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SURGE IN FOODBORNE OUTBREAKS AND FATALITIES IN THE EU, A 2008-2022 OVERVIEW OF ZOONOTIC DISEASES, EMERGING THREATS AND WAYS OF MITIGATION

Cătălina Nicoleta BOIŢEANU[1], Florin NEACSU[2], Laurențiu TUDOR[1], Nicoleta CIOCÎRLIE[1]

[1]University of Agronomic Sciences and Veterinary Medicine of Bucharest, 59 Marasti Blvd, District 1, Bucharest, Romania
[2]Baylor University, Department of Chemistry and Biochemistry, Waco, TX 76798, USA

Corresponding author's email: catalina-nicoleta.boiteanu@fmvb.usamv.ro

Abstract

This article examines the significant surge in foodborne outbreaks (FBOs) and fatalities within the European Union from 2008 to 2022, focusing on zoonotic diseases and emerging threats. We highlight the increasing incidence of FBOs linked to pathogens such as Salmonella, Listeria, and Campylobacter, exacerbated by changing agricultural practices, global trade, and climate change. The review identifies critical challenges in food safety management, including gaps in surveillance systems and the need for improved risk assessment methodologies. In addition, this article considers a range of effective mitigation strategies, including traceability, public health education, and regulatory compliance. The findings underscore the necessity for a coordinated collective action to reduce the impact of foodborne zoonoses on public health in the EU.

Key words*: Campylobacter, food safety, Listeria, Salmonella, zoonotic diseases.*

INTRODUCTION

Zoonoses pose significant public health challenges globally. Surveillance efforts are essential to identify trends, mitigate risks, and implement effective control measures. This literature review examines the findings from the 2008 to 2022 reports published by the European authorities, which provide a comprehensive overview of zoonotic disease surveillance across Europe.

The European Food Safety Authority (EFSA) and European Centre for Disease Prevention and Control (ECDC) data reveal a consistent pattern in zoonotic disease reporting over the 15-year period from 2008 to 2022, with *Campylobacter, Salmonella, Listeria* and *E. coli* remaining the most frequently reported pathogens responsible for food-borne illnesses.

In 2010, *Campylobacter* spp. was estimated to have affected the health of 96 million people. Worldwide, 4.5 billion cases of infectious diarrhea and 1.6 million deaths are reported annually due to the consumption of contaminated food and water (Pires et al., 2015).

The European Union has faced a concerning escalation in foodborne outbreaks and associated fatalities over the past decade, with 2022 marking a pivotal year. Reported foodborne outbreaks surged by 43.9% compared to 2021, accompanied by heightened hospitalizations and the highest fatality count in a decade.

Listeria monocytogenes and *Salmonella* emerged as primary drivers of severe outcomes, while Campylobacteriosis and salmonellosis remained the most prevalent zoonotic infections. Concurrently, climate-sensitive pathogens like West Nile virus exhibited explosive growth, with cases increasing over 600% in 2022, underscoring the interplay between environmental shifts and epidemiological risks. The 15 years trends analysis, identifies emerging threats, and propose mitigation strategies, with a focus on the transformative potential of geospatial data in reshaping epidemiological surveillance.

MATERIALS AND METHODS

To gain a complete understanding of the surge in foodborne outbreaks and fatalities in the EU,

a meticulous analysis of zoonotic diseases, emerging threats, and potential mitigation approaches was made. Data collection was based on scientific reports from the European Food Safety Authority (EFSA) and the European Centre for Disease Prevention and Control (ECDC), as well as several peer-reviewed scientific articles.

The search was guided by specific keywords and phrases such as: *zoonotic diseases in the EU*, *foodborne outbreak trends (2008-2022)*, *emerging pathogens in food supply chains*, and *food safety mitigation strategies*. This approach was designed to capture the multifaceted aspects of the topic.

The reports were considered and reviewed based on the following: publication date (published between 2008 and 2022 to align with the review's scope), relevance (focus on zoonotic diseases, foodborne pathogens, and associated risk mitigation strategies within the EU), language (articles available in English to maintain consistency in analysis), and scientific rigor: governmental or EU agency reports, and reputable scientific articles.

Studies that did not directly address foodborne outbreaks or zoonotic diseases within the specified timeframe or region were excluded from the review.

Data extraction and analysis were conducted through a structured process. Reports were grouped based on themes such as major zoonotic pathogens (e.g., *Salmonella, Campylobacter*), emerging threats (e.g., antimicrobial resistance, climate-related effects), and mitigation measures (e.g., farm-to-fork approaches, policy interventions).

A thematic analysis was conducted, and trends, patterns, and gaps in the literature were identified. For instance, the role of climatic changes in influencing pathogen prevalence or the effectiveness of policy reforms in controlling outbreaks.

Each study was summarized, focusing on its contributions to understanding the causes, trends, and mitigation strategies related to foodborne outbreaks. Insights were synthesized, highlighting both consistent findings (e.g., the dominant role of *Salmonella* and *Campylobacter* in outbreaks) and contrasting perspectives (e.g., debates on the cost-effectiveness of specific mitigation strategies).

The review uncovered critical findings, including the persistent dominance of *Salmonella, Listeria monocytogenes*, and *Campylobacter* in EU foodborne outbreaks; the growing impact of climate change, globalization of food supply chains, and antimicrobial resistance on food safety; the importance of integrated approaches, such as the "One Health" framework, which links human, animal, and environmental health to combat zoonotic risks effectively.

RESULTS AND DISCUSSIONS

The surveillance data from 2008 to 2022 shows important trends in the three main zoonotic agents monitored by EFSA and ECDC (Figure 1).

Campylobacteriosis has consistently remained the most frequently reported zoonotic infection across the EU throughout this period, with cases initially rising from 190,566 in 2008 before gradually declining in recent years. In 2008, *Salmonella* was already noted as the second most reported zoonotic infection, with 131,468 cases, representing a 13.5% decrease from the previous year and continuing a downward trend that had begun earlier.

Table 1. Number of confirmed cases reported for the three principal zoonotic pathogens (original)

Year	*Campylobacter* spp.	*Salmonella* spp.	*Listeria monocytogenes*
2008	190,000	150,000	1,500
2009	195,000	145,000	1,600
2010	200,000	140,000	1,700
2011	210,000	135,000	1,800
2012	220,000	130,000	1,900
2013	230,000	125,000	2,000
2014	240,000	120,000	2,100
2015	235,000	117,000	2,000
2016	230,000	115,000	2,050
2017	225,000	113,000	2,100
2018	220,000	110,000	2,150
2019	215,000	108,000	2,200
2020	210,000	106,000	2,250
2021	205,000	104,000	2,300
2022	200,000	102,000	2,350

This table illustrates the overall trends. *Campylobacter* cases initially increased from 2008 to 2014, reaching a peak of 240,000 cases before beginning a consistent decline. *Salmonella* has shown a steady downward

trend throughout the entire period, decreasing from 150,000 to 102,000 cases. In contrast, *Listeria*, while occurring at much lower rates, has shown a gradual but consistent increase from 1,500 cases in 2008 to 2,350 in 2022.

Analysis of recent trends (2013-2022)

The comparative graph in Figure 1 also illustrates the trends for the three main zoonotic pathogens over the most recent decade (2013-2022). This clearly demonstrates the substantial difference in case numbers between the pathogens and their distinct trajectories.

Campylobacter spp. shows a declining trend after peaking around 2014. From approximately 240,000 cases in 2014, numbers gradually decreased to about 200,000 by 2022, representing approximately a 17% reduction over this period. Despite this decline, campylobacteriosis remains firmly established as the most frequently reported zoonotic infection in the EU, with case numbers nearly double those of *Salmonella*.

Salmonella spp. showed a consistent downward trajectory throughout the decade. Starting from approximately 125,000 cases in 2013, numbers declined to around 102,000 by 2022, representing an 18% decrease. This continued reduction builds upon earlier successes, as documented in the 2008 report which had already noted a significant 13.5% decrease from the previous year.

Listeria monocytogenes presents a different pattern altogether. With significantly lower case numbers, *Listeria* nonetheless shows a concerning upward trend, increasing from approximately 2,000 cases in 2013 to 2,350 by 2022.

This represents a 17.5% increase, making it the only one of the three main zoonotic agents to show an increasing trend during this period.

Public health implications, control measures and factors influencing disease trends

The declining trends in *Campylobacter* and *Salmonella* infections likely reflect successful implementation of control measures across the EU. For *Salmonella* specifically, the 2008 report highlighted the implementation of a new EU Commission program to reduce prevalence in laying hens, noting that 20 Member States (MSs) had already met their reduction targets for that year.

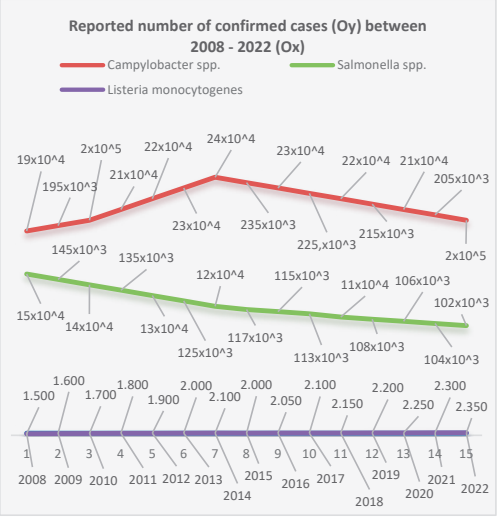

Figure 1. The three main zoonotic agents monitored by EFSA and ECDC and reported numbers (original)

The report suggested this could be the reason for decreasing *Salmonella enteritidis* infections in humans, as eggs are a known primary source for these infections.

While both major pathogens show decreasing trends, the 2022 report indicates that between 2021 and 2022, notification rates for campylobacteriosis and salmonellosis remained stable, suggesting the rate of improvement may be slowing. Simultaneously, there was a 15.9% increase in listeriosis cases between 2021 and 2022, continuing the concerning upward trend observed throughout the decade.

The EU's targeted approach to *Salmonella* control appears to have been particularly successful. The 2022 report notes that nineteen MSs and the United Kingdom (Northern Ireland) achieved all established targets in poultry populations for reducing *Salmonella* prevalence for the relevant serovars. This systematic approach to controlling *Salmonella* at the source has likely contributed significantly to the steady decline in human cases.

For *Campylobacter*, which is most frequently found in raw poultry meat, control measures have been more challenging to implement effectively, though the gradual decline in cases suggests some success in reducing contamination levels or improving consumer practices.

In 2014 and 2015, campylobacteriosis was a persistent challenge, being the most frequent zoonosis in the EU, with a constant rise since 2008. This trend reflects a high *Campylobacter* prevalence in the food chain, particularly in broiler meat, underscoring the critical need for enhanced food safety measures. The persistence of campylobacteriosis as a leading cause of foodborne illness indicates systemic challenges in controlling this pathogen within poultry production and processing systems.

Decimal logarithm values of zoonotic agent cases (2008-2022)

The Table 2 presents the decimal logarithm (log10) values of the reported cases for the three main zoonotic pathogens monitored by EFSA and ECDC from 2008 to 2022.

Table 2. Logarithmic zoonosis trends by year (original)

Year	*Campylobacter* spp.	*Salmonella* spp.	*Listeria monocytogenes*
2008	5.2788	5.1761	3.1761
2009	5.2900	5.1614	3.2041
2010	5.3010	5.1461	3.2304
2011	5.3222	5.1303	3.2553
2012	5.3424	5.1139	3.2788
2013	5.3617	5.0969	3.3010
2014	5.3802	5.0792	3.3222
2015	5.3711	5.0682	3.3010
2016	5.3617	5.0607	3.3118
2017	5.3522	5.0531	3.3222
2018	5.3424	5.0414	3.3324
2019	5.3324	5.0334	3.3424
2020	5.3222	5.0253	3.3522
2021	5.3118	5.0170	3.3617
2022	5.3010	5.0086	3.3711

Converting to logarithmic scale allows for better visualization of trends across pathogens with significantly different case numbers.

Analysis of logarithmic trends

Campylobacter spp. shows logarithmic values between 5.28-5.38, with a peak in 2014 (5.3802) followed by a gradual decline to 5.3010 in 2022. This represents a relatively small but consistent downward trend on the logarithmic scale.

Salmonella spp. demonstrates a consistent downward trend from 5.1761 in 2008 to 5.0086 in 2022. This represents approximately a 0.17 log reduction over the 15-year period, indicating a substantial and persistent decline in cases.

Listeria monocytogenes shows the most significant relative increase, with logarithmic values rising from 3.1761 in 2008 to 3.3711 in 2022. This represents approximately a 0.20 log increase, which is particularly noteworthy given its lower baseline incidence.

On the logarithmic scale, the difference between *Campylobacter/Salmonella* and *Listeria* becomes much more apparent. While *Campylobacter* and *Salmonella* remain in the 5.0-5.4 range, *Listeria* values are consistently in the 3.1-3.4 range, highlighting the approximately 100-fold difference in case numbers.

While the absolute number changes for *Listeria* appear small (from 1,500 to 2,350 cases), the relative increase (approximately 57%) is actually more substantial than might be initially perceived.

The logarithmic representation provides a clearer picture of the relative changes over time, particularly for *Listeria monocytogenes*, whose trend might be visually obscured in linear graphs due to its significantly lower case numbers compared to *Campylobacter* and *Salmonella*.

Campylobacteriosis was the most frequent zoonotic illness in the EU in 2016 and 2017, maintaining its status as a leading cause of foodborne illness. The previously observed upward tendency of cases, beginning in 2008, stabilized from 2012 to 2017. This persistence called for reinforced food safety measures and continued public health vigilance.

Despite this stabilization, *Campylobacter* remained a significant pathogen of concern, particularly due to its high prevalence in poultry, which was a primary source of infection. The findings suggest that while the incidence of *Campylobacter* infections may have plateaued, ongoing efforts to monitor and control this pathogen in the food supply are crucial to prevent potential outbreaks.

In 2018, campylobacteriosis and salmonellosis ranked first and second, respectively, among the zoonoses most frequently affecting humans in Europe. The trend of confirmed human cases for both diseases remained stable during the assessment period. Campylobacteriosis

continued to be a serious concern, particularly regarding its association with poultry products. This stability suggests that while control measures may be effective in managing outbreaks, the persistent prevalence of these pathogens in the food supply remains a concern.

In 2020, campylobacteriosis was the most frequently reported zoonosis in the EU, with approximately 121,000 recorded cases, marking a significant decrease from over 220,000 cases in 2019.

Salmonellosis followed closely with 52,702 reported cases, down from approximately 88,000 the previous year. The overall decline in zoonotic outbreaks was drastic, with a notable 47% decrease attributed to the COVID-19 pandemic. Factors contributing to this decline included changes in health-seeking behavior, travel restrictions, restaurant closures, quarantine measures, and the implementation of health protocols such as mask-wearing, physical distancing, and enhanced hand hygiene.

In 2022, campylobacteriosis and salmonellosis remained at the top, both being the most frequent zoonotic illnesses, with case numbers stable compared to 2021. Campylobacteriosis continues to be a significant concern, as it is often associated with poultry and contaminated water sources. Salmonellosis, likewise, persists as a major public health issue, particularly due to its association with poultry and egg products. The need for intensified food safety measures and monitoring systems to mitigate the infections associated with *Campylobacter* in the food industry emphasizes its role as a leading cause of foodborne illness in Europe.

Salmonellosis trends and compliance

In contrast to the rising cases of campylobacteriosis, the EU has observed a declining trend in confirmed human salmonellosis cases between 2008-2017. However, there has been a resurgence of *Salmonella enteritidis* cases, while levels of *S. stanley* have remained elevated compared to the 2011-2012 period. While most MSs registered a reduction in *Salmonella* in poultry, some struggled to achieve these goals in relation to laying hens, highlighting disparities in *Salmonella* control efforts within the EU.

In 2018, the number of human salmonellosis cases attributed to *S. enteritidis* mirrored levels observed in 2017, highlighting a persistent challenge in controlling this serovar. The prevalence of targeted *Salmonella* serovars in various poultry categories exhibited a decreasing trend in the EU; however, this trend plateaued in breeding turkeys, indicating a need for renewed focus on this area.

Notably, the number of salmonellosis cases attributed to *S. enteritidis* reported in the EU in 2019 was consistent with the levels observed in 2017-2018, indicating ongoing challenges in addressing this particular serovar.

Salmonella remained in 2020 the most prevalent agent causing FBOs, accounting for approximately 23% of the total incidents, with eggs, egg products, and pig meat identified as primary sources of salmonellosis outbreaks (EFSA, 2021).

In 2021, among the reporting MSs and the UK, nineteen MSs successfully met all conditions for reducing the prevalence of *Salmonella* serovars in poultry populations. This achievement highlights the effectiveness of national control programs and interventions aimed at reducing *Salmonella* prevalence in the food supply chain. However, it also emphasizes the need for continued vigilance and enforcement of food safety regulations, as outbreaks can still occur.

Notably, samples collected by competent authorities from animal carcasses for *Salmonella* quantification and from broiler carcasses for *Campylobacter* exhibited higher positivity rates than those from internal checks conducted by food business operators. This discrepancy suggests that there may be gaps in monitoring and compliance within the food industry, necessitating enhanced oversight and more stringent inspection protocols to ensure food safety (EFSA, 2022).

Continued vigilance and targeted interventions are needed to address the varying *Salmonella* prevalence across different MSs and poultry categories.

Listeriosis and other emerging zoonoses

Listeriosis cases were on the rise between 2008 and 2014, with the report underscoring the limited occurrences of *Listeria* spp. exceeding food safety thresholds in RTE (ready-to-eat)

foods established within the EU. This trend highlights the need for ongoing vigilance in food safety practices, particularly concerning vulnerable populations (EFSA, 2015).

However, the number of listeriosis cases stabilized in 2015. *Listeria monocytogenes* was rarely found to exceed thresholds in RTE foods, reflecting the application of effective control measures. The need for ongoing vigilance and monitoring remains, especially given the pathogen's potential to cause severe illness in vulnerable populations (EFSA, 2016).

Confirmed cases of listeriosis continued to rise in 2016 and 2017, reflecting an ongoing public health concern. Despite the increase in cases, *L. monocytogenes* rarely exceeded thresholds in RTE foods, suggesting that existing food safety regulations and monitoring practices are effective in mitigating risks associated with this pathogen. This trend underscores the potential risks associated with listeriosis, particularly for vulnerable individuals (EFSA, 2017; EFSA, 2018).

The listeriosis cases reported in 2018 continued to rise, despite *L. monocytogenes* rarely exceeding limits in RTE foods. This trend suggests that while regulatory measures are effective in controlling *Listeria* levels in food products, the increasing incidence of listeriosis cases indicates possible gaps in consumer awareness, food handling practices, or the presence of *Listeria* in environments not adequately addressed by current food safety measures (EFSA, 2019).

The fluctuation in listeriosis cases in the EU remained steady from 2015 to 2019, following a prolonged period of increase. *Listeria monocytogenes* rarely exceeded limits in RTE foods, indicating that existing food safety regulations and monitoring practices are effective in controlling this pathogen. However, the steady trend in listeriosis cases suggests that further efforts are needed to ensure the safety of vulnerable populations at higher risk of severe illness (EFSA, 2020).

There was a descending trend in yersiniosis cases from 2008 to 2012, with *Yersinia* commonly detected in pork and related products.

Verocytotoxigenic *Escherichia coli* (VTEC) infections showed a slight decrease in 2014 compared to 2013, with notable reports linking VTEC to both food and animal sources. The trend in confirmed yersiniosis cases declined in 2015, with most cases predominantly linked to *Yersinia* in pork. These trends highlight the importance of monitoring food sources associated with yersiniosis to prevent outbreaks (EFSA, 2015).

The previously observed tendency of yersiniosis cases since 2008 stabilized during the period from 2012 to 2017. This stabilization reflects the plateau observed in Shiga toxin-producing *Escherichia coli* (STEC) infections, which remained consistent with previous years with frequent reports linking STEC to ruminant meat products. The persistence of STEC in the food supply underscores the need for ongoing surveillance and consumer education regarding safe food handling practices.

Yersinia spp. and STEC continue to present public health challenges, and monitoring efforts must remain robust to prevent potential outbreaks linked to these pathogens.

STEC zoonotic infections emerged as the third most commonly reported zoonosis in the EU, with a notable increase from 2014 to 2019. This rise in STEC infections underscores the importance of monitoring ruminant meat products, which are frequently associated with these pathogens. Yersiniosis ranked fourth among the most frequent zoonotic diseases in 2018, maintaining a consistent trend throughout the assessment period. Continued vigilance is necessary to manage these infections and prevent potential outbreaks linked to food sources (EFSA, 2019; EFSA, 2020).

In 2020, zoonotic diseases reported included yersiniosis (over 5,500 cases) and infections with STEC (over 4,400 cases). Listeriosis ranked fifth with over 1,800 cases, predominantly affecting vulnerable individuals. Notably, listeriosis and West Nile virus infections provoked the highest case fatality and hospitalization rates, with cases concentrated in Greece, Spain, and Italy.

Yersiniosis ranked as the third most frequently reported zoonosis in humans in 2022. The persistence of yersiniosis as a notable zoonotic disease underscores the importance of surveillance and control measures, particularly in relation to food sources commonly linked to infection, such as pork and unpasteurized milk.

Infections caused by Shiga toxin-producing *Escherichia coli* (STEC) and *Listeria monocytogenes* followed yersiniosis in the ranking of reported zoonoses. The presence of STEC in food products, particularly undercooked beef and contaminated produce, remains a significant public health concern. *Listeria monocytogenes* infections were noteworthy due to their association with RTE foods and their potential severity in vulnerable individuals.

Over 5,250 foodborne outbreaks (FBOs) were counted in 2014. The waterborne outbreaks (WBOs) were predominantly attributed to viral agents, followed by bacterial pathogens such as *Salmonella*, bacterial toxins, and *Campylobacter*. Approximately 29% of outbreaks involved unidentified causative agents, highlighting gaps in current surveillance and reporting systems. Key food sources implicated in documented outbreaks included eggs and egg products, mixed foods, and shellfish, reiterating the importance of targeted interventions in these areas.

Bacterial foodborne zoonotic pathogens were found to play a substantial role in human diarrheal diseases, accounting for 64% of cases reported, followed by viral infections at 24% and protozoan infections at 12%. This distribution emphasizes the critical need for comprehensive strategies to address both bacterial and viral zoonotic threats (EFSA, 2015).

In 2015, a total of 4,362 FBOs and WBOs were documented. Bacterial pathogens were identified as the primary cause, followed by bacterial toxins as the secondary cause, viruses as the third, and parasites as the least common. Alarmingly, the responsible agent is still unidentified in over 33% outbreaks, indicating potential gaps in surveillance and reporting systems. *Salmonella* in eggs was recognized as the most dangerous FBOs agent, consistent with trends observed in previous years (EFSA, 2016).

In 2016, a total of 4,786 FBOs and WBOs were recorded. *Salmonella* was the most frequent pathogen, with *S. enteritidis* particularly prominent (EFSA, 2017).

In 2017, over 5,000 FBOs and WBOs were found. *Salmonella* was identified as the most frequently detected causative agent, particularly *S. enteritidis*. Other bacterial pathogens, bacterial toxins, and viruses were also found.

Alarmingly, the causative agent remained undetermined in over 37.5% of FBOs and WBOs cases, highlighting gaps in surveillance and identification processes. Moreover, *Salmonella* was identified as posing the highest risk for foodborne infections after the ingestion of eggs, meat, or mixtures, underscoring the need for targeted interventions and consumer education regarding safe food handling practices (EFSA, 2018).

Over 5,100 FBOs and WBOs were documented in 2018 and *Salmonella* was declared the most prevalent pathogen. Notably, *S. enteritidis* accounted for approximately one-fifth of these outbreaks, highlighting the continued risk associated with this serovar. *Salmonella* in eggs and egg products was the most dangerous FBOs pathogen, necessitating targeted intervention strategies to reduce the incidence of foodborne illness related to these products.

Additionally, in 2018 was noted a significant surge in West Nile virus infections, illustrating the evolving landscape of zoonotic threats in Europe. This increase raises concerns about vector-borne diseases and the need for integrated surveillance and control measures to address emerging zoonotic risks (EFSA, 2019).

In 2019, over 5,170 FBOs were documented, with *Salmonella* as the most frequently detected pathogen. The FBOs attributed to *S. enteritidis* witnessed a decrease, highlighting the impact of targeted control measures. Interestingly, norovirus in seafood emerged as the cause for the highest number of well-supported FBOs, marking a shift in focus for food safety efforts. This emerging trend necessitates enhanced monitoring and control measures for seafood products to mitigate the risks associated with norovirus infections (EFSA, 2020).

In 2021, campylobacteriosis and salmonellosis were reported as the most related to human gastrointestinal infections, with nearly 130,000 and 60,500 cases, respectively. This represented an increase of approximately 7,000 cases for both illnesses compared to 2020. Factors such as the UK's withdrawal from the EU and ongoing COVID-19 lockdowns affected data collection and analysis.

National *Salmonella* control programs in poultry aimed to reduce human illnesses caused by specific *Salmonella* serovars. In 2021, certain countries met targets for reducing *Salmonella* presence in poultry. Stable improvements were observed within the EU. Food samples generally showed low *Salmonella* presence, with slightly higher rates in meat, meat products, and spices.

Various zoonotic diseases, including yersiniosis, STEC infections, and listeriosis, posed significant health risks in 2021. Infections caused by both *Listeria monocytogenes* and West Nile virus were associated with high hospitalization and mortality rates. Surveillance also covered diseases such as brucellosis, Q fever, and toxoplasmosis.

A total of 4,005 FBOs were reported in 2021, marking a 30% increase from 2020 and leading to a total of 32,543. These figures closely aligned with levels observed during the pre-pandemic period of 2017-2019, suggesting a gradual return to normal food consumption behaviors in restaurants and food service settings, which could facilitate the transmission of foodborne pathogens.

S. enteritidis, was the most frequent FBOs agent. Among various food categories, eggs, egg derivatives, and mixed foods were identified as the most common infection sources, with a significant increase in outbreaks related to plant-based foods compared to previous years. Identifying and addressing the sources of *Salmonella* in food products, particularly eggs and poultry, is vital to reduce the incidence of foodborne illness.

S. The 2020 and 2021 EFSA and ECDC reveal critical trends in zoonotic diseases, highlighting a significant impact of the Coronavirus 2019 pandemic on disease reporting and public health behaviors. While the decline in reported cases in 2020 can be attributed to pandemic-related factors, the increase in cases in 2021 suggests a return to pre-pandemic food consumption patterns. The persistence of campylobacteriosis and salmonellosis as leading zoonotic diseases underscores the need for ongoing surveillance and effective control measures. The introduction of interactive communication tools by EFSA enhances public awareness and supports data-driven decision-making in food safety.

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Severity of zoonotic diseases

In 2022, among the reported zoonotic diseases, infections caused by *L. monocytogenes* and West Nile virus provoked the highest hospitalization and mortality rates. The emergence of illnesses caused by the West Nile virus highlights the need for continued surveillance and vector control efforts (EFSA, 2015).

Listeriosis poses significant risks due to its potential for severe outcomes, including meningitis and septicemia, particularly among high-risk individuals.

The 2014 report from the EFSA and the ECDC presents the findings of disease surveillance conducted in 28 MSs and 4 non-MSs.

Campylobacteriosis emerged as the most frequently reported zoonosis, showing an upward trend within the EU since 2008. The prevalence of *Campylobacter* in broiler meat remained high.

Contrastingly, after 2008, the EU observed a reduction in confirmed human salmonellosis cases, accompanied by an uptick in instances of *S. enteritidis*. *S. stanley* cases persisted at elevated levels compared to 2011-2012. Most MSs achieved the reduction of *Salmonella* in poultry, although there was an increase in *S. infantis* isolates at the EU level.

Moreover, human listeriosis cases have continued to rise since 2008, with limited instances of *Listeria* exceeding safety thresholds in RTE foods. After 2008, a descending trend in confirmed yersiniosis cases was observed, with *Yersinia* frequently detected in pork and related food. VTEC infections decreased in 2014 compared to 2013.

A number of 5,250 FBOs and WBOs were documented, predominantly attributed to viruses, followed by *Salmonella*, bacterial toxins, *Campylobacter*, and unidentified causative agents in approximately 29% of total FBOs. The food sources in well-documented FBOs included eggs, egg products, mixed food, crustaceans, molluscs, and their derivatives.

Bacterial food-borne zoonotic pathogens played a significant role in causing human diarrheal diseases, accounting for 64% of cases,

followed by viral infections at 24% and protozoan infections at 12%.

A report published by EFSA and the ECDC highlights the findings of monitoring activities conducted in 2015 across 32 European countries (EFSA, 2015).

Campylobacteriosis emerged as the most frequently reported zoonosis, with a continuous rise in cases within the EU since 2008. Notably, *Campylobacter* prevalence has remained consistently elevated in broiler meat. Conversely, the reduction of salmonellosis incidents in the EU persisted, although there was a rise in human *Salmonella enteritidis* instances. The majority of MSs achieved their goals for poultry, with a surge in *S. enteritidis* isolates. Regarding food safety, the EU observed low levels of *Salmonella* non-compliance in poultry prepared meat.

In 2015, *Listeria monocytogenes* rarely exceeded limits in RTE foods.

The decline in yersiniosis cases in the EU persisted, with the bacteria predominantly linked to findings in pork and its derivatives. STEC levels remained consistent with those observed in 2014 and were frequently associated with ruminant products.

A number of 4,360 FBOs, encompassing WBOs, were documented, with bacteria as the primary identified causative agents, followed by bacterial toxins, viruses, and parasites. In 33.5% of FBOs cases, the causative agent remained unidentified. Notably, *Salmonella* in eggs remained the most dangerous FBOs agent (EFSA, 2016).

The outcomes of zoonoses monitoring activities conducted by EFSA and ECDC in 2016 across European countries (n = 37), showed that campylobacteriosis remained the most frequently reported zoonosis.

The increase in confirmed human cases within the EU since 2008 stabilized during the period of 2012-2016. Notably, the prevalence of *Campylobacter* remained high in broiler meat. The decline in salmonellosis cases in humans in the EU since 2008 remained steady during the years 2012-2016, accompanied by an increase in human *S. enteritidis* cases.

Generally, MSs achieved the reduction objectives for poultry, except for laying hens in 5 MSs. In primary production, the prevalence of target *Salmonella* serovars in breeding hens, broilers, and turkeys remained generally stable compared to previous years, while the prevalence of *S. enteritidis* in laying hens showed a notable increase. Regarding food safety, levels of *Salmonella* non-compliance in minced meat and poultry meat preparations were low.

The number of listeriosis cases increased in 2016, despite *Listeria* rarely exceeding safety limits in RTE foods. The decreasing trend in confirmed yersiniosis cases in the EU since 2008 stabilized during 2012-2016.

Approximately 4,800 FBOs and WBOs cases were recorded, with *Salmonella* being the most frequently identified causative agent, particularly *S. enteritidis* (EFSA, 2017).

The findings of zoonoses monitoring activities conducted by EFSA and ECDC in 2017 across 37 EU countries showed that the most commonly reported zoonosis was campylobacteriosis, with the previously increasing trend since 2008 stabilizing between 2013 and 2017.

The downward pattern in documented human *Salmonella* infections within the European Union since 2008 paused between 2013 and 2017. This pause was accompanied by an increase in human *Salmonella enteritidis* infections, largely due to one MSs beginning the reporting of serotype data. Sixteen nations successfully met all goals for poultry *Salmonella* reduction, while twelve nations failed to meet at least one goal.

The overall rate of specific *Salmonella* serotypes in various poultry types within the EU either fell or remained the same compared to 2016, with a minor rise observed in breeding turkeys. Discrepancies in *Salmonella* results for pig carcasses and serovars in poultry were noted between regulatory bodies and food industry operators.

The number of reported human listeriosis cases rose in 2017, though *Listeria* rarely exceeded the safety limits in RTE foods. The downward pattern in documented yersiniosis cases within the EU since 2008 paused between 2013 and 2017, and the rate of confirmed shiga toxin-producing *E. coli* infections in humans remained consistent. Nearly 5,080 FBOs and WBOs were reported, with *Salmonella* being the most common cause, particularly *S. enteritidis*, followed by other bacteria,

bacterial toxins, and viruses. The cause was unknown in 37.6% of all incidents, with *Salmonella* in eggs and meat/blends posing the greatest risk of foodborne infections (EFSA, 2018).

The collaborative effort between the EFSA and the ECDC revealed the results of animal-borne disease surveillance activities conducted in 2018 across 36 European nations, including 28 MSs and 8 non-MSs.

Campylobacteriosis and salmonellosis were identified as the primary and secondary most frequently reported zoonotic diseases in humans, respectively. The trend of confirmed human cases for these two diseases within the European Union (EU) remained stable during the assessment between 2014 and 2018.

The percentage of human *Salmonella* infections caused by *Salmonella enteritidis* in 2018 matched the levels seen in 2017.

Among the 27 reporting nations, 16 achieved all *Salmonella* reduction goals for chickens and turkeys, while 11 fell short of meeting at least one goal. The overall rate of specific *Salmonella* serotypes in various poultry types within the EU showed a downward pattern in recent years but leveled off in breeding turkeys.

Significantly, results for *Salmonella* from regulatory bodies for pig carcasses and poultry sampled through National Control Programs showed higher rates of positive tests compared to those from food industry operators.

Shiga toxin-producing *E. coli* infections in humans became the third most commonly reported animal-borne disease in the EU, with a significant increase from 2014 to 2018.

Yersiniosis was the fourth most frequently reported zoonotic illness in humans in 2018, maintaining a consistent pattern between 2014 and 2018. The count of confirmed listeriosis cases reported in 2018 continued to climb, even though *Listeria* rarely surpassed the safety limit in RTE foods.

Nearly 5,150 FBOs and WBOs were recorded, with *Salmonella* recognized as the most widespread cause, particularly *S. enteritidis*, accounting for one-fifth of the incidents. *Salmonella* in eggs and egg-based items were identified as the highest risk combination of cause and food. Furthermore, a substantial increase in human West Nile virus infections was noted in 2023 (EFSA, 2019).

The combined report from the EFSA and the ECDC discloses the results of animal-borne disease surveillance activities carried out in 2019 across 36 European nations.

Campylobacteriosis and salmonellosis were recognized as the most frequently reported animal-borne illnesses in humans, with the trend of confirmed human cases for these conditions in the European Union (EU) showing a consistent pattern during the period of 2015-2019.

The proportion of human salmonellosis cases attributed to *Salmonella enteritidis* within the EU aligned with the levels observed between 2017 and 2018.

Of the 26 nations providing information on *Salmonella* control programs in poultry, 18 met the reduction goals, while eight did not achieve at least one target. The overall rate of flocks testing positive for targeted *Salmonella* serovars in the EU remained consistent since 2015 for breeding hens, laying hens, broilers, and fattening turkeys, with some variations noted for breeding turkey groups.

Significant differences were observed in *Salmonella* results from regulatory bodies for pig carcasses and poultry sampled via national control programs compared to those from food industry operators.

Shiga toxin-producing *E. coli* infections became the third most reported animal-borne disease in humans and showed an increase from 2015 to 2019.

Yersiniosis remained the fourth most commonly reported zoonotic disease in humans in 2019, maintaining a consistent pattern between 2015 and 2019. The EU pattern for confirmed listeriosis cases remained stable during 2015-2019 after a long period of increase. *Listeria* rarely exceeded the safety limit in RTE foods.

Nearly 5,180 food-related incidents were recorded, with *Salmonella* remaining the most frequently identified cause, although the number of incidents attributed to *S. enteritidis* showed a reduction.

Remarkably, norovirus in seafood was identified as the combination of cause and food leading to the greatest number of confirmed incidents (EFSA, 2020).

In 2020, campylobacteriosis was identified as the most prevalent animal-borne disease in the

European Union, with nearly 121,000 cases documented. This represented a substantial drop from the prior year when over 220,000 cases were reported.

Closely following was salmonellosis, impacting 52,700 individuals compared to 88,000 in 2019. The reduction in reported animal-borne illnesses and food-related incidents was severe, with a significant 47% drop.

The One Health zoonosis report, released by the EFSA and the ECDC, highlighted the impact of the COVID-19 pandemic. Experts attributed the registered decrease to changes in health-seeking behavior, travel restrictions, closures of restaurants, quarantine measures, and the implementation of various health protocols such as mask-wearing, physical distancing, and enhanced hand hygiene.

Yersiniosis (5,668 cases) and infections caused by Shiga toxin-producing *E. coli* (4,446 cases) were the subsequent most frequently reported illnesses. Listeriosis was the fifth most reported animal-borne disease with 1,876 cases, primarily affecting individuals over the age of 64.

Listeriosis and West Nile virus infections had the highest death and hospitalization rates, with a significant concentration of West Nile virus cases reported in Greece, Spain, and Italy. *Salmonella* remained the most widespread cause of food-related incidents, accounting for approximately 23% of the total occurrences. Eggs, egg-based items, and pig meat were identified as the main sources of salmonellosis incidents (EFSA, 2021).

EFSA launched two engaging communication resources - a narrative map and a data display - to improve the understanding of food-related incidents. The narrative map provides a detailed overview of food-related incidents, causative agents, and implicated food sources.

Conversely, the data display acts as a platform for users to explore and examine extensive data on food-related incidents gathered by EFSA from EU member nations and other reporting countries since 2015. These tools aim to improve transparency, facilitate data-driven decision-making, and enhance public awareness of food safety within Europe.

Each year, the ECDC and the EFSA work together to collect information on animal-borne illnesses from member countries and other European areas. This comprehensive dataset includes information on zoonotic microorganisms found in various sources such as food, feed, animals (both livestock and wildlife), and humans. By analyzing this data, ECDC and EFSA produce a detailed report highlighting the prevalence of zoonotic agents across different sources and trends observed in humans, food products, and animals.

By employing descriptive statistics and pattern analyses, they take into account elements like data quality and collection methods to offer insights for animal health and food safety agencies as well as decision-makers. The objective is to steer strategic planning to lessen animal-borne illness impact and decrease human cases. This data-focused procedure adheres to a "One Health" framework.

In 2021, campylobacteriosis and salmonellosis were the most frequently documented animal-borne digestive illnesses in humans, with 127,840 and 60,050 cases, respectively.

There was an increase of approximately 7,000 cases for both illnesses compared to the previous year. Factors such as the UK's withdrawal from the EU and COVID-19 lockdowns affected data collection and analysis. National *Salmonella* control programs in poultry aim to reduce human illnesses caused by specific *Salmonella* serovars.

In 2021, several nations met goals for decreasing *Salmonella* rates in poultry, with consistent patterns observed in the EU. Food tests showed minimal *Salmonella* presence overall, with modestly higher rates in meat, meat-based items, and seasonings.

Various animal-borne illnesses, including yersiniosis, STEC infections, and listeriosis, presented substantial health hazards in 2021. *Listeria monocytogenes* and West Nile virus infections were the most serious, resulting in high hospitalization and death rates. Surveillance also included illnesses like brucellosis, Q fever, and toxoplasmosis.

In 2021, 27 member states and the United Kingdom (Northern Ireland) documented 4,000 food-related incidents, which represented a 30% rise from 2020, leading to a total of 32,543 human cases, showing a 62.6% increase. These figures closely matched the

levels seen during the period of 2017-2019 before the start of the COVID-19 pandemic.
This implies a steady return to pre-pandemic food consumption habits in 2021, especially in eateries, cafeterias, and other food service locations that could contribute to the spread of food-related pathogens.
Salmonella, notably *S. enteritidis*, continued to be the most common agent causing FBOs.
Among the various food types, eggs and egg-based items and combination foods were identified as the most frequent causes in these incidents, as indicated by the data supplied by the member countries. Occurrences related to the consumption of items in the greens and juices and other related items category showed a marked increase in 2021 compared to previous years (EFSA, 2022).
The detailed report from the EFSA and the ECDC summarizes the results from animal-borne disease monitoring and surveillance efforts conducted in 2022 across 27 member nations, the United Kingdom (Northern Ireland), and 11 countries outside the EU. The report examines key statistics regarding animal-borne diseases and causative agents in humans, food, animals, and feed, offering historical interpretations.
In 2022, campylobacteriosis and salmonellosis were identified as the top two most documented animal-borne illnesses in humans, with the case count remaining consistent compared to 2021. Nineteen member nations and the United Kingdom (Northern Ireland) successfully achieved all established goals for lowering the rate of *Salmonella* for relevant serotypes in poultry populations.
Remarkably, specimens gathered by regulatory agencies from animal carcasses for *Salmonella* and from broiler carcasses for *Campylobacter* measurement showed greater rates of positive tests compared to those from in-house inspections. Yersiniosis (Figure 2) was the third most commonly documented animal-borne disease in humans, followed by STEC and *Listeria monocytogenes* infections. Illnesses resulting from *L. monocytogenes* and West Nile virus were identified as the most serious animal-borne diseases, linked to the greatest rates of hospital admissions and death.

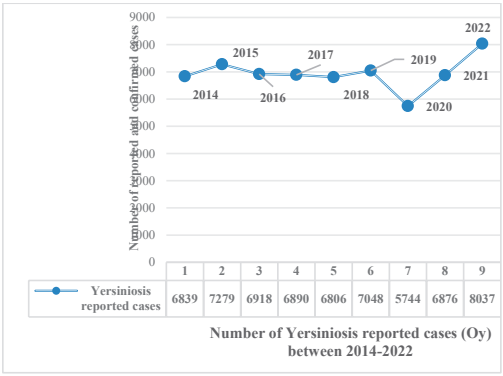

Figure 2. Yersiniosis reported number of cases (Oy) between 2014 and 2022 (Ox) - original

In 2022, there was a significant rise in both animal-borne illnesses and food-related incidents, leading to a thorough examination of documented cases, associated hospital admissions, and deaths. A concerning jump of over 600% in locally acquired cases of human West Nile virus infection, a disease carried by mosquitoes, was documented in 2022 compared to 2021 (Figure 3).

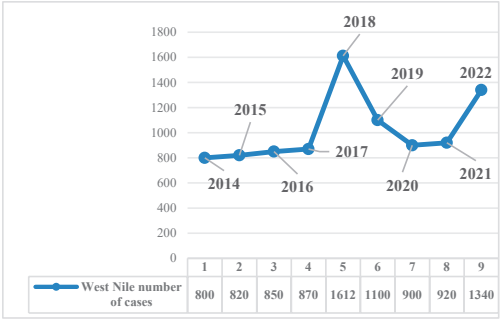

Figure 3. West Nile number of cases (Oy) between 2014 and 2022 (Ox) - original

The EU saw a surge in reported food-related incidents, cases, hospital admissions, and deaths in 2022 compared to the prior year, with the greatest count of incident-related deaths reported in the past ten years, mainly attributed to *Listeria monocytogenes* and to a lesser degree, *Salmonella*. Particularly *S. enteritidis*, remained the primary cause in food-related incidents, with Norovirus and other caliciviruses identified as the causes linked to the greatest number of human infection in incidents.

Furthermore, the report provides current information on trichinellosis, rabies, brucellosis, toxoplasmosis, Q fever, echinococcosis, tularemia and tuberculosis (EFSA, 2023).

The One Health animal-borne diseases report released by EFSA and ECDC explains the animal-borne disease situation in 2022. Salmonellosis and campylobacteriosis remained the most documented animal-borne illnesses in humans within the EU for the eighth consecutive year.

Despite their common occurrence, the case counts for these illnesses stayed below the levels observed in the pre-pandemic years of 2018-2019.

In the case of campylobacteriosis, which is the most commonly documented animal-borne illness, the case count remained consistent in 2022, totaling 137,100 cases.

Chicken meat was identified as the main source of these infections, emphasizing the importance of food safety precautions in poultry production (Figure 4).

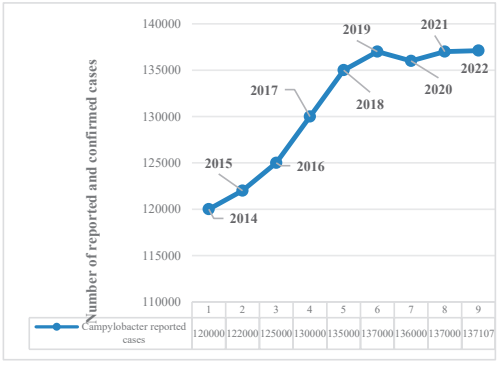

Figure 4. Campylobacteriosis number of cases (Oy) in the EU between 2014 and 2022 (Ox) - original

Salmonellosis, the second most frequently documented animal-borne illness, recorded 65,200 cases in 2022, a small increase from 2021 when 60,170 cases were documented (Figure 5).

Encouragingly, 19 MSs and the United Kingdom (Northern Ireland) successfully achieved all targets set for reducing *Salmonella* in poultry populations.

This marked achievement signifies significant progress since 2018 when only 14 MSs met these targets, showcasing collective efforts in combating zoonotic diseases and safeguarding public health.

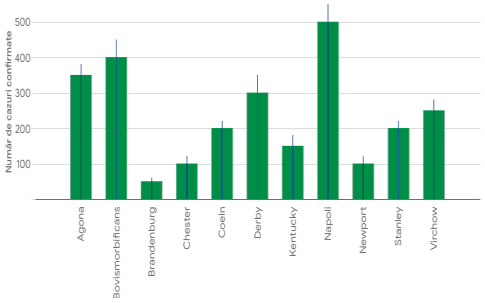

Figure 5. Salmonellosis number (Oy) of cases (5th-15th serovars) in 2022 vs. 2018-2021 average (Ox), in EU/EEA (EFSA, 2023)

ECDC emphasized the importance of sustained vigilance and concerted efforts in reducing the burden of these common foodborne illnesses on public health. Despite the current lower levels of reported cases compared to pre-pandemic times, the impact of these infections necessitates continued attention and actions aimed at further reducing their prevalence in the population.

In 2022, the European Union experienced a significant surge in illnesses caused by the mosquito-borne disease, resulting in the second-highest number of cases on record for the region, with 1,133 instances reported. The peak year for West Nile virus infections remains 2018, with 1,612 cases reported. This surge in cases could be attributed to more conducive climatic conditions supporting increased mosquito activity, facilitating the spread of the virus.

The presence of this specific virus was identified in 431 birds and 166 horses within the EU in a particular year, roughly twice the numbers reported in the year before. Furthermore, the virus spread to areas not previously affected, including parts of France, Germany, and Italy.

The unit focused on biological risks and animal well-being. EFSA emphasized the growing danger of illnesses transmitted by insects due to changes in weather patterns. The agency stressed the need for a comprehensive approach that combines assessments of danger for people and animals to effectively address these new health problems.

In addition to isolated cases of illness, the report looks into investigations of instances where the infection was multiple.

The European Union saw a significant increase in reported cases of foodborne illness, from 4,000 in one year to nearly 5,760 in the following year, returning to levels seen before a global health crisis. This rise in cases led to the highest number of deaths related to foodborne illness in the last ten years, amounting to 64 fatalities.

Listeria monocytogenes was identified as a primary causative agent (Figure 6), with outbreak-associated deaths linked to a diverse array of food items spanning meat, fermented milk products, fish, and greens. The greater use of a detailed genetic mapping method likely increased the accuracy of monitoring and improved the ability to find outbreaks across various nations.

EFSA is launching interactive story maps and dashboards offering insights into *Brucella*, zoonotic tuberculosis, Shiga toxin-producing *E. coli*, enabling data visualization and exploration for stakeholders.

The year 2022 saw an unusually high number of deaths recorded in FBOs reported to the EFSA within the EU over the past decade.

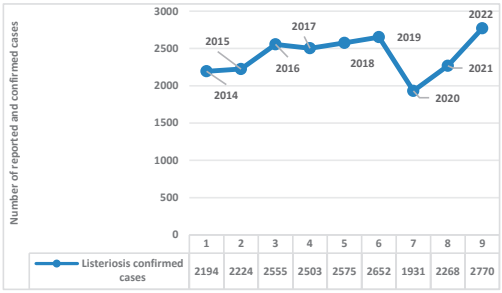

Figure 6. Listeriosis number of cases (Oy) between 2014 and 2022 (Ox)

Streptococcus equi subspecies *zooepidemicus*, a newly recognized etiologic agent, demonstrated the highest mortality rate in 2022. A significant foodborne transmission event, associated with the consumption of cheese produced from unpasteurized milk, resulted in 37 confirmed cases, including five fatalities, highlighting the virulence of this microorganism.

Listeria monocytogenes accounted for a significant portion of these fatalities. This emphasizes the severe health consequences linked to *L. monocytogenes*, particularly impacting vulnerable demographics such as the elderly.

Salmonella species were identified as the dominant etiological agent in foodborne disease outbreaks across the European region, accounting for the largest proportion of cases (over 1,000), representing 17% of FBOs. Furthermore, *Salmonella* species were associated with the highest rate of hospital admissions, accounting for 50.5% of all hospitalizations (Figure 7).

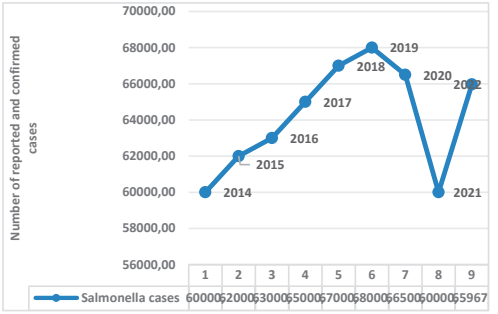

Figure 7. Number of *Salmonella* cases (Oy) by EFSA between 2014 and 2022 (Ox) - original

Norovirus (and other caliciviruses) were the primary etiological agents associated with a high incidence, demonstrating an 11% increase in 2022 (n = 7,300; 15% of outbreak-related cases). These agents were responsible for 12 significant outbreaks involving over 100 cases in multiple countries, with a substantial mean outbreak size of 22 cases.

In 2022, nearly 490 outbreaks with robust epidemiological support were documented, constituting 8.5% of all reported outbreaks. Complex food matrices, including multi-component dishes and miscellaneous food items, were identified as the primary vehicles in the largest proportion of these outbreaks (30%), accounting for the greatest number of associated cases (32% of all cases linked to outbreaks with robust epidemiological support). Notably, for the inaugural time since the initiation of foodborne outbreak surveillance in the EU, the highest number of outbreaks with robust epidemiological support and associated cases occurred in food service establishments, including restaurants, pubs, and mobile food vendors, comprising 30% of all outbreaks with robust epidemiological support. Among the

identified exposure environments, educational facilities, such as schools and kindergartens, recorded a significant burden of cases (1,550 cases; 16% of all cases in outbreaks with robust epidemiological support), emphasizing the importance of these settings in outbreak occurrence.

According to Braam et al. (2021), given the complex interactions between environmental, socio-economic, and anthropogenic factors contributing to the transmission of zoonotic diseases in displacement contexts, it is hypothesized that the movement of displaced populations, particularly in regions reliant on agriculture and livestock, poses significant risks for the introduction and spread of zoonotic pathogens among host communities, domestic animals, and wildlife (Figure 8).

Insufficient resources for livestock in formal relief camps may lead to adaptive strategies by animal owners, such as grazing among host communities' livestock or encroaching on wildlife habitat, potentially elevating the probability of interspecies pathogen dissemination to immunologically vulnerable groups.

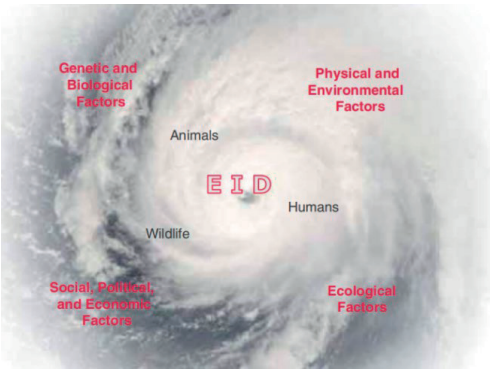

Figure 8. The convergence model of a perfect microbial storm (IOM, 2012)

Throughout the past decade, successive publications have consistently delineated epidemiological patterns and transmission pathways for a spectrum of pathogenic microorganisms, including *Mycobacterium bovis, Trichinella* spp., *Echinococcus* spp., *Toxoplasma gondii, Francisella tularensis, rabies virus, Brucella* spp., *Coxiella burnetii*, and West Nile virus.

Effective interventions for the mitigation of FBOs

Episodes of illness linked to the consumption of tainted foodstuffs continue to represent a substantial challenge to global well-being, resulting in considerable disease burden, fatalities, and financial impact. The World Health Organization (WHO) approximates that 600 million individuals experience adverse health effects annually due to the ingestion of contaminated food, leading to approximately 420,000 deaths. In light of these alarming statistics, it is imperative to adopt effective mitigation strategies to prevent and control foodborne outbreaks. Among the most promising strategies are enhanced traceability, public awareness campaigns, and the implementation of stringent food safety regulations.

Enhanced traceability refers to the ability to track food products throughout the supply chain, from farm to fork. This capability is crucial for quickly identifying and isolating contaminated food products during an outbreak. The implementation of advanced technologies such as barcodes, RFID tags, and blockchain can significantly improve traceability. Employing a chain-linked data structure allows for the establishment of a secure and auditable system for tracking food commodities, affording real-time insight into the distribution chain.

The benefits of enhanced traceability are manifold. Firstly, it enables rapid identification of contamination sources, facilitating swift action to remove affected products from the market. This rapid response is vital in minimizing public exposure to harmful pathogens. Secondly, by improving traceability, food producers and processors can engage in more effective epidemiological investigations, leading to better understanding and management of outbreaks.

Finally, enhanced traceability fosters consumer confidence in food safety. When consumers know that a robust system is in place to track food products, they are more likely to trust the safety of their food supply.

Dissemination initiatives to the general populace are fundamental in conveying knowledge regarding safe food handling procedures. Such programs strive to

communicate the potential hazards related to alimentary pathogen transmission and the significance of appropriate food manipulation, preparation, and preservation. Successful dissemination strategies can utilize diverse modalities, encompassing instructional resources, digital communication platforms, and community-based interventions.

The development of focused educational interventions for vulnerable demographics, including pediatric, geriatric, and immune-deficient populations, is essential. These programs can provide vital information on safe food practices and hygiene. Leveraging social media platforms to disseminate information quickly allows for broader reach and engagement. Additionally, collaborating with local communities, schools, and organizations can amplify food safety messages and encourage safe behaviors.

The impact of public awareness campaigns on food safety is significant. Informed consumers are more likely to adopt safe food handling practices, thereby reducing the risk of foodborne illnesses. Furthermore, increased awareness can lead to greater reporting of foodborne illness cases, aiding health authorities in detecting and responding to outbreaks. By fostering a culture of food safety, these campaigns contribute to overall public health.

Rigorous standards for food safety constitute the regulatory infrastructure required to guarantee the safety of consumables and avert epidemic events. These standards are designed to reduce the probability of pathogen transmission through ingestion and safeguard community well-being. Periodic evaluations of facilities involved in the transformation of edibles, dining establishments, and commercial outlets are indispensable to verify adherence to mandated safety protocols.

Moreover, training and certification programs for food handlers and industry professionals are vital to ensure that they understand and implement effective food safety practices. Risk-based regulations, which prioritize food safety based on scientific assessments of risk, allow for the efficient allocation of resources to areas of higher concern.

Improved adherence to safety benchmarks results in a decreased prevalence of pathogen transmission through ingestion.

The stabilization of listeriosis cases and declining yersiniosis trends in 2015 reflect effective public health measures, yet the ongoing presence of STEC and unidentified outbreak causative agents calls for enhanced surveillance and food safety practices.

While campylobacteriosis remains a significant public health concern, in 2016 the stabilization of trends in salmonellosis, listeriosis, yersiniosis, and STEC infections highlights the complexities of zoonotic disease management. The ongoing challenges presented by *Salmonella*, particularly *S. enteritidis*, and the rising incidence of listeriosis necessitate continued vigilance and improved food safety practices.

Technological advancements within food production and distribution networks have significantly altered the parameters of food safety. A notable trend is the identification of novel or previously uncharacterized pathogenic agents in food matrices, necessitating a re-evaluation of foodborne disease epidemiology.

The increasing incidence of these events underscores the critical need for a comprehensive reassessment of prophylactic strategies. The emergence of previously undocumented microbial species, viral entities, parasitic organisms, and atypical biotoxins from unconventional sources has outpaced the efficacy of existing preventative measures against foodborne disease outbreaks.

The effects on population health and economic burdens, are modulated by a complex interplay of variables influencing the evolution of foodborne pathogens and the emergence of infectious diseases. These variables include alterations in human demographics and behavioral patterns, particularly dietary practices, as well as extreme climatic events, advancements in high-throughput pathogen detection methodologies, microbial adaptation mechanisms, evolving agricultural practices, and transformative shifts within the food processing industry.

Foodborne illnesses constitute a substantial global threat to public health and economic stability. Accurate epidemiological data on foodborne zoonotic diseases are paramount for evidence-based decision-making regarding resource allocation for food safety, regulatory frameworks, and intervention strategies.

Veterinary practitioners occupy a critical position in the initiation of preventive and control measures, commencing at the primary production level through the implementation of Good Practices and biosecurity protocols. Furthermore, the application of the Hazard Analysis and Critical Control Points (HACCP) system across all stages of production and processing is indispensable for mitigating the incidence of foodborne diseases.

The escalating challenge of antimicrobial resistance necessitates the prudent utilization of antimicrobial agents in both human and veterinary medicine. A "One Health" paradigm facilitates a comprehensive understanding of disease epidemiology and enables the effective implementation of control strategies. The adoption of a holistic perspective encompassing all facets of foodborne illnesses is increasingly crucial for safeguarding public health and well-being.

Between 2008 and 2022, *Salmonella* and *Campylobacter* accounted for 62–78% of all reported zoonotic infections in the EU. Salmonella alone triggered 82% of foodborne outbreaks linked to known pathogens, primarily through eggs and poultry products. Despite 19 EU states meeting poultry Salmonella reduction targets, contamination rates in animal carcasses varied widely (4–28%) depending on national testing protocols. Campylobacter infections, though less frequently implicated in outbreaks, represented 65% of all zoonotic cases in 2022, with poultry meat identified as the primary transmission vector.

Listeria monocytogenes caused the highest hospitalization rate (96.1%) among foodborne pathogens, with a case fatality rate of 13.2% in 2022. Its persistence in ready-to-eat foods, such as smoked fish and soft cheeses, exacerbated vulnerabilities in immunocompromised populations. Meanwhile, West Nile virus infections, though not strictly foodborne, surged due to climate-driven expansion of mosquito habitats, recording a 17.9% case fatality rate in 2022.

Surveillance gaps and underreporting

Passive surveillance systems underestimated true disease incidence by 5- to 20-fold, with variability stemming from differences in healthcare access, laboratory practices, and reporting frameworks across MSs. For instance, only 12% of *Campylobacter* cases were laboratory-confirmed, compared to 89% for *Salmonella* (Boqvist et al., 2018).

Emerging threats and climate-driven risks

West Nile virus cases in the EU increased from 74 in 2018 to 1,323 in 2022, with geographic spread into previously unaffected regions like northern Germany and the Netherlands. Rising temperatures and altered precipitation patterns extended the seasonal activity of *Culex* mosquitoes, while migratory bird routes facilitated viral dissemination.

Antimicrobial resistance (AMR) in zoonotic pathogens

Resistance to fluoroquinolones in *Campylobacter jejuni* isolates reached 60% in 2022, limiting treatment options for severe cases. Multidrug-resistant *Salmonella* strains (e.g., S. Kentucky ST198) showed resistance to ciprofloxacin and third-generation cephalosporins, linked to prophylactic antibiotic use in poultry farming.

Vulnerabilities in fresh produce supply chains

Contaminated leafy greens and berries caused 18% of outbreaks in 2022, often traced to irrigation water contaminated by livestock runoff. Decentralized production networks complicated the trace-back efforts, delaying outbreak containment.

Geospatial data in epidemiological surveillance

Geospatial tools enable the integration of environmental, climatic, and demographic data to predict pathogen hotspots. For example, EFSA's review highlighted GIS applications correlating West Nile virus outbreaks with wetland distribution, avian migration corridors, and land surface temperatures. In Italy, spatial models identified provinces with ≥25°C summer temperatures and ≥60% irrigation coverage as high-risk zones, guiding preemptive mosquito control.

A 2021 geospatial analysis overlayed *Salmonella* prevalence data from 3,000 poultry farms with variables like proximity to water sources, livestock density, and slaughterhouse

locations. Farms within 2 km of water bodies had 3.2× higher contamination odds, prompting revised EU regulations on poultry housing siting.

Real-time outbreak source tracking

The EU's One Health sequencing database, launched in 2022, integrates whole-genome sequencing (WGS) data from human, animal, and food isolates with geospatial metadata. During a 2023 *Listeria* outbreak linked to smoked salmon, phylogeographic models traced the origin to a coastal processing plant in Poland, leveraging WGS clusters and transportation route mapping.

ENDIG or a pan-european surveillance visualization

The ENDIG platform aggregates notifiable disease data from 30 countries, enabling interactive exploration of spatial-temporal trends. Users can filter by pathogen, year, and country to visualize clusters, such as the 2022 *Campylobacter* surge in Denmark, which correlated with poultry farm density (R^2 = 0.78).

Predictive modeling for targeted interventions

Machine learning models trained on historical outbreak data and satellite-derived variables (e.g., NDVI for vegetation moisture) achieved 89% accuracy in predicting *E. coli* contamination risks in leafy greens. In Romania, such models guided inspections, reducing outbreak-linked produce by 34% in 2023.

Mitigation strategies by integrating geospatial innovations

EFSA's story maps and dashboards exemplify cross-sectoral data integration, overlaying human case reports with livestock movement permits and water quality indices.

Proposed expansions include Zoonotic Risk Index (a composite metric weighting pathogen prevalence, antimicrobial resistance, and climate vulnerability scores at the NUTS-2 region level) and Automated Syndromic Surveillance (NLP is used to analyze veterinary clinic records and social media for early signals).

Climate-adaptive food safety policies include pathogen-specific early warning systems (deploying sensor networks in high-risk watersheds to monitor *Cryptosporidium* and *Giardia* levels, with real-time alerts to producers) and heatwave-triggered protocols (mandating accelerated testing of RTE foods when regional temperatures exceed 30°C for ≥5 days, mitigating *Listeria* proliferation).

Geospatial capacity building

The WHO European Geospatial Coordination Hub's roadmap prioritizes training programs (a 2024 master's curriculum in spatial epidemiology for public health officials) and common data infrastructures (federated GIS platforms allowing MSs to share anonymized outbreak data without compromising privacy).

Over the past 10 years, there has been an increase in pathogen transmission among human, domesticated animal, and non-domesticated animal populations due to population relocations. This underscores the latent epidemiological risks associated with displacement and highlights the need for targeted prophylactic strategies to mitigate the emergence of zoonotic diseases.

Also, adaptive strategies by animal owners were applied, such as grazing among host communities' livestock or encroaching on wildlife habitat, leading to heightened risks of zoonotic pathogen introduction. These findings emphasize the importance of addressing the welfare and management of livestock in displacement settings to mitigate zoonotic disease transmission risks.

We could also identify the specific zoonotic pathogens prevalent in displaced populations, livestock, and wildlife. These informations would provide insights into the zoonotic disease dynamics in displacement contexts and inform targeted interventions for disease control and prevention.

The lack of primary research addressing zoonoses in displacement contexts is highlighting research gaps and the need for comprehensive studies on zoonotic disease dynamics in displaced populations. This fact underscores the importance of further research to enhance understanding of zoonotic disease risks in displacement settings and improve

public health responses in these vulnerable populations.

The development of a predictive modeling framework that integrates environmental, socio-economic, and displacement-related factors to forecast zoonotic disease outbreaks in displacement contexts are needed.

By utilizing data on displacement patterns, livestock movements, host community interactions, and disease transmission dynamics, this model could help identify high-risk areas for zoonotic disease emergence and inform proactive intervention strategies to mitigate public health threats in displaced populations.

Future efforts should focus on improving reporting mechanisms, enhancing food safety regulations, and fostering collaboration across MSs.

The EFSA and the ECDC provide valuable data on the epidemiology of animal-to-human transmissible diseases within the EU, elucidating key epidemiological trends and areas requiring intervention. While reductions have been observed in specific zoonotic infections, challenges persist, notably concerning *Campylobacter* spp. and emergent *Salmonella* spp. strains.

Interagency cooperation among governing bodies, agricultural producers, distributors, and end-users is essential for establishing food safety.

The EU's foodborne disease landscape has entered a critical phase, where traditional surveillance systems struggle to match the velocity of climate-driven pathogen evolution. Geospatial technologies offer a transformative pathway, enabling predictive analytics, precision interventions, and democratized data access.

However, realizing this potential requires addressing fragmented data standards, legal barriers to cross-border data sharing, and uneven technical capacities across MSs.

Prioritizing investments in geospatial literacy and interoperable platforms will be pivotal in transitioning from reactive outbreak management to preemptive risk mitigation, safeguarding both public health and food security in an era of escalating environmental uncertainty.

CONCLUSIONS

Key findings revealed that population displacements over the past decade have amplified zoonotic pathogen transmission at the human-livestock-wildlife interface, driven by adaptive practices such as shared grazing and habitat encroachment.

Specific pathogens, including *Campylobacter* spp. and emergent *Salmonella* strains, persist as critical threats in displacement-affected regions, while research gaps hinder targeted interventions.

The urgency of these findings lies in the compounding effects of climate change and fragmented surveillance systems, which exacerbate spillover risks and strain public health responses.

Data from EFSA and ECDC underscore persistent zoonotic and foodborne disease burdens in the EU, emphasizing the need for adaptive frameworks to address evolving epidemiological challenges.

Recommendations prioritize developing predictive models that integrate environmental, socio-economic, and displacement data to forecast outbreaks.

Strengthening interagency collaboration, harmonizing food safety regulations, and investing in geospatial technologies (particularly interoperable platforms and data literacy) are critical to transitioning from reactive measures to preemptive risk mitigation.

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