2010;**51**(3):221-232

[89] CDC (Centers for Disease Control and Prevention). 2011. FoodNet—Foodborne Diseases Active Surveillance Network. http://www.cdc.gov/foodnet/. [Accessed: January 23, 2012]

[90] Dean AS, Crump L, Greter H, Schelling E, Zinsstag J. Global burden of human brucellosis: A systematic review of disease frequency. PLoS Neglected Tropical Diseases. 2012;**6**(10):e1865

[91] Holubová N, Zikmundová V, Limpouchová Z, Sak B, KonečnýR. and Hlásková L. *Cryptosporidium proventriculisp*. n. (Apicomplexa: Cryptosporidiidae) in Psittaciformes birds. European Journal of Protistology. 2019;**69**:70-87

[92] Müller B, Dürr S, Alonso S, Hattendorf J, Laisse CJ, Parsons SD, et al. Zoonotic Mycobacterium bovis–induced tuberculosis in humans. Emerging Infectious Diseases. 2013;**19**(6):899

[93] Li M, Havelaar AH, Hoffmann S, Hald T, Kirk MD, Torgerson PR, et al. Global disease burden of pathogens in animal source foods, 2010. PLoS One. 2019;**14**(6):e0216545

[94] Yoshida A, Doanh PN, Maruyama H. Paragonimus and paragonimiasis in Asia: an update. Acta Tropica. 2019;**199**:105074

[95] Foreyt WJ, Abbott RC, Van Riper C. Trichinosis. Circular. 2013

[96] Rostami A, Gamble HR, Dupouy-Camet J, Khazan H, Bruschi F. Meat sources of infection for outbreaks of human trichinellosis. Food Microbiology. 2017;**64**:65-71

[97] Pavel R, Ursoniu S, Paduraru AA, Lighezan R, Lupu MA, Olariu TR. Seroprevalence and risk factors of trichinella spiralis infection in blood donors from Western Romania.

Medicina. 2022;**58**:128. DOI: 10.3390/medicina58010128

[98] Hoofnagle JH, Nelson KE, Purcell RH. Hepatitis E. The New England Journal of Medicine. 2012;**367**(13):1237-1244

[99] Meng XJ. Hepatitis E virus: Animal reservoirs and zoonotic risk. Veterinary Microbiology. 2010;**140**(3-4):256-265

[100] Meng XJ. From barnyard to food table: The omnipresence of hepatitis E virus and risk for zoonotic infection and food safety. Virus Research. 2011;**161**(1):23-30

[101] Treagus S, Wright C, Baker-Austin C, et al. The foodborne transmission of hepatitis E virus to humans. Food and Environmental Virology. 2021;**13**:127-145. DOI: 10.1007/s12560-021-09461-5

[102] Rein DB, Stevens GA, Theaker J, Wittenborn JS, Wiersma ST. The global burden of hepatitis E virus genotypes 1 and 2 in 2005. Hepatology. 2012;**55**(4):988-997

[103] WHO. Monkeypox. 2022. https://www.who.int/news-room/fact-sheets/detail/monkeypox

[104] Halpin K, Hyatt AD, Fogarty R, Middleton D, Bingham J, Epstein JH, et al. Pteropid bats are confirmed as the reservoir hosts of henipaviruses: A comprehensive experimental study of virus transmission. American Journal of Tropical Medicine and Hygiene. 2011;**85**:946-951

[105] Luby SP, Gurley ES, Hossain MJ. Transmission of human infection with Nipah virus. Clinical Infectious Diseases. 2009;**49**(11):1743-1748

[106] Epstein JH, Field HE, Luby S, Pulliam JR, Daszak P. Nipah virus: Impact, origins, and causes of emergence. Current Infectious Disease Reports. 2006;**8**(1):59-65

[107] Libera K, Konieczny K, Grabska J, Szopka W, Augustyniak A, Pomorska-Mól M. Selected livestock-associated zoonoses as a growing challenge for public health. Infectious Disease Reports. 2022;**14**:63-81. DOI: 10.3390/idr14010008

[108] FAO. World Food and Agriculture—Statistical Yearbook 2021. Rome, Italy: FAO; 2021

[109] Zhou X, Wang Y, Liu H, Guo F, Doi SA, Smith C, et al. Effectiveness of market-level biosecurity at reducing exposure of poultry and humans to avian influenza: A systematic review and meta-analysis. The Journal of Infectious Diseases. 2018;**218**:1861-1875

[110] Turlewicz-Podbielska H, Pomorska-Mól M. Swine diseases caused by circoviruses and swine influenza according to data from the 11th European symposium of porcine health management (ESPHM) in Utrecht. Życie Weterynaryjne. 2019;**94**:804-809

[111] Li S, He Y, Mann DA, Deng X. Global spread of Salmonella enteritidis via centralized sourcing and international trade of poultry breeding stocks. Nature Communications. 2021;**12**:5109

[112] Tang JW, Shetty N, Lam TT-Y. Features of the new pandemic influenza a/H1N1/2009 virus: Virology, epidemiology, clinical and public health aspects. Current Opinion in Pulmonary Medicine. 2010;**16**:235-241

[113] Hilgenfeld R, Peiris M. From SARS to MERS: 10 years of research on highly pathogenic human coronaviruses.

Antiviral Research. 2013;**100**(1):286-295. DOI: 10.1016/j.antiviral.2013.08.015

[114] Knipe DM, Howley PM, Griffin D, Lamb R, Martin M. Filoviridae: Marburg and Ebola viruses. In: Fields Virology. 5th ed. Philadelphia, PA, USA: Lippincott Williams & Wilkins; 2006. pp. 1410-1448

[115] Ghareeb OA. Ebola—A fatal emerging zoonotic disease: A review. Annals of R.S.C.B. 2021;**25**(6):8748-8754

[116] Malvy D, McElroy AK, de Clerck H, Günther S, van Griensven J. Ebola virus disease. The Lancet. 2019;**393**(10174):936-948

[117] Leendertz SAJ, Gogarten JF, Düx A, Calvignac-Spencer S, Leendertz FH. Assessing the evidence supporting fruit bats as the primary reservoirs for Ebola viruses. EcoHealth. 2016;**13**(1):18-25. DOI: 10.1007/s10393-015-1053-0

[118] WHO. Introduction to Lassa Fever Managing Infectious Hazards. 2018. https://cdn.who.int/media/docs/default-source/documents/emergencies/health-topics---lassa-fever/lassa-fever-introduction.pdf?sfvrsn=b1b96509_2&download=true

[119] Shao D, Shi Z, Wei J, Ma Z. A brief review of foodborne zoonoses in China. Epidemiology & Infection. 2011;**139**(10):1497-1504

[120] Roe D, Dickman A, Kock R, Milner-Gulland E, Rihoy E. Beyond banning wildlife trade: COVID-19, conservation and development. World Development. 2020;**136**:105121

[121] FAO. (2019). The State of Food and Agriculture 2019: Moving Forward on Food Loss and Waste Reduction. http://www.fao.org/3/ca6030en/ca6030en.pdf. [Accessed: February 9, 2022]

[122] UNEP. Food Waste Index Report 2021. In United nations Environment Programme; 2021 https://www.unep.org/resources/report/unep-food-waste-index-report-2021

[123] Gauthier-Clerc M, Lebarbenchon C, Thomas F. Recent expansion of highly pathogenic avian influenza H5N1: A critical review. Ibis. 2007;**149**(2):202-214

[124] Burgos S, Burgos SA. Avian influenza outbreaks in Southeast Asia affects prices, markets and trade: A short case study. International Journal of Poultry Science. 2007;**6**(12):1006-1009

[125] Civitello DJ, Allman BE, Morozumi C, Rohr JR. Assessing the direct and indirect effects of food provisioning and nutrient enrichment on wildlife infectious disease dynamics. Philosophical Transactions of the Royal Society of London B. 2018;**373**:20170101

[126] Gross R, Schoeneberger H, Pfeifer H, Preuss HA. The Four Dimensions of Food and Nutrition Security: Definitions and Concepts. Rome, Italy: Food and Agriculture Organization of the United Nations; 2000

[127] ILRI. Project Brief: Participatory Risk Assessment of Pork in ha Noi and ha Tay, Vietnam. Improving the Competitiveness of Pig Producers in Vietnam Project Brief 3. Nairobi, Kenya: International Livestock Research Institute; 2010

[128] Cornelsen L, Alarcon P, Häsler B, Amendah DD, Ferguson E, Fevre EM, et al. Cross-sectional study of price and other drivers of demand for animal source foods in low-income urban areas of Nairobi, Kenya. BMC Nutrition. 2016;**2**:70. DOI: 10.1186/s40795-016-0109-z

[129] Grace D. Food safety in low- and middle-income countries. International Journal of Environmental Research and Public Health. 2015;**12**(9):10490-10507

[130] Barbara H, Dominguez-Salas P, Fornace K, Garza M, Grace D, Rushton J. Where food safety meets nutrition outcomes in livestock and fish value chains: A conceptual approach. Food Security. 2017. DOI: 10.1007/s12571-017-0710-2

[131] Kavle JA, El-Zanaty F, Landry M, Galloway R. The rise in stunting in relation to avian influenza and food consumption patterns in Lower Egypt in comparison to upper Egypt: Results from 2005 and 2008 demographic and health surveys. BMC Public Health. 2015;**15**. DOI: 10.1186/s12889-015-1627-3

[132] Knutie SA, Wilkinson CL, Wu QC, Ortega CN, Rohr JR. Host resistance and tolerance of parasitic gut worms depend on resource availability. Oecologia. 2017;**183**:1031-1040

[133] Young SL, Sherman PW, Lucks JB, Pelto GH. Why on earth? Evaluating hypotheses about the physiological functions of human geophagy. The Quarterly Review of Biology. 2011;**86**:97-120

[134] Pieracci GE, Hall JA, Gharpure R, Haile A, Walelign E, Deressa A, et al. Prioritizing zoonotic diseases in Ethiopia using a one health approach. One Health. 2016;**2**:131-135. DOI: 10.1016/j.onehlt.2016.09.001PMID:28220151

[135] Grace D, Gilbert J, Randolph T, Kang'ethe E. The multiple burdens of zoonotic disease and an eco-health approach to their assessment. Tropical Animal Health and Production. 2012;**44**:67-73. DOI: 10.1007/s11250-012-0209-y PMID: 22886445

[136] Alsan M. The effect of the tsetse fly on African development. The American Economic Review. 2015;**105**:382-410

[137] Ngonghala CN et al. General ecological models for human subsistence, health and poverty. Nature Ecology & Evolution. 2017;**1**:1153-1159

[138] Barrett CB, Carter MR, Chavas J. The Economics of Poverty Traps. Univ. Chicago Press; 2019

[139] Monalisa S, Panigrahi C, Aradwad P. Management strategies emphasizing advanced food processing approaches to mitigate food borne zoonotic pathogens in food system. Food Frontiers. 2022:1-25. DOI: 10.1002/fft2.153

[140] FAO–OIE–WHO Collaboration. Sharing responsibilities and coordinating global activities to address health risks at the animal–human–ecosystems interfaces. A tripartite concept note. 2010. http://www.who.int/foodsafety/zoonoses/final_concept_note_Hanoi.pdf.

[141] Xie T, Liu W, Anderson BD, Liu X, Gray GC. A system dynamics approach to understanding the one health concept. PLoS One. 2017;**12**:e0184430

[142] Sofia B, Söderqvist K, Vågsholm I. Food safety challenges and one health within Europe. Acta Veterinaria Scandinavica. 2018;**60**:1. DOI: 10.1186/s13028-017-0355-3

[143] Grace D et al. Safe food, fair food: Participatory risk analysis for improving the safety of informally produced and marketed food in sub-Saharan Africa. Revue Africaine de Santé et de Productions Animales. 2010;**8**:3-11

[144] Roesel K, Grace D. Food Safety and Informal Markets: Animal Products in Sub-Saharan Africa. 1st ed. Routledge; 2014

[145] Häsler B, Gilbert W, Jones BA, Pfeiffer DU, Rushton J, Otte MJ. The economic value of one health in relation to the mitigation of zoonotic disease risks BT. In: Mackenzie JS, Jeggo M, Daszak P, Richt JA, editors. One Health: The Human-Animal-Environment Interfaces in Emerging Infectious Diseases: The Concept and Examples of a One Health Approach. Berlin Heidelberg: Springer; 2013. pp. 127-151. DOI: 10.1007/82_2012_239

[146] Kelly TR, Karesh WB, Johnson CK, Gilardi KVK, Anthony SJ, Goldstein T, et al. One health proof of concept: Bringing a transdisciplinary approach to surveillance for zoonotic viruses at the human-wild animal interface. Preventive Veterinary Medicine. 2017;**137**:112-118

[147] American Veterinary Medical Association AVMA. One health: A new professional imperative. One Health Initiative Task Force: Final Report. 2008;**2008**. https://www.avma.org/sites/default/files/resources/onehealth_final.pdf

[148] Prudêncio M, Costa JC. Research funding after COVID-19. Nature Microbiology. 2020;**5**(8):986

[149] Zinsstag J, Utzinger J, Probst-Hensch N, Shan L, Zhou X-N. Towards integrated surveillance-response systems for the prevention of future pandemics. Infectious Diseases of Poverty. 2020;**9**(1):1-6

[150] Marshall BM, Levy SB. Food animals and antimicrobials: Impacts on human health. Clinical Microbiology Reviews. 2011;**24**(4):718-733

[151] Notarnicola B, Sala S, Anton A, McLaren SJ, Saouter E, Sonesson U. The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges. Journal of Cleaner Production. 2017;**140**:399-409. DOI: 10.1016/j.jclepro.2016.06.071

[152] Cycle Initiative L. What is Life Cycle Thinking?. 2016. https://www.lifecycleinitiative.org/starting-life-cycle-thinking/what-is-life-cycle-thinking/. [Accessed: January 20, 2021].

[153] Saouter E, Aschberger K, Fantke P, Hauschild MZ, Kienzler A, Paini A, et al. Improving substance information in USEtox®, part 2: Data for estimating fate and ecosystem exposure factors. Environmental Toxicology & Chemistry. 2017;**36**(12):3463-3470. DOI: 10.1002/etc.3903

[154] Environmental Protection Agency. 2017 National Emissions Inventory (NEI) Data Air Emissions Inventories. 2021. https://www.epa.gov/air-emissions-inventories/2017-national-emissions-inventory-nei-data

[155] NREL. U.S. Life Cycle Inventory Database. 2012. https://www.lcacommons.gov/nrel/search. [Accessed: January 20, 2021]

[156] Thakrar SK, Goodkind AL, Tessum CW, Marshall JD, Hill JD. Life cycle air quality impacts on human health from potential switchgrass production in the United States. Biomass and Bioenergy. 2018;**114**(June 2016):73-82. DOI: 10.1016/j.biombioe.2017.10.031

[157] Shanker R, Singh G, Jyoti A, Dwivedi PD, Singh SP. Nanotechnology and detection of microbial pathogens. In: Animal Biotechnology. Academic Press; 2020. pp. 593-611

[158] Kazi M, Annapure US. Bacteriophage biocontrol of foodborne pathogens. Journal of Food Science and Technology. 2016;**53**:1355-1362

[159] Rivera H, Hamilton-West D, Moreno-Switt P. Two Phages of the

genera Felixounavirus subjected to 12 hour challenge on Salmonella Infantis showed. Distinct Genotypic and Phenotypic Changes. Viruses. 2019;**11**:586

[160] EFSA and ECDC. The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2015. EFSA Journal. 2016;**14**(12):4634. DOI: 10.2903/j.efsa.2016.4634

[161] Jahan NA, Lindsey LL, Kipp EJ, Reinschmidt A, Heins BJ, Runck AM, et al. Nanopore-based surveillance of zoonotic bacterial pathogens in farm-dwelling Peridomestic rodents. Pathogens. 2021;**10**:1183. DOI: 10.3390/pathogens10091183

[162] Sheahan T, Hakstol R, Kailasam S, Glaister GD, Hudson AJ, Wieden H-J. Rapid metagenomics analysis of EMS vehicles for monitoring pathogen load using nanopore DNA sequencing. PLoS One. 2019;**14**:e0219961

[163] Goodwin S, McPherson JD, McCombie WR. Coming of age: Ten years of next-generation sequencing technologies. Nature Reviews Genetics. 2016;**17**:333

[164] Tyler AD, Mataseje L, Urfano CJ, Schmidt L, Antonation KS, Mulvey MR, et al. Evaluation of Oxford Nanopore's MinION sequencing device for microbial whole genome sequencing applications. Scientific Reports. 2018;**8**:123

[165] Byrd AL, Belkaid Y, Segre JA. The human skin microbiome. Nature Reviews. Microbiology. 2018;**16**:143

[166] Azinheiro S, Kant K, Shahbazi M-A, Garrido-Maestu A, Prado M, Dieguez L. A smart microfluidic platform for rapid multiplexed detection of foodborne pathogens. Food Control. 2020;**114**:107242. DOI: 10.1016/j.foodcont.2020.107242

[167] Sahoo M, Vishwakarma S, Panigrahi C, Kumar J. Nanotechnology: Current applications and future scope in food. Food Frontiers. 2021;**2**(1):3-22

[168] Gilmartin N, O'Kennedy R. Nanobiotechnologies for the detection and reduction of pathogens. Enzyme and Microbial Technology. 2012;**50**(2):87-95

[169] Manuja A, Kumar B, Singh RK. Nanotechnology developments: Opportunities for animal health and production. Nanotechnology Development. 2012;**2**:e4. DOI: 10.4081/nd.2012.e4

[170] Zhang D, Carr DJ, Alocilja EC. Fluorescent bio-barcode DNA assay for the detection of *Salmonella enterica serovar enteritidis*. Biosensors and Bioelectronics. 2009;**24**(5):1377-1381