

Intensive animal farming operations and outbreaks of zoonotic bacterial diseases in Ukraine

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In Ukraine zoonoses are a permanent threat to human health, some of them are bacterial diseases associated with farm animals. Complete avoidance of outbreaks of bacterial zoonoses is not possible but it is appropriate to study them to reduce the risks of transmission of zoonosis pathogens from industrial farms to the human population and the environment. The article highlights the results of a literature review on the potential role of industrial livestock farms in the spread of major bacterial zoonoses in Ukraine. About half of all of the country's farmed animals are kept on farms using industrial technology; more than half of the establishments are classified as medium and large. The technology of keeping animals on such farms contributes to the development of diseases of obligate hosts caused by fecal bacteria. The systematic search and selection of literary sources, which are relevant to the topic of the study were carried out. The vast majority of analyzed publications are published in Ukrainian in local peer-reviewed scientific journals. An analysis of open-access official statistics from the state authorities of Ukraine was also conducted. The authors analyzed statistics and scientific papers published over the last 10–15 years discussing the outbreaks of food-borne zoonoses among humans and the studying their pathogens (*Campylobacter* spp., *Salmonella* spp., *Escherichia coli* (STEC strains), *Listeria* spp.) on industrial livestock farms. The main source of *Campylobacter* spp. and *Salmonella* spp. distribution are industrial poultry, including broilers and chickens, respectively. The STEC strains *E. coli* carriers are various types of farm animals, including cattle and pigs. The majority of infections documented in Ukraine are cases of salmonellosis in humans and animals. Despite reports of a significant prevalence of campylobacteriosis, colibacillosis and listeriosis in livestock farms, their association with outbreaks of food-borne zoonoses in humans remains poorly understood. The concept of an industrial livestock farm involves a permanent presence of a risk of outbreaks of bacterial zoonoses and their rapid spreading to the human population. This is due to concentrated maintenance of animals, standardized feeding, the priority of achieving the highest productivity of animals and economic indicators. Under such conditions, disturbance of hygienic norms and technologies significantly increases the risk of bacterial zoonoses on industrial farms. It is important to enforce the continuous control of the level of microbial pollution of farms, animal health, hygiene of milk production and processing, meat, eggs, etc. Farms have a negative impact on the ecological welfare of the surrounding territories. The problem of spread of antibiotic-resistant strains of bacterial zoonoses is a very serious one. Efforts for the formation of a national system of epidemiological supervision over bacterial zoonoses, comprising epidemiological, epizootological, ecological, microbiological, serological and molecular genetic monitoring, as well as the development on this basis of effective prophylactic and anti-epidemic measures are relevant and necessary.

Keywords: intensive animal farming; zoonoses; *Campylobacter* spp.; *Salmonella* spp.; *E. coli* (STEC strains); *Listeria* spp.

Introduction

Today, animal husbandry in Ukraine is well-developed, with a structure consisting of dairy and beef cattle, poultry, pigs, sheep and goats, as well as, to a lesser extent, rabbit breeding and fur farming. Beekeeping and aquaculture are also present. Animal husbandry is developed in all regions of the country. Historically, the structure of animal husbandry in Ukraine was shaped by the USSR and mainly comprised medium-sized collective farms and household plots. For example, in 1983, relative to total production, private producers in Soviet Ukraine accounted for 34% of meat, 26% of milk and 38% of eggs (Wädekin, 1990).

Over 30 years, the number of farmed animals in Ukraine has declined: cattle by 87.4%, including cows by 78.7%, pigs by 70.5%, small ruminants by 85.7%, poultry by 10.4% (Table 1). Only the poultry industry has recovered after an almost 50.0% decline, primarily due to the production of broiler meat, which accounts for a significant share of the meat market in Ukraine. As of December 1, 2020, there were 3.15 million head of cattle in Ukraine, including 1.73 million cows, 6.12 million head of pigs and 1.27 million head of small ruminants. The number of poultry was

218.93 million (State Statistics Service of Ukraine, 2019, 2020a, 202b). In the new economic conditions, the only way to maintain the industry was to increase the productivity of animals by intensifying production processes. As a result of the gradual change in technologies of production of cattle breeding, pig breeding and poultry farming from extensive to intensive new factors appeared that can potentially affect the stability of the sanitary situation on farms and enhance the influence of such farms on the environment, including the spread of pathogens of bacterial zoonoses. Currently, there is a complex situation in the development of livestock breeding due to protracted military actions, pandemic and prolonged crisis (Lavruk & Lavruk, 2020). Economic reasons underlie a decrease in some farms of biosafety standards and sanitation. At the same time, there is a reform of sanitary supervision of infectious diseases and public health systems in Ukraine. All this against the backdrop of insufficient financing of state control bodies creates many risks for distribution of pathogens of zoonotic diseases from livestock industrial farms to people and new outbreaks of zoonotic diseases.

All regions of Ukraine have farms with the main species of farm animals raised in the country, these are cattle (including cows), pigs and

poultry (broilers and laying hens), to a lesser extent goats and sheep. The farm animals are not evenly distributed, among the leaders in the terms of major species of animals are Lviv region in the west, Zhytomyr, Kyiv and Vinnytsia regions in the center and the Dnipropetrovsk region in the east of Ukraine. In some regions, there may be significantly more specific species of farm animals than others, for example poultry in Vinnitsa region or pigs in Donetsk region. This is due to the presence of large industrial animal husbandry enterprises in the region (Fig. 1).

Table 1

Number of farm animals in all categories of farms in Ukraine, thousand head (according data from statistical compendiums of State Statistics Service of Ukraine)

Years	Cattle	Including cows	Pigs	Sheep and goats	Poultry
1990	24623.4	8378.2	19426.9	8418.7	246104.2
2000	9423.7	4958.3	7652.3	1875.0	123722.0
2001–2005	7931.7	4295.7	7682.7	1838.4	148281.4
2006–2010	5213.3	2933.3	7427.6	1717.4	181732.7
2011–2015	4248.0	2141.9	7460.4	1581.8	212488.6
2015	3750.3	2166.6	7079.0	1325.3	203986.2
2016	3682.3	2108.9	6669.1	1314.8	201668.0
2017	3530.8	2017.8	6109.9	1309.3	204830.9
2018	3332.9	1919.4	6025.3	1268.6	211654.4
2019	3092.0	1788.5	5727.4	1204.5	220485.8
2019 to 1990, %	12.6	21.3	29.5	14.3	89.6



Fig. 1. TOP-5 regions of Ukraine by the number of farm animals, as of December 1, 2020 (source: Ministry for Development of Economy, Trade and Agriculture of Ukraine, based on data of State Statistics Service of Ukraine)

The stock of farm animals in Ukraine traditionally been divided into two types: household and industry. Household animal husbandry is the breeding of productive animals near the owner's home, the purpose of which is not always economic benefit (Fig. 2). However, household cattle breeding, as well as milk production, is twice as great as industrial breeding (Fig. 3). In pigs and poultry industrial farms predominate and most of the meat and eggs in Ukraine are produced by such enterprises.

Industrial agricultural enterprises are classified by the number of animals and scale of production on small, medium and large farms. For livestock farms, small farms are those which hold up to 100 animals, average farms 100–999 animals and large farms more than 1000 animals, for pig farming, this gradation will be respectively 100–199, 200–4999, more than 5000 pigs. The latter is the predominant factor that determines the technology of keeping animals and obtaining livestock products, including safety and quality control procedures. According to the State Statistics Service of Ukraine (www.ukrstat.gov.ua), as of January 1, 2020, about half the farms keeping various species of animals were medium and large establishments. 62.5% of farms keep more than 100 head of cattle, and 55.0% of farms keep more than 100 dairy cows. More than 200 pigs are kept on 55.1% of farms, more than 5,000 poultry on 62.1% of farms, and on more than 37.1% of poultry farms the number of birds exceeds 50,000. Such farms are characterized by a high concentration of animals, application of standard technologies and use of industrial equipment at all stages

of animal breeding and exploitation. Specialists in animal husbandry technology and veterinarians are engaged on all farms. Additionally, the state veterinary service controls veterinary preventive and anti-epizootic measures, as well as outbreaks of infectious diseases (Pidpala et al., 2018). Nevertheless, such farms are at the highest risk of outbreaks of bacterial zoonoses of obligate hosts. The technology of keeping and exploiting animals, especially when not applied properly, causes favourable conditions for the reproduction and spread of bacterial pathogens, while weakening the animals' resistance (Lytvyn et al., 2002).

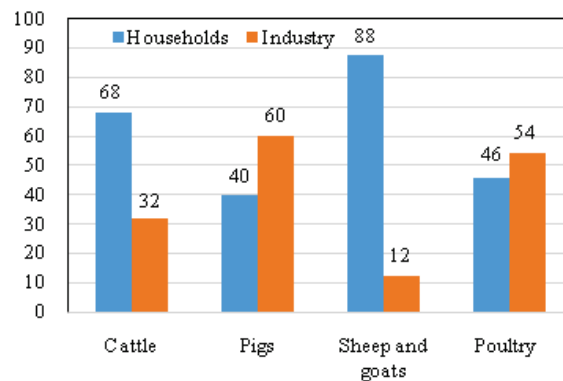


Fig. 2. Percentage of farmed animals in Ukraine by farm categories as of December 1, 2020 (source: Ministry for Development of Economy, Trade and Agriculture of Ukraine based on data of State Statistics Service of Ukraine)

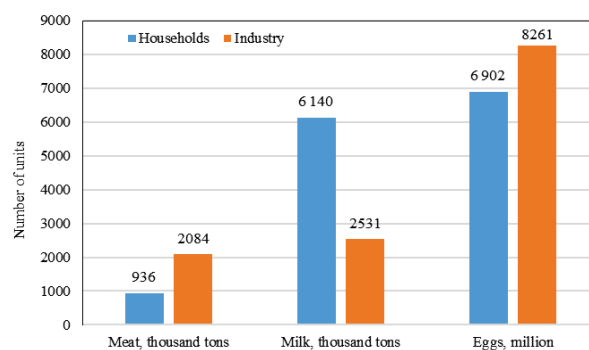


Fig. 3. Production of livestock products by farm categories in January–November 2020 (source: Ministry for Development of Economy, Trade and Agriculture of Ukraine based on data of State Statistics Service of Ukraine)

The World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the World Organization for Animal Health (OIE) define zoonoses as diseases that can normally spread from vertebrates to humans. In this case, animals can be both a reservoir of infection and a certain part of its path to humans (Hallaj, 2010). A total of 1,415 species of microbial and parasitic agents cause diseases in humans, including most of all, bacteria and rickettsiae – 538 species, fungi – 307 species, 217 species of viruses and prions, 287 helminths and 66 protozoa. Of the total number of pathogens, 868 (61.0%) are zoonoses (Taylor et al., 2001). Bacterial zoonoses are transmitted from animals to humans through direct contact or contaminated materials. In the context of public health, transmission of infectious agents through food (food-borne) and food poisoning by bacterial toxins (toxicoinfections) are the most crucial ones. The main livestock products that carry the risk of zoonotic diseases are raw meat, milk and eggs, as well as products made from them, such as sausages, cheeses, etc. (Cutler, 2015; Morwal, 2017). Zoonoses are a threat to human health and life, and can have a significant impact on public health. Also, economic losses are incurred in case of animal diseases that require treatment, culling or destruction of products made from sick animals. Human disease creates a social and economic burden due to temporary unfitness for work and the need for additional government spending on the elimination and prevention of zoonoses (Berthe et al., 2013; Casey et al., 2015; Antunes et al., 2019). According to the latest available

data from the European Food Safety Authority and the European Centre for Disease Prevention and Control, in 2018, in 36 countries of Europe, the main bacterial zoonoses were campylobacteriosis, salmonellosis, colibacillosis caused by Shiga toxin-producing *Escherichia coli* (STEC), yersiniosis and listeriosis, which occur when food is contaminated with pathogens of these diseases or when people come into contact with sick animals and contaminated environment (EFSA, 2019).

In Ukraine, the State Veterinary Service, which is part of the State Service of Ukraine for Food Safety and Consumer Protection (SSUFSCP) is responsible for controlling zoonoses among animals. The State Institution “Public Health Centre of the Ministry of Health of Ukraine” carries out surveillance and prevention of, as well as response to human zoonoses. The institution is a healthcare facility responsible for maintaining and strengthening the health of the population, as well as for social and hygienic monitoring of diseases, epidemiological surveillance and biological safety, preventing diseases in groups and populations, control of epidemics and strategic management in the field of public health. Each of these institutions does its own reporting, so consolidated reports and data analyses are not available. Among bacterial zoonoses, monitoring of bovine tuberculosis, brucellosis, anthrax, leptospirosis and salmonellosis by the state veterinary service is mandatory. In addition, mandatory annual serological tests of all cattle and small ruminants for brucellosis, as well as monitoring serological study of cattle (5–10% of the total population) for leptospirosis are performed, and the State Programme for the Control of Avian Salmonellosis has to be followed. It provides for regular laboratory tests aimed at detecting and preventing salmonellosis infections on poultry farms. Health system reporting involves the collection and consolidation of human cases of infectious diseases, including bacterial zoonoses. The reports are published on a monthly basis by the state institution “Center for Public Health of the Ministry of Health of Ukraine”. Given the lack of structured data, a developed system for monitoring bacterial zoonoses and analytical materials, as well as selective research by various authors performed in recent decades are important sources for analysing the problem.

The aim of the study was to perform systematic analysis of the literature on the prevalence of bacterial zoonoses among the human population and farmed animals, identifying risk factors associated with industrial livestock farming and assessing its potential role in the spread of bacterial zoonoses in Ukraine.

Criteria for collecting and selecting sources for analysis

For the purpose of this study, the authors analysed publications according to a scheme similar to those recommended for systematic review (Gupta et al., 2018). Studies that could fully or partially reveal the potential role of intensive livestock farming in the emergence of bacterial zoonoses in Ukraine were selected. Publications published in 2010–2020 were selected (in some cases, papers published after 2000 were also included).

Table 2

Human and animal morbidity rate of the main bacterial zoonoses in Ukraine in 2018–2020 (according to official statistics from state institution “Center for Public Health of the Ministry of Health of Ukraine” and The State Service of Ukraine on Food Safety and Consumer Protection)

Zoonotic disease	Morbidity among people						Morbidity among animals			
	for 11 months of 2018		for 11 months of 2019		for 11 months of 2020		January–December 2018		January–December 2019	
	number of cases	per 100,000	number of cases	per 100,000	number of cases	per 100,000	farms	sick animals (head)	farms	sick animals (head)
Campylobacteriosis	136	0.3	146	0.4	138	0.3	n/a	n/a	n/a	n/a
Salmonellosis	7452	17.6	8150	19.3	3621	8.6	5	647494	6	275012
Listeriosis	2	0.0	2	0.0	1	0.0	n/a	n/a	n/a	n/a

Campylobacteriosis (*Campylobacter* spp.)

Campylobacteriosis is caused by the *Campylobacter* bacteria, i.e. consumers residing in the intestinal tract of many animals, including poultry, pigs and ruminants. *Campylobacter* are gram-negative curved rods that move in a characteristic corkscrew motion, and do not form spores and capsules. The *Campylobacter* series includes about 20 species, but the *C. jejuni* and *C. coli* species are of the greatest importance in the etiology of campylobacteriosis (Facciola et al., 2017; Chlebicz & Ślizewska, 2018). Broilers, as the main source of infection, play the largest role in the etiology of campylobacteriosis in humans. Bacteria *Campylobacter* spp.

Scientific articles and official reports of the Veterinary Service, the Ministry of Health of Ukraine, and other competent authorities were selected from all sources of information. Sources in the Ukrainian, Russian and English languages were analysed. The criteria for selecting studies for analysis were as follows: survey papers, experimental papers or publications describing clinical cases; studies concerning Ukraine and containing data that allow one to draw conclusions about the prevalence of the disease, epidemiological features and the potential role of intensive livestock farming in the spread of the disease. To be included in the study, sources had to come from peer-reviewed scientific journals, research had to be methodologically correct and not show signs of bias and conflict of interest.

For the literature search, the following were used: the national database of scientific literature, national database of scientific journals “Science Periodicals of Ukraine” (www.irbis-nbu.gov.ua), international database: Google Scholar (www.scholar.google.com.ua) PubMed (www.pubmed.ncbi.nlm.nih.gov), Web of Science (www.webofknowledge.com) and Scopus (www.scopus.com).

The following list of diseases was selected for analysis: campylobacteriosis (*Campylobacter* spp.), salmonellosis (*Salmonella* spp.), escherichiosis (including STEC), listeriosis (*Listeria* spp.), which corresponds to the list of diseases monitored in the European Union (EFSA, 2019). Search queries for each pathogen followed the pattern: “pathogen or disease” + “animal species” + “Ukraine” in each of the languages. All papers found in the databases were filtered for compliance with the research topic and the compliance and quality criteria. As a next step, materials were re-evaluated qualitatively and, finally, included in the list of materials for analysis. Based on the analysis of selected materials, a critical review of the literature on the subject matter was formed and conclusions about the potential role of intensive animal husbandry in outbreaks of zoonotic bacterial diseases in Ukraine were formulated.

As a result of a search conducted according to the method described above and upon filtering publications for analysis, only 111 publications were selected, 15–41 for each disease in Ukrainian and Russian (cyrillic). The Google Academy search engine had the largest coverage of “cyrillic” publications, and the national database of scientific journals “Scientific Periodicals of Ukraine” was the most accurate. Statistical data on the diseases under study available from competent state bodies on an open-access basis tended to be limited and inconsistent (Table 2).

The number of cases of campylobacteriosis and listeriosis in humans reported during 2018–2020 remained on a steady level, whereas the number of cases of salmonellosis decreased twofold. Data on animal morbidity and the number of contamination points are available only for salmonellosis and mainly reflect the results of salmonellosis monitoring on poultry farms according to the State Salmonellosis Monitoring Programme, which explains the large number of sick animals, considering that poultry farms in Ukraine mostly keep large numbers of birds.

colonize the digestive tract of chickens during their first two weeks of life, and without causing any symptoms are released into the environment in large quantities with feces until slaughter (Schiaffino et al., 2019). In European countries, campylobacteriosis is the most common cause of infectious gastroenteritis. According to EFSA and ECDC, 246,571 cases of human campylobacteriosis were documented in the EU in 2018, with an average incidence rate of 64.1 per 100,000 population, with 99.6% of campylobacteriosis outbreaks being of food origin and resulting from consumption of contaminated milk and broiler meat (EFSA, 2019). According to the Centre for Public Health of the Ministry of Health of Ukraine, the average incidence of campylobacteriosis in 2018–2020 was

only 0.32–0.35 per 100,000 population. Such a significant difference in the incidence of campylobacteriosis in humans should be attributed to the imperfect diagnosis of the disease in Ukraine due to the absence of a developed system of surveillance and notification rather than to an improved epidemiological situation (Kyryk, 2012a, 2016; Pinchuk & Pustovit, 2018). For example, studies conducted in 2000–2009 show that campylobacteriosis was detected in sick children in 1.0% of cases in 2000; 3.0% in 2005, and up to 5.0% in 2009 (Tarasenko, 2011), while 50–60 thousand cases of infectious diarrhea in children are detected in Ukraine per year (Andrukh, 2015). Epidemiological studies from 2013 showed that the proportion of patients with campylobacteriosis among 26,707 patients with acute intestinal infections was 1.9% (Kyryk, 2013). It should also be noted that in 2018–2020, 15,508–48,554 cases of acute intestinal diseases of unknown etiology were confirmed in Ukraine, i.e. an intensity of 36.94–114.47 per 100,000 population.

An analysis of 90 strains of *Campylobacter* spp. of different origin: clinical isolates, “chicken” strains and strains from environmental objects (30 strains from each group) detected in Ukraine in 2011 showed that 31.6% of the strains were highly cytopathogenic, i.e. the most dangerous for humans, while 53.1% were cytopathogenic and 15.3% were acytopathogenic. The largest number of highly cytopathogenic strains was among isolates from clinically ill people – 52.6%. Among farm animals, the largest percentage of highly cytopathogenic strains were detected in chickens – 44.1%, calves – 30.0%, and pigs – 29.4%. A smaller number of highly cytopathogenic strains of campylobacter was found among those isolated from wastewater (16.7%) and open water (10.0%) (Kyryk, 2011).

In 2012, as a result of an extensive epidemiological survey of 216 foci of campylobacteriosis, analysis of 1569 samples from animals of different species, birds, and environmental objects, including wastewater from the equipment of meat and poultry processing enterprises, bacteria of the genus *Campylobacter* were detected in the intestines of cattle in 13.3%, pigs – 20.5%, ducks – 25.6% of the cases. Regular examination of chickens in poultry farms in the Zaporizhia and Kyiv regions has proven that the *Campylobacter* contamination rate of slaughtered chickens ranged from 28.0% to 33.7%. The contamination of chicken carcasses with *Campylobacter* was at the level of 18.2–20.0%. *Campylobacter* was found in 20.0% of chicken manure samples. Chickens were the main source of infection in outbreaks of campylobacteriosis in humans (38.2%), the spread of the disease in family households was confirmed in 34.2% of cases. In 79.1% of cases, the infection was transmitted through food (meat, eggs, milk), and in 20.9% of cases – through water. Of great epidemiological significance in the spread of campylobacteriosis in humans is *Campylobacter* contamination of slaughter chickens (29.6%), ducks (25.6%), pigs (20.5%), cattle (13.1%), as well as environmental objects: poultry farm wastewater (35.7%), meat processing enterprises (20.0%) and reservoirs that partially receive wastewater (12.5%). It was also found that pigs are the main carriers of *Campylobacter coli* (61.8% of isolated strains) (Kyryk, 2012b). In other studies, the circulation of campylobacteriosis pathogens was determined at 30.0% in the studied poultry and 20.0% in cattle (Babkin, 2013). The circulation of *Campylobacter* in the population of farm animals and the environment creates epidemic foci of the disease and increases the incidence of the disease in humans (Kyryk, 2012b).

There is a need for systemic epidemiological surveillance of campylobacteriosis, which includes epidemiological, epizootiological, environmental, microbiological, serological, and molecular genetic monitoring, as well as the development of effective preventive and anti-epidemic measures on that basis (Kyryk, 2017). One of the sources of difficulties in ensuring effective surveillance of campylobacteriosis is the relatively complex bacteriological and biochemical diagnosis of the pathogen (Drahut, 2013) which is the main method of detecting and identifying campylobacter (Babkin & Kalinichenko, 2010; Lapa et al., 2015).

Monitoring the incidence of *Campylobacter* spp. in farmed animals as well as checking slaughter products for contamination is essential for controlling the risks of human campylobacteriosis. Numerous studies indicate that in Ukraine, there is a problem of *Campylobacter* spp. contamination of livestock products, which is confirmed by the fact that similar strains of pathogens are detected in both sick people and food, indicating their wide circulation in the environment (Fotina et al., 2018). One of the

main ways in which broiler meat becomes contaminated with *Campylobacter* is by contamination of carcasses during slaughter. *C. jejuni* is detected in 8.0–21.8% of samples of caecal contents of slaughter birds, while for *C. coli* the number ranges from 2.4% to 8.0%. The detection rate of *Campylobacter* spp. in wastewater from washing the cages in which the poultry was transported to the slaughterhouse was 4.0–8.0% (Kasianenko et al., 2019). In another study, the detection rate of *Campylobacter* spp. in the intact caecum of broilers was 7.5%, and in wastewater from washing the carcasses it was 4.5% (Rodionova, 2017). Variable levels of excretion of microorganisms of the genus *Campylobacter* were found in other studies of poultry in slaughterhouses at different stages of processing of healthy and sick birds: from the surfaces of carcasses isolated before gutting – 1.1%, 4.1%; from the surfaces of poultry carcasses after gutting – 5.9%, 14.5%; from the content of the cecum – 6.4% and 19.2%; from poultry carcasses after washing – 5.1% and 18.1%; from poultry carcasses after cooling – 3.2% and 14.6%, respectively. Isolates of *Campylobacter* spp. were presented to the following serotypes by *C. jejuni* – 77.1%, *C. coli* – 21.1% and *C. lari* – 1.9% (Kasianenko, 2012).

Campylobacter jejuni bacteria has an expressed resistance to low temperatures, although the number of viable *Campylobacter* decreases over time when meat is frozen: 2.5 times after 30 days and 11.8 times after 60 days. The culture of *C. jejuni* is capable of forming morphologically altered colonies of R-forms, and in cooled meat – colonies characterized by S-forms (Kasianenko, 2009). During the cooling and freezing of poultry carcasses, the risk of cross-contamination of their surfaces increases. *Campylobacter jejuni* strains detected on the surface of poultry carcasses have been found to be pathogenic for laboratory animals and laying hens (Kasianenko et al., 2017), confirming their epidemiological and epizootiological significance in the context of carcass contamination during slaughter. Such risks require compliance with cleanliness and sanitary norms at slaughterhouses and processing enterprises; refraining from feeding poultry before slaughter, which may slightly reduce the level of contamination of transport and equipment of slaughterhouses (Kasianenko et al., 2019); prevention of rupture of poultry intestines at slaughter, fixation of the cloaca, prevention of fecal release (Kasianenko & Gusjev, 2019). Methods are proposed to reduce contamination of poultry carcasses by treating them with various mildly acidic solutions, providing treatment with hot water or steam, freezing followed by maintenance lasting several days or weeks (Kasianenko, 2009) or instant freezing to form a glazed layer of ice (Kasianenko & Gusjev, 2019). The use of peracetic acid and hydrogen peroxide drugs to improve the sanitary and hygienic condition of water in baths for cooling poultry carcasses after slaughter and to prevent cross-contamination of poultry carcasses with *Campylobacter* spp. was experimentally tested (Rodionova, 2017). It is crucial that the regimes of heat treatment of meat be followed at processing and culinary facilities (Kasianenko & Gusjev, 2018).

At the level of poultry farms, especially medium and large ones, the risks of spreading *Campylobacter* spp. are significant, given the concentration of poultry in a limited area, intensive management, and the shortcomings of the monitoring system of campylobacteriosis in Ukraine (Kyryk, 2017). Factors that must be controlled on industrial farms to ensure the prevention of campylobacteriosis are as follows: vertical transmission of the pathogen, seasonality, farm staff, contamination of feed and water, insects, wild animals (including rodents) and synanthropic birds, livestock, contamination of the territory of poultry farm, the stocking density in the poultry house, air pollution in the poultry house, the presence of bacteria carriers in the poultry house, the number of poultry houses on the farm and the health of the poultry (Kasianenko & Gusjev, 2019). Achieving the required sanitary condition is possible with the effective use of conventional disinfectants (Kasianenko & Fotina, 2010; Pustovit & Pinchuk, 2017), as complex disinfection significantly reduces the number of microbial cells in the air and on surfaces and equipment of poultry house, but disinfection as a targeted anti-epizootic measure in the prevention and elimination of infectious diseases is effective only in the context of a general set of measures, as control of all parts of the epizootic chain (Nechyporenko et al., 2018). At the same time, additional methods for controlling campylobacteriosis on poultry farms by treating poultry with antibacterial drugs (Kasianenko & Sobyna, 2013) and probiotics in combination with adsorbents have been developed and proposed in Ukraine (Kasianenko, 2014).

Salmonellosis (*Salmonella* spp.)

Salmonellosis is an animal and human disease with a fecal-oral transmission mechanism, manifesting as a lesion of the digestive system caused by pathogenic strains of *Salmonella* spp. Zoonotic non-typhoid pathogenic bacteria of the genus *Salmonella*, including *S. choleraesuis* and *S. dublin*, cause diarrhea in humans, whereas serotypes of *S. typhimurium*, *S. enteritidis*, *S. newport*, and *S. heidelberg* more often cause food poisoning (Yakubchak & Kobysh, 2012; Chlebicz & Ślizewska, 2018; Rukambile et al., 2019). According to EFSA and ECDC, salmonellosis is the second leading cause of intestinal infections in the European Union after campylobacteriosis and one of the leading causes of outbreaks of food poisoning. In 2018, 91,857 cases of the disease were reported in humans, and the intensity of the disease was 20.1 cases per 100,000 population. The highest levels of salmonella-positive samples were collected from poultry and other raw meat. *Salmonella enteritidis* was most often isolated during outbreaks of food poisoning by eggs and complex foods. *Salmonella infantis* was most commonly found in disadvantaged poultry flocks, namely 36.7% of all isolates, including 36.5% from broilers and 56.7% from broiler meat (EFSA, 2019).

According to the state institution “Center for Public Health of the Ministry of Health of Ukraine”, salmonellosis is considered to be the main cause of infection-induced diarrhea and food poisoning in Ukraine. At the same time, 1–4 cases of typhoid and paratyphoid salmonellosis are reported per year, and other cases are caused by other (zoonotic) *Salmonella* serotypes. In 2018–2020, 3,621–7,452 such cases were registered annually, the intensity indicator was 8.62–19.3 per 100,000 population, i.e. comparable to those in the European Union. According to the State Food and Consumer Service, in 2018 and 2019 in Ukraine five and six outbreaks of salmonellosis, respectively were confirmed on livestock farms, as well as 647,494 and 275,012 patients with salmonellosis of animal origin, mainly poultry. Poultry salmonellosis control programmes in Ukraine operated in 2009–2013, and now there is a valid normative document: instruction on the prevention and elimination of poultry salmonellosis, which contains clear science-based requirements for the implementation of salmonellosis control measures on poultry farms, including bacteriological control procedures. Sampling is carried out at all stages of rearing, slaughter and processing of poultry, as well as obtaining, sorting and distributing chicken eggs. Certainly, *Salmonella* can be found at some stages, which is the reason for the immediate use of precautionary measures against the spread of the pathogen, as well as its typification for establishing the level of its pathogenicity (Bojko et al., 2014).

In recent years, the epidemiological situation in Ukraine has remained tense. In 2010–2015, the incidence of salmonellosis in Ukraine was in the range of 18.5–22.1 per 100,000 population, without a tendency to decrease. The proportion of salmonellosis in the overall structure of acute intestinal infections (ACI) ranged from 8.1% to 10.3% (Malysh et al., 2016). The incidence differed in various regions of Ukraine: Kharkiv – average frequency is 53.4, Khmelnytsky – 29.9, Cherkasy – 30.2 cases per 100,000 people. The lowest rates were observed in Kherson and Ternopil regions (average incidence of 8.4 and 4.7 per 100,000 population, respectively) (Doan & Malysh, 2017). According to the results of the study from 2014–2015, there is a tendency to a higher manifestation of salmonellosis in the urban population rather than in the rural: 11.69–12.52 cases per 100,000 population, including children under 17 with 34.14–37.26 cases per 100,000 population. These cases were mainly related to food consumption rather than direct contact with sick people or animals (Zarytskyj et al., 2016; Ivakhno & Kozyar, 2019). *Salmonella enteritidis* and *S. typhimurium* predominate in the etiology of food salmonellosis in Ukraine. About 19.0–31.0% of such strains are detected annually (Neverkovets, 2011).

The incidence of salmonellosis in Ukraine is due to the constant inflow of *Salmonella*-contaminated raw meat, milk and eggs into the retail network. In general, in 2014–2018, the share of salmonellosis in the structure of outbreaks of acute intestinal infections ranged from 29.5% to 60.3%. Most outbreaks of salmonellosis have occurred in public catering. At the same time, a significant number of them were associated with the infection of people at home, during various traditional events (weddings, funerals, memorial services, etc.), where a large number of dishes were

prepared, probably in violation of sanitation rules. As the main causes of salmonellosis, the people affected listed the use of “questionable” (in terms of quality) food, including eggs and meat. In 89.6% of cases, outbreaks were caused by *S. enteritidis*, in 2.1% by *S. typhimurium*. *S. blegdam* and *S. glostrup* (strains which are relatively exotic in Ukraine) were the cause in 6.2% and in 2.1% of cases, respectively (Malysh, 2019); in the Ternopil region in 2009–2017 *S. enteritidis* was detected in 56.8–93.5%, and *S. typhimurium* in 7.8–43.8% of cases. Exotic strains of salmonella not typical for the region were also found: *S. soncord* (in 2009), *S. braenderup* (in 2015), *S. soncord* and *S. wippra* (in 2009), *S. give* (in 2010), *S. braenderup* (in 2015), *S. haifa* (in 2016) (Pokryshko et al., 2017). In the Chernivtsi region in 2011–2015, patients were mainly diagnosed with *S. enteritidis* (325 cases) and *S. typhimurium* (37), rare types of *Salmonella* were detected in 12 cases (Moskalyuk et al., 2016). Salmonellosis is characterized by seasonality, an increase in the number of outbreaks of salmonellosis was observed in the warm season, mainly in July–August (Kozishkurt et al., 2019). The main factors in the transmission of non-typhoid salmonellosis are livestock products – meat, milk, eggs. *Salmonella* infection in animals is rarely diagnosed due to asymptomatic disease caused by host-adapted salmonella serovars. Therefore, the epidemic process of salmonellosis is associated with the dynamics of consumption of livestock products, rather than the dynamics of morbidity of animals and birds (Galushko, 2014).

Salmonellosis is now an extremely common disease among animals on industrial farms in Ukraine. Prevalence monitoring is mandatory and controlled by state authorities only in the case of poultry farms. According to studies conducted in Sumy region, *S. enteritidis* was isolated from the meat of forcibly slaughtered cattle in $8.8 \pm 0.8\%$ of cases, whereas *S. choleraesuis* was detected in $14.7 \pm 0.7\%$ of samples taken from the meat of slaughtered pigs. The frequency of isolation of *S. typhimurium* from pathological material of chickens reached 16.1%, whereas for fur animals the rate was 12.8%, for bees – 14.3%, and for the meat of compulsory slaughtered cattle – 4.4% of the studied samples. A direct, strong relationship was confirmed between the frequency of isolation of *S. typhimurium* from pathological material of animals and the frequency of isolation of this pathogen from the clinical material of patients ($r = 0.89$; $m_r = 0.10$; $t = 8.9$). That is, the activation of the epizootic process of this infection among animals entails a higher incidence of salmonellosis in the region (Malysh, 2019). The prevalence of *Salmonella* spp. cultures isolated from poultry determines the number and prevalence of salmonellosis outbreaks in humans, which are primarily related to the consumption of poultry products. Studies in Dnipropetrovsk region have established epizootiological patterns of salmonellosis in animals, namely: the leading role of poultry as a source of infection for poultry (*S. gallinarum-pullorum*, *S. enteritidis*) and humans (*S. enteritidis*) (Martynenko, 2019), such a situation was typical for most regions of Ukraine (Galka et al., 2019).

Salmonellosis in pigs and cattle has been reported in scientific studies less frequently than in the case of poultry. Salmonellosis was the second most common disease (after *Escherichia coli*) on Ukrainian pig farms in 1999–2013, and accounted for 13.3% of all confirmed cases of infectious diseases in pigs (Yakubchak et al., 2014). In the Poltava region in 2015, the share of salmonellosis in pigs was 35.1% of all documented diseases. All age groups of pigs, including 1.8% of fattening pigs, were infected on industrial farms. Such animals are especially dangerous to humans, as they are a source of infected meat (Melynk & Derevianko, 2015). Cases of salmonellosis in about 30-day-old calves have been detected on industrial farms and confirmed by serological methods when the disease was caused by *S. dublin* and *S. typhimurium*, and serological studies have indicated that calves were possible carriers of *Salmonella* (Pundjak, & Kurtjak, 2013).

Circulation of *Salmonella* among pigs and cattle on farms inevitably leads to carcass contamination and a constant risk of salmonellosis. Research conducted in local markets of Mykolayiv established that 11.1% of carcasses of pigs and 9.1% of carcasses of cattle were contaminated with *Salmonella* of serovars of *S. typhimurium* (25.0%), *S. enteritidis* (18.7%), *S. cholera suis* (37.5%) and *S. paratyphi* (18.7%) (Brodovskiy & Kovbansko, 2016).

In recent years, a major problem has been the spread of antibiotic-resistant *Salmonella* strains on Ukrainian farms. A 1996–2005 study revealed the highest resistance of salmonella to sulfamethizole (83.3%),

cotrimoxazole (75.0%), kanamycin (58.3%) and tetracycline (50.0%). In 2006–2012, the development of resistance to cefoxitin (73.2%) and ceftriaxone (42.3%), tetracycline (31.5%) was observed (Bubalo, 2015). In 2016–2017, on poultry farms of Sumy region, *Salmonella* exhibited high resistance to amoxicillin, clindamycin, gentamicin, doxycycline, egocin and colistin (Klishhova, 2017). The proportion of antibiotic-resistant strains is constantly increasing, especially in the case of β -lactam antibiotics (cefazolin, ceftriaxone), aminoglycosides (gentamicin, streptomycin, kanamycin), tetracycline and polymyxin (Vygovska, 2018c; Chumachenko et al., 2019; Arefiev et al., 2020); poly-resistant strains appear (Rublenko & Golovko, 2020). Antibiotic-resistant strains are spread in the environment, thus cultures of *Salmonella* isolated from wild birds were resistant to macrolides, benzylpenicillin and tetracyclines. This poses a threat to ecological systems and can lead to the emergence of reservoirs of resistant strains of *Salmonella* (Rula et al., 2019). Studies of egg yolk from wild migratory birds of different species in their nesting sites in the south of Ukraine reveal the presence of salmonella in an average of 17.0% of samples, mainly *S. enteritidis*, *S. typhimurium*, whereas isolated cultures were resistant to macrolide, penicillin and tetracyclines (Gljebova et al., 2014).

Escherichiosis (*E. coli* including STEC)

Escherichia coli is a Gram-negative, facultative anaerobic, rod-shaped bacterium of the Enterobacteriaceae family. *Escherichia coli* is one of the most common bacteria among normal non-pathogenic intestinal inhabitants of warm-blooded animals and Aves. However, strains of *E. coli* display an extremely large antigenic and morphological diversity. Some of the *E. coli* strains are an etiological factor of enterocolitis and diarrhea in animals and humans (diarrhoeal strains) (Malysk & Chernych, 2015), other strains can cause various extra-intestinal diseases in humans (Salmanov et al., 2019). Strains of *E. coli*, which can cause diarrhea, are divided according to virulent and immunological properties, mechanisms of pathogenesis and the nature of symptoms of diseases that they cause. The following five groups of diarrhoeal strains of *E. coli* are commonly listed: enterotoxigenic *E. coli* (ETEC), enteropathogenic *E. coli* (EPEC), enteroaggregative *E. coli* (EAaggEC), enteroinvasive *E. coli* (EIEC) and Shiga (Vero) toxin-producing *E. coli* (STEC/VTEC) (Wasteson, 2001).

Currently, consolidated statistical reports on human *E. coli* in Ukraine are not publicly available, however, the analysis covering the period 2003–2013 indicates that the incidence of diarrhoeal *E. coli* can vary in the range of 1.7–5.4 per 100,000 population, while the etiological structure is dominated by enteroinvasive *E. coli*. There is a correlation between the prevalence of samples of milk and dairy products that do not meet sanitary and bacteriological indicators, and the incidence of escherichiosis caused by enteroinvasive *E. coli*. In addition, diarrheal escherichiosis was caused by EIEC *E. coli* in $33.6 \pm 2.1\%$ of cases, including $29.4 \pm 1.9\%$ cases associated with serogroup O1, i.e. the major cause of escherichiosis in poultry, wildfowl and decorative birds. In Sumy region, every third incident of diarrheal escherichiosis was caused by *E. coli* of the O1 serogroup (Malysk & Chernych, 2015). At the same time, studies in Vinnytsya region have shown that colibacillosis accounts for an average of 35.9% of cases in the general infectious pathology of poultry of bacterial etiology, the disease is the most frequently observed in chickens (85.9%) and has a seasonal character, with the greatest prevalence from April to September (86.2% of all incidents) and morbidity rates peaking in August (20.0%) (Melnyk & Onyshchuk, 2015). Feed contaminated with mycotoxins is a contributing factor to the outbreak of colibacillosis in chickens (Ivchenko et al., 2018). In the industrial farming of turkeys, escherichiosis accounted for 78.6% of diseases of bacterial etiology. The etiological cause of colibacillosis was strains *E. coli* serovariants O2, O78 and O111. The intensity of the infectious process was associated with the level of total microbial contamination of aviaries, including the air inside (Bezvershenko et al., 2013).

During 2004–2015, *E. coli* was detected in 7.1% of samples of pathological material collected from cattle, 7.3% from pigs, and 4.4% from poultry. Animal farms provide favourable conditions for the passage of pathogenic *E. coli*, which contributes to the spread of colibacillosis through

the country among all types of livestock (Vasilyeva, 2016). In 2011–2017 in Ukraine, the main pathogens in the infectious pathology of pigs of bacterial etiology were *E. coli* – 41.9% and the most frequently registered diseases were colibacillosis – 41.9% and choleraetoxemia (edema) – 23.1% of all cases among confirmed diagnoses (Gorbatjuk et al., 2018; Zhovnir et al., 2019). Accessory factors for an increased prevalence of colibacillosis in piglets are high stocking density, characteristic of commercial pig farming, feeding defects that lead to hemodynamic disorders and changes in parenchymal organs and immunodeficiency states (Skrypka & Zapeka, 2016).

The problem of antibiotic resistance of *E. coli* has been shown in studies in medicine and veterinary medicine (Borovyk, 2016). Polyantibiotic-resistant *E. coli* strains were found in isolates from clinically healthy ($49.2 \pm 9.8\%$) and sick ($87.2 \pm 5.4\%$) people (Voida, 2014). Antibiotic resistance of *E. coli* strains isolated from the surface of pig carcasses in Odesa region manifested itself in an average of 34.7% of cases, and in Sumy region in an average of 53.7% of cases. The greatest resistance of the isolate was to ampicillin – in 67.3% of isolates from Odesa region, and in 80.6% from Sumy region. In 45–47% of cases, resistant *E. coli* isolates exhibited monoresistance to antibiotics, while 32.0% of isolates were resistant to two antibiotics or more. *Escherichia coli* strains were resistant to ofloxacin in more than 95.0% of cases (Kasianchuk et al., 2018). Studies of antibiotic resistance of strains from the udder of cows with mastitis suggested that long presence of yeast cultures in the microbiocenosis together with *E. coli* cultures increases the antibiotic resistance of the latter (Kalashnikov, 2011), while in about 30.0% of cows with mastitis, *E. coli* was isolated from milk (Palii et al., 2020).

Though various *E. coli* serovariants are widespread and their etiological significance in human and animal diseases as well as the zoonotic potential of *E. coli* serovariants is inherent in various animal species, a major public health hazard and a generally recognized zoonotic *E. coli* is Shiga toxin-producing *E. coli* (STEC) (also known as verotoxigenic, verocytotoxigenic, verotoxin-producing, verocytotoxin-producing *E. coli* (VTEC)), in particular serotype O157:H7, spread worldwide, and serogroups O26, O103, O111, O145, which caused outbreaks in Europe (Wasteson, 2001). In 2018, the EU reported 8,161 confirmed cases of Shiga toxin-producing *E. coli* (STEC) infections in humans, accounting for 2.28 cases per 100,000 population, with a total of 48 outbreaks associated with contaminated *E. coli* food (milk, cheese, and mixed dishes, including plant-based foods) and five with contaminated water (EFSA, 2019). Currently, consolidated data on monitoring human colibacillosis caused by STEC and monitoring the prevalence of these serovariants among animals are not publicly available in Ukraine. Such information was not provided for by mandatory reporting in the health care system. However, since 2021, the updated legislation requires registering cases of human diseases caused by *E. coli* (with the exception of non-pathogenic strains) and *E. coli*, verocytotoxigenic strains (e.g. O157: H7 or O103) as separate items, as well as accumulating and analysing such information.

Currently, some difficulties in identifying STEC serotypes by bacteriological and immunological methods (Baluta et al., 2009; Sukharev, 2011) can be successfully solved using molecular genetic methods (Berhilevych et al., 2014, 2016, 2019; Kasianchuk et al., 2015). Molecular genetic studies have shown that STEC serovariants of *E. coli* can be collected from the carcasses of cattle and pigs. Between 2012 and 2015, 97 *E. coli* isolates (42.2%) were isolated from 230 bacterial samples collected from flushes from beef (130) and swine (100) carcasses obtained from five slaughterhouses in Ukraine, among which seven (7.2%) STEC strains (five beef and two swine carcass swabs) were identified by PCR (Berhilevych et al., 2018). In another study, Shiga toxin-producing *E. coli* (STEC) was detected in 8.1% and 5.7% of samples collected from beef and swine carcasses, respectively (Berhilevych et al., 2019). It indicates the extreme relevance of STEC monitoring at all stages of livestock production.

Previous scientific research suggests that STEC are common in Ukraine. STEC isolates were collected in 60.0% of unaffected farms, in 2.9–30.6% of cases from clinically healthy animals. In 29.4% of farms affected by diarrheal diseases of calves, STEC serotypes were detected in 12.9% of sick calves. STEC was also detected in 9.7% of piglets with diarrhea. Strains of *E. coli* serogroup O157 accounted for 2.0% of the total number of epizootic isolates of *E. coli* on Ukrainian farms, including 0.5%

of the total number of *E. coli* crops isolated from cattle of different age groups and with different clinical status, and 1.5% of the total number of *E. coli* crops isolated from pigs (Zotsenko & Volynets, 2002). The human and animal disease monitoring system for Shiga toxin-producing *E. coli* (STEC) and prevention of outbreaks of the disease needs to be improved, including strengthening monitoring of the spread of STEC among live-stock.

Listeriosis (*Listeria* spp.)

The etiological factor of listeriosis in humans is the bacterium *L. monocytogenes*. Since the early 1980s, the pathogen has been associated with food poisoning. The genus *Listeria* includes 17 species of bacteria divided into two groups: *Listeria sensu stricto*, which includes *L. monocytogenes*, *L. seelgeri*, *L. ivanovii*, *L. marthii*, *L. welshimeri*, *L. innocua*, and *Listeria sensu lato*, which includes 11 more species divided into three genera. However, only *L. monocytogenes* is considered a zoonotic pathogen pathogenic to humans. *Listeria monocytogenes* is a Gram-positive bacterium, relatively aerobic, oxidase-negative and catalase-positive small mobile bacillus. The bacterium is able to grow in adverse temperature conditions (-0.4 to 45 °C) and pH values (4.4–9.4), as well as in low humidity environments (Chlebicz & Śliżewska, 2018).

In European Union countries, animals with listeriosis are an etiological factor in human listeriosis in 4.0% of cases; raw materials obtained from sick animals are the cause of contamination of food by pathogenic microorganisms in 38.0% of cases. In 45.0% of cases of human illness, food was the source of the pathogen (Machuskyi & Kovtun, 2014). In Ukraine, 1–2 cases of listeriosis are officially registered annually, data on animal diseases are not officially accumulated. In 2018 in the EU there were 2,549 cases of listeriosis among people, with morbidity rate of 0.47 cases per 100,000 population and mortality rate of 15.6%, making listeriosis one of the most serious foodborne diseases (EFSA, 2019).

In Ukraine, listeriosis is given insufficient attention in human and veterinary medicine (Randjuk et al., 2013). Human listeriosis is known as a serious threat to public health, manifested by severe meningitis and a high mortality rate (Pikul et al., 2011). Such clinical cases are described in Lviv region (Zinchuk et al., 2011) and Poltava region (Pikul et al., 2011). Listeriosis is a naturally occurring disease and the pathogen can survive for a long time in natural habitats, including populations of wild rodents and birds (Randjuk et al., 2013). Listeriosis is a saprozoosis and characterized by a number of sources of infection, a variety of transmission routes, polymorphism of clinical manifestations and high mortality. Accordingly, it is possible to directly point to the basic difference between this infection and other food-borne zoonoses – listeriosis, like any saprozoosis, is equally dangerous for both animals and humans. In soils of different geographical zones of Ukraine, depending on their use (in this case samples of soils used by the population for growing vegetables in-ground were the main subject of the study), *Listeria* was found in 18.7% of samples. Application of phosphorus and nitrogen fertilizers to the soil is the most conducive to the preservation and reproduction of listeria of different strains (Perotska, 2014).

In industrial livestock farming, cases of the spread of the listeriosis pathogen among the production livestock have been described. During 2011–2015, listeriosis infection was confirmed on livestock farms in the north-western region, as well as central and south-eastern parts of Ukraine. The highest incidence of listeriosis was found among small ruminants on farms in Zhytomyr region, with a tendency to increase from 50.0% of confirmed positive diagnoses in 2011 to 66.7% in 2015. There is an upward trend of the incidence of listeriosis in cattle in Cherkasy region, as from 11.1% of confirmed positive results in 2011, these figures increased to 18.2% in 2015 and in pigs, respectively, from 13.2% of positive cases detected in 2011 to 14.3% in 2014 (Uhovska et al., 2017).

Laboratory diagnosis of *Listeria* spp. is imperfect, as the presence of other microflora and special conditions of cultivation and typing of the pathogen render the detection of the pathogen from food complicated (Borovyk & Zazharska, 2019). Methods of laboratory diagnosis of listeriosis in Ukraine are improved by optimizing standard bacteriological methods of food testing (Kozhokaru et al., 2012), testing of meat of different species of animals (Bogatko, 2019), development of molecular genetic

methods based on polymerase chain reaction (Ushkalov et al., 2014; Vyhovska, 2018d). The issue of antimicrobial resistance is also relevant for listeriosis. It was found that field isolates have a greater spectrum of antibiotic resistance than reference strains, and resistance differs in different field isolates (Vyhovska, 2018a, 2018b).

Manifestation features of food-borne bacterial zoonoses

Zoonoses have a direct impact on public health in every country, Ukraine being no exception. For an outbreak of food-borne zoonosis, the following elements of the epidemic chain are necessary: the source of the pathogen – the routes of infection – susceptible organisms. This is true for any combination of elements from human and animal populations. The causative agents of common bacterial zoonoses in animals are either saprophytes (listeriosis) or have obligate hosts among animals (species-specific variants of *E. coli*, *Salmonella*, *Campylobacter*). In this case, these pathogens can also cause disease in humans (Lytvyn et al., 2002). The epidemiology of bacterial zoonoses includes several clusters: human population, animal population, environment. To a limited extent, pathogens of bacterial food-borne zoonoses can circulate in human populations, transmitted by contacts in a family or communal environment, involving permeating into food and causing outbreaks. However, this cannot be widespread given the very small number of latent carriers and the lack of social conditions for patients to come into contact with food (Bakhariev & Nakonechnyi, 2019).

Bacterial pathogens also often contaminate food via slaughterhouses and processing plants with raw materials and food. For example, *E. coli* O1 serotypes, whose obligate hosts are considered to be chickens, often cause diarrhea in children in the Suny region of Ukraine (Malysh & Chernych, 2014). Mechanisms and risks of contamination of livestock products in slaughterhouses and processing plants are known and are mainly associated with violations of sanitary norms (Kasianenko & Gusejev, 2019). Contamination of such factories can lead to contamination of large amounts of primary animal products by pathogenic bacteria, being a “bottleneck” in the food production chain.

In Ukraine, there is a noticeable gap between the medical and veterinary surveillance systems for bacterial zoonoses. The relationship between the circulation of bacterial zoonoses in humans and animals is difficult to grasp, but some authors point to facts that indicate that one exists (Fotina et al., 2014; Malysh et al., 2016). The underdiagnosis of campylobacteriosis cases in humans is obvious, given the prevalence of *Campylobacter* spp. in livestock, in particular broiler poultry, and the number of reported cases in humans and compared to the number of reported cases in humans in EU countries. There is no systematic monitoring of the spread of STEC in livestock, and the registration of human cases should begin in 2021. Human listeriosis is not always associated with animal products, although scientific studies indicate a significant prevalence of *Listeria* spp. not only in the environment, but also in industrial livestock farms. Avian salmonellosis seems to be the most controlled in Ukraine. In recent years, there have been special state programmes to control salmonellosis on poultry farms, and now such measures are enshrined in national legislation. At the same time, the role of pigs and cattle in outbreaks of salmonellosis in humans has not been studied sufficiently (Kyryk, 2013). Salmonellosis is the most commonly reported bacterial zoonosis in humans in Ukraine. The surveillance and response system for zoonotic bacterial pathogens requires a transformation based on the principles of the “One Health” approach.

Potential role of industrial livestock farms in the spread of bacterial zoonoses

Pathogens of food zoonoses are almost always microorganisms inherent in the fecal microflora of farm animals (*Campylobacter*, *Salmonella*, *E. coli*) or saprophytes, which are common on livestock farms (*Listeria*). Pathogenic strains of such bacteria also contaminate raw materials and food or the environment (water) and cause outbreaks of foodborne infections in humans. However, the onset among animals does not necessarily happen, because the animals may be carriers and show no symptoms of the disease. The peculiarity of such diseases is that the very presence of the

pathogen in the animal's body is a necessary but insufficient condition for the development of the disease; such diseases are called "factor" (Lytvyn et al., 2002). A sufficient set of factors for the development of the disease is formed due to the peculiarities of the technologies of industrial keeping of animals. Factors caused by the very concept of an industrial livestock farm are always present: the concentration of a large number of animals on one farm, the same standardized feeding, limited territory, the contacts of livestock with technological processes and personnel, the focus on reaching the highest productivity, economic feasibility of technologies for keeping animals. Factors that occur on industrial farms in case of technological defects or violations of sanitation, feeding, keeping and transportation conditions, etc.: inadequate hygienic conditions which reduce the resistance of animals, excess microbial contamination in the farms' environment, long-term feeding violations affecting the whole herd, age groups mixture and introduction of new animals into the herd without quarantine (import of pathogens), joint or close keeping different animal species together or nearby, uncontrolled widespread use of antibiotics. Industrial livestock farms affect the ecology of the environment: excessive pressure on ecosystems due to the production of large amounts of feces, pollution of water resources, the formation of antimicrobial resistance in the microflora of habitats. Outbreaks of factor bacterial zoonotic diseases on industrial livestock farms are highly likely, given the presence of all necessary (pathogens) and sufficient (factors) elements and the apparently low resistance of farmed animals. Therefore, industrial livestock farms are an important potential source of bacterial zoonoses for humans (Fig. 4).

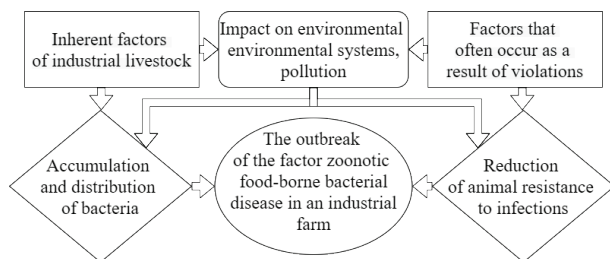


Fig. 4. Scheme of outbreak of factor zoonotic bacterial disease on an industrial farm

A combination of favourable factors for the accumulation and passage of pathogens of bacterial diseases and animal immunological insufficiency, acquired as a result of industrial farming, contributes to outbreaks of factor bacterial diseases (Skrypka & Zapeka, 2016) and significantly increases the risk of the pathogen entering livestock products and the environment.

Conclusions

The system of state supervision over the main food zoonoses (campylobacteriosis, salmonellosis, STEC, listeriosis) is characterized by an imbalance of medical and veterinary components. Ukraine has the highest number of confirmed cases of salmonellosis in humans and poultry. The system of notification and surveillance of other bacterial zoonoses is not organized effectively enough, although scientific studies indicate their significant spread among humans and animals. In Ukraine, the practice of industrial farming is widespread. Depending on the species, 30–60% of animals are kept on industrial farms, more than half of farms can be classified as medium and large. Industrial technology actively affects the health status of animals, and in the event of a violation of technology, the risk of factor diseases increases dramatically and the risk of spreading their pathogens along with livestock products increases. For each of the studied pathogens, scientific research highlights the problem of antimicrobial resistance. The general trend for bacterial zoonoses is expanding the resistance spectrum of strains isolated from sick people, animals and the environment on livestock farms. The potential role of industrial livestock farms in the spread of bacterial zoonoses can be identified as important and in need of further study.

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