



## Retrospective analysis of the spread of bacterial poultry diseases on the territory of Ukraine for the period 2012–2020

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One of the most important livestock industries in the world is poultry breeding, which meets human needs for high-quality protein products (poultry meat, eggs) and is characterized by rapid return on investment. Bacterial infectious diseases of poultry are a major problem for the poultry industry and its strategic future. Given the relevance of bacterial diseases of poultry in the world and in Ukraine in particular, the authors conducted a retrospective analysis of the spread of these diseases in Ukraine for the period 2012–2020 by analyzing and systematizing the results of bacteriological investigations. In order to analyze the spread of bacterial diseases of poultry in terms of regions in Ukraine, we analyzed data on 20 diseases of poultry, namely: hemophilosis, infectious enterotoxemia, yersiniosis, campylobacteriosis, colibacteriosis, coligranulomatosis, klebsiella, listeriosis, mycoplasmosis, neisseriosis, pasteurellosis, pathogenic proteus, pneumococcosis, pseudomonosis, pullorosis, erysipelas septicemia, salmonellosis, staphylococcosis, streptococcosis and tuberculosis. According to the results of research, it is found that bacterial diseases of poultry are significantly common in Ukraine, the average infection of poultry with bacterial diseases for the period from 2012 to 2020 was 0.8%. The leading role in the etiological structure of pathogens of bacterial diseases of poultry was played by colibacillosis – 56.9% of the total number of all positive samples. Also, the dominant bacterial diseases of poultry in Ukraine during the analyzed period are: salmonellosis (13.5%), staphylococcosis (7.8%), pasteurellosis (7.0%), pseudomonosis (6.8%), pullorosis (3.6%) and streptococcus (2.6%). Significantly fewer positive samples were registered in the bacteriological investigations of other diseases: pneumococcosis 0.5%, tuberculosis 0.4%, infectious enterotoxemia 0.3%, pathogenic proteus 0.2%, erysipelas septicemia 0.1%, klebsiellosis 0.1%, listeriosis 0.1%, neisseriosis 0.08%, coligranulomatosis 0.05% and hemophilosis 0.02%. According to the results of bacteriological research of poultry for such diseases as yersiniosis, campylobacteriosis and mycoplasmosis – no positive test was found for the entire analyzed period. According to the results of ecological and geographical analysis, the heterogeneity of the nosological profile of bacterial diseases of poultry in different regions of Ukraine was established.

**Keywords:** poultry farming; nosological profile; epizootology; bacteriological research; monitoring; mapping.

### Introduction

Poultry is the most important livestock industry in the world, meeting the human need for high-quality protein products (poultry meat, eggs) and is characterized by a rapid return on investment. Poultry meat and eggs are available animal proteins and are the most nutritious. Poultry and egg production are growing worldwide every year. Today, there are 22.8 billion chickens on Earth. There are about 135 chickens for each cow and three for each person. Egg production worldwide exceeded 86.67 million metric tons in 2020 against 74.14 million metric tons in 2016. Since 1990, world egg production has increased by more than 100%. In 2018, world production of broiler meat was about 92.7 million metric tons, and increased to about 100 million metric tons in 2021 (Jeni et al., 2021). Over the last 10–15 years, modern poultry farming has been significantly transformed. These changes are primarily due to the use of new poultry crosses with high productive properties. Such crosses require unconditional implementation of all technological and sanitary standards for their maintenance. In case of non-compliance with these components there is a decrease in immunity and alteration of the microbiocenosis in poultry. Under such preconditions, the microflora in poultry premises is activated, its passage is increased, the probability of pathogenic bacteria entering the body of poultry increases, as a result of which the development of the industry is restrained and economic indicators decrease due to infectious and invasive diseases. Infectious poultry diseases are a major

problem for the poultry industry and its strategic future. Bacterial and viral zoonoses are especially dangerous in this regard (Carenzi & Verga, 2009). Significant concentration of poultry in limited areas, artificial microclimate, frequent stressful situations, the flow system of poultry farming, non-compliance with technological parameters of breeding and keeping poultry, deficiency in the ration of the required amount of trace elements and vitamins, unreasonable use of excessive concentrations of antibiotics and disinfectants, etc., contribute to the passage of pathogens, increase their virulence, worsen the epizootic situation, causing significant morbidity and mortality among diseased poultry. An important element in today's globalised world is the spread of virulent strains through international movements of poultry products. Bacterial diseases in all these factors significantly hinder the development of poultry. They cause significant, including direct (high feed conversion rates, poultry death, hypersensitivity to stressful situations, reduced productivity, low feed conversion, deterioration of embryonic biological qualities, reduction of egg-laying and output of young growth from eggs, low weight gain of broilers, etc.) and indirect (immunosuppressive influence on the organism, resulting in reduced post-vaccination immunity) economic losses (Carenzi & Verga, 2009; Haféz, 2010). In addition, it should be taken into account that most bacterial infections in modern poultry farming are factorial, i.e. the causative agents of the latter are mainly cohabitants with the poultry organism, they are constantly in the organism and under certain unfavourable conditions for the organism of poultry acquire pathogenic characteristics (Lyt-

vyn et al., 2002; Carenzi & Verga, 2009). In total, bacterial diseases occupy more than 70% of the overall structure of avian infections (Rozhdestvenskaya et al., 2020).

Finally, poultry and eggs (in case of violation of sanitary requirements) become factors in the transmission of infectious agents to humans. Consumption of contaminated products leads to outbreaks of toxicoinfections in adults and children. In general, bacterial diseases of poultry are not only a veterinary but also a medical and environmental problem. Poultry can be carriers of pathogens with zoonotic potential: *Escherichia coli*, *Citrobacter freundii*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Salmonella enteritidis*, *Campylobacter jejuni* (Line et al., 2008; Borisenkova & Novikova, 2014; Novikova & Pavlova, 2018).

Campylobacteriosis, salmonellosis, and *Escherichia coli* have been linked to the consumption of contaminated protein products. The risks of human disease after consumption of poultry products associated with these diseases remain quite high (ESFA, 2015; Haféz & Attia, 2020). One should also keep in mind such pathogens of infectious diseases of poultry as salmonellosis, listeriosis and chlamydia (ornithosis) can cause fatal diseases in humans. In general, in accordance with the International Terrestrial Animal Code, each country provides epizootic surveillance for salmonella in poultry farms. Such a program is mandatory for countries that sell poultry products.

Outbreaks of salmonellosis in humans can become widespread. *Salmonella enteritidis*, often found in the droppings of infected poultry, even enters the egg through the shell, and such a product (often fresh eggs) becomes a factor in the transmission of the pathogen to humans. *Mycoplasma* can also enter the human body through poultry eggs. Also dangerous to humans is the pathogen *Salmonella arizona*, which mainly affects turkeys, the disease is called arizonosis. Pathogens of pullorosis of poultry (*Salmonella pullorum* and *S. gallinarum*) can also cause toxicoinfections in humans. Concerns about dietary salmonella have prompted many countries to introduce microbiological criteria for certain foods, especially raw poultry products, which are an important part of the global food market. Uncertainty of imports and exports, confusion in regulations due to different requirements for salmonella prompted the convening of an international group of scientific experts from 16 countries to discuss scientific and technical issues affecting the establishment of microbiological criteria for salmonella contamination of raw chicken. Of particular concern to this group was the use of criteria that assume zero tolerance to *Salmonella* and complete absence of the pathogen. Researchers and experts have pointed out that terms such as “zero tolerance” or “microbial absence” for raw poultry should be avoided unless defined and interpreted by international agreement. Risk evaluation provides a more meaningful approach than the “zero-tolerance” philosophy, and new indicators such as human health performance targets should be used throughout the food chain to help identify risk and identify ways to reduce negative influence on public health (Mead et al., 2010; Cox et al., 2011).

*Salmonella*, staphylococci and clostridia (pathogens of anaerobic enterotoxemia) are pathogens that cause acute intestinal diseases (toxicoinfections). The causative agent of avian colibacillosis *Escherichia coli* can be present in the intestines of poultry almost permanently. The causative agent of colibacillosis often complicates diseases in poultry caused by viruses, pasteurellae, mycoplasmas or other bacteria. The pathogen can cause fever, diarrhea, and skin rashes (Sukumaran & Prasadarao, 2003). *E. coli* O157:H7, which is dangerous to humans, is often circulated in poultry farms and is even isolated from broiler meat (Bitzan et al., 1993). Tuberculosis in poultry is caused by *Mycobacterium avium*. The pathogen can affect people with immune problems (immunodeficiency). *Pseudomonas aeruginosa* (blue purulent bacillus) is also common in poultry. However, people with a high level of immunity and intact mucous membranes do not develop the disease. The disease occurs in people with immunodeficiency, the elderly and children. Of the respiratory bacterial infections in poultry farms, the most common are pasteurellosis and respiratory mycoplasmosis (Bakulin, 2016; Reuben et al., 2021). Anaerobic enterotoxemia, caused by *Clostridium perfringens*, is characterized by damage to the small intestine, and leads to losses due to loss of productivity caused by the influence of toxins on the organism of poultry, increasing mortality. In addition, there is an increased risk of the pathogen and toxins entering poultry products (Van Immerseel et al., 2004; Wei et al., 2020).

Given the relevance of bacterial diseases of poultry in the world and, in particular, in Ukraine, the aim of our work was to conduct a retrospective analysis of the spread of these diseases in Ukraine over nine years by analyzing and systematizing the results of bacteriological investigation.

## Materials and methods

The authors conducted a retrospective analysis of the spread of bacterial diseases of poultry in Ukraine for the period 2012–2020. For this purpose, the reports of the regional laboratories of the State Food and Consumer Service and the State Research Institute for Laboratory Diagnostics and Veterinary Sanitary Examination (SSRILDVSE, Kyiv) for 9 years were studied, systematized and analyzed.

In order to analyze the spread of bacterial diseases of poultry in the context of the regions in Ukraine, we analyzed data on 20 diseases of poultry, namely: hemophilia, infectious enterotoxemia, yersiniosis, campylobacteriosis, colibacillosis, coligranulomatosis, klebsiella, listeriosis, mycoplasmosis, neisseriosis, pasteurellosis, pathogenic proteus, pneumococcosis, pseudomonosis, pullorosis, erysipelas septicemia, salmonellosis, staphylococcosis, streptococcosis and tuberculosis.

Numerical data are presented in the article without taking into account the temporarily occupied territory of the Autonomous Republic of Crimea, the city of Sevastopol and part of the temporarily occupied territories of Donetsk and Luhansk regions.

Information on the total number of poultry on the territory of Ukraine was obtained on the website of the State Statistics Service of Ukraine (<http://ukrstat.gov.ua>), information on poultry in the world, the number of poultry meat and eggs produced from site statista.com (<http://surl.li/bjknk>, <http://surl.li/bjknt>).

Area mapping was presented in the software Quantum GIS 3.16.0 (International Quantum GIS Project, version 2020, Germany), which is freely available ([www.qgis.org/ru/site/forusers/download.html](http://www.qgis.org/ru/site/forusers/download.html)). Vector layers for the borders of the regions of Ukraine were downloaded at [www.diva-gis.org/Data](http://www.diva-gis.org/Data). A quantile with 4 data classes was chosen for classification with 4 data classes.

## Results

*Epizootic situation regarding bacterial diseases of poultry in Ukraine.* Analyzing the volume of bacteriological diagnosis of poultry diseases in Ukraine for the period 2012–2020, we see that the largest number of samples from poultry was studied in 2012 and 2013 – 137,809 and 121,987 samples, respectively, and the lowest in 2020 – 58,320 samples. It should be noted that for the entire analyzed period, the volume of bacteriological diagnosis of poultry diseases is constantly declining, as evidenced by the trend line. The number of bacterially tested samples from poultry decreased from 137,809 samples in 2012 to 58,320 samples in 2020 (the number of tested samples decreased by 57.7% between 2012 and 2020, Fig. 1).

In order to compare the volume of bacteriological studies of poultry and the number of poultry, Figure 1 shows the dynamics of the number of the poultry population in Ukraine, according to the State Statistics Service of Ukraine as of January 1 of each year. As can be seen from the graph, the number of poultry in Ukraine during the analyzed period fluctuated significantly: from 2012 to 2014 it increased – from 200,760.6 to 230,289.8 thousand head; from 2014 to 2017 it decreased – from 230,289.8 to 201,668.0 thousand head; from 2017 to 2020 it increased – from 201,668.0 to 226,333.0 thousand head. Thus, during the period 2012–2020, when the decrease in the volume of bacteriological diagnostics began, the poultry population in Ukraine ranged from 200,760.6 to 230,289.8 thousand head, i.e. there was a fluctuation in the number of the poultry population by 14.7% for the specified period. Comparing the indicators of reduction of bacteriological diagnostics (by 57.7% in 2012–2020) and indicators of fluctuations in the number of the poultry population (by 14.7% over the same period), we can affirm that the volume of bacteriological diagnostics of poultry has significantly decreased recently and they are not related to objective reasons, namely fluctuations in poultry population.

As shown in Figure 2, the infection of poultry with bacterial pathogens during the analyzed period was the highest in 2013 and 2017 – 0.9%

and 0.8%, respectively. The lowest infection rate was observed in 2019 – 0.5%. In 2014–2017, there was a gradual increase in infection, in the next three years (2018–2020) the infection began to decrease – from 0.8% in 2017 to 0.5% in 2019. In general, during the analyzed period, from 2012 to 2020, there was a steady trend to reduction in the number of positive samples from poultry during bacteriological studies.

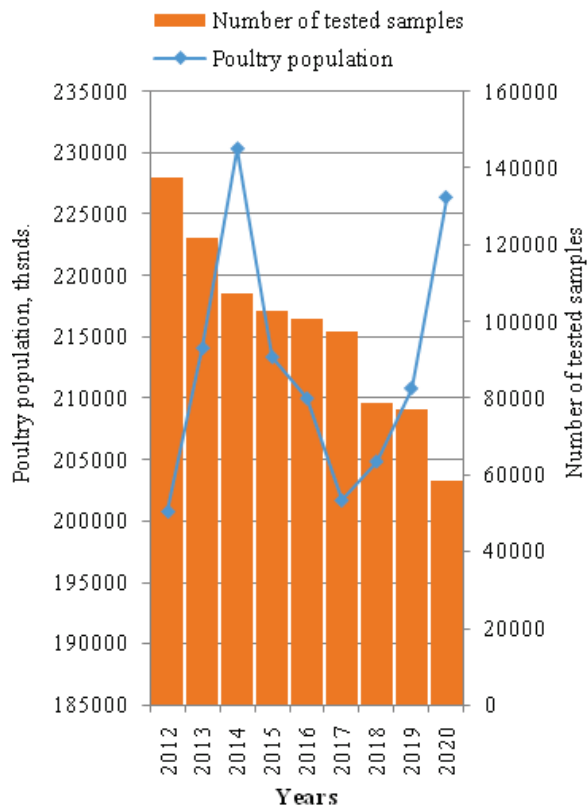


Fig. 1. Dynamics of the number of bacteriological studies of poultry samples in Ukraine (2012–2020)

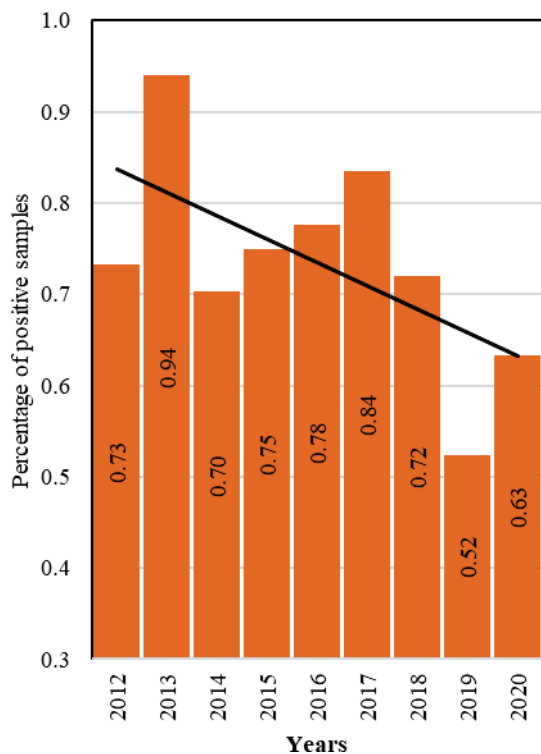


Fig. 2. Dynamics of the number of positive samples from poultry detected during bacteriological research in Ukraine (2012–2020)

In the nine years (2012–2020) that were analyzed, the veterinary laboratories of Ukraine conducted 882,121 bacterial investigations of poultry samples and obtained 6,614 positive results. The generalized results of bacterial investigations of poultry diseases are presented in Table 1.

**Table 1**  
Structure of bacterial diseases of poultry in Ukraine by the results of studies for the period 2012–2020

The name of the disease	Number of tested samples	Number of positive samples	Prevalence, %
Hemophilosis	1,778	1	0.05
Yersiniosis	2,409	0	0.0
Infectious enterotoxemia	376	17	4.5
Campylobacteriosis	1,178	0	0.0
Klebsiellosis	2,107	6	0.3
Colibacteriosis	212,759	3,766	1.8
Coligranulomatosis	1,316	3	0.2
Listeriosis	34,467	6	0.02
Mycoplasmosis	354	0	0.0
Neisseriosis	2,414	5	0.2
Pasteurellosis	88,877	463	0.5
Pathogenic proteus	9,959	10	0.1
Pneumococcosis (diplococci)	18,225	35	0.2
Pseudomonosis	21,063	449	2.1
Pullorosis	48,561	237	0.5
Erysipelas septicemia	16	8	50.0
Salmonellosis (patmat.)	306,466	892	0.3
Staphylococcosis	62,666	516	0.8
Streptococcosis	66,944	174	0.3
Tuberculosis	186	26	14.0
Total	882,121	6,614	0.8

As shown in Table 1, the predominant number of positive samples in the bacteriological diagnosis is detected in poultry with colibacillosis – 56.9% of the total number of all positive samples. Also, the dominant bacterial diseases of poultry in Ukraine during the analyzed period were: salmonellosis (13.5%), staphylococcosis (7.8%), pasteurellosis (7.0%), pseudomonosis (6.8%), pullorosis (3.6%) and streptococcosis (2.6%). Significantly fewer positive samples were registered in the bacteriological investigation of other diseases: pneumococcosis 0.5%, tuberculosis 0.4%, infectious enterotoxemia 0.3%, pathogenic proteus 0.2%, erysipelas septicemia 0.1%, klebsiellosis 0.1%, listeriosis 0.1%, neisseriosis 0.08%, coli-granulomatosis 0.05% and hemophilosis 0.02%. According to the results of bacteriological investigations of poultry for such diseases as yersiniosis, campylobacteriosis and mycoplasmosis – no positive test was found for the entire analyzed period.

According to most leading experts in the study of infectious bacterial diseases of poultry, the nosological profile of bacterial diseases of poultry requires constant monitoring in both poultry and wild, synanthropic and zoological birds. Therefore, we conducted a retrospective ecological and geographical analysis of the spread of the seven most common bacterial diseases of poultry in Ukraine.

The investigation of the spread of colibacteriosis among poultry in Ukraine. During the analyzed period during the bacteriological diagnosis of poultry we received 3,766 positive samples for colibacteriosis, which is 56.9% of the total number of all positive samples. This disease is widespread in Ukraine among poultry, and ranks first (in the number of positive samples) in the etiologic structure of bacterial diseases of poultry (Fig. 3). Infection of poultry with colibacteriosis in the analyzed period was the highest in 2013 – 2.4%. The lowest infections were in 2019 and 2020 – 1.1% and 1.2%, respectively. In general, during the analyzed period, we observed a steady decrease in the infection of poultry with colibacteriosis. In absolute terms, a similar trend was observed to reduction in the incidence of this disease.

*Study of the prevalence of salmonellosis among poultry in Ukraine.* During the period analyzed, the state veterinary laboratories of Ukraine received 892 positive samples for salmonellosis, which is 13.5% of the total number of positively responding poultry. Such a significant percentage of infection indicates that on the territory of Ukraine this disease is one of the dominant, and the causative agents of this disease play a significant role in infecting poultry with bacterial diseases (Fig. 4). The peak of poultry infection with salmonellosis in the analyzed period was in 2013,

2014 and 2015 and amounted to 0.4%, 0.5% and 0.4%, and the fewest cases were observed in 2019 – 0.05%. In general, from 2012 to 2020, as evidenced by the trend line, there was a steady decrease in the infection of poultry with salmonellosis.

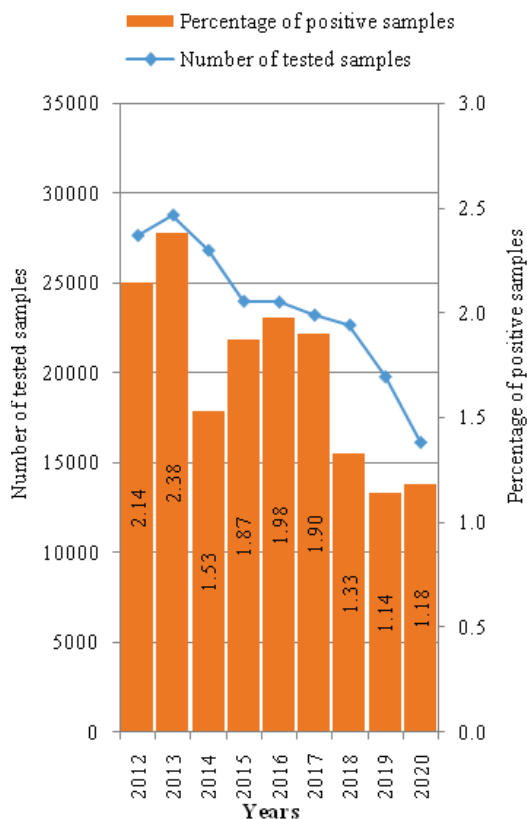


Fig. 3. Dynamics of the number of detected cases of colibacillosis among poultry in Ukraine (2012–2020)

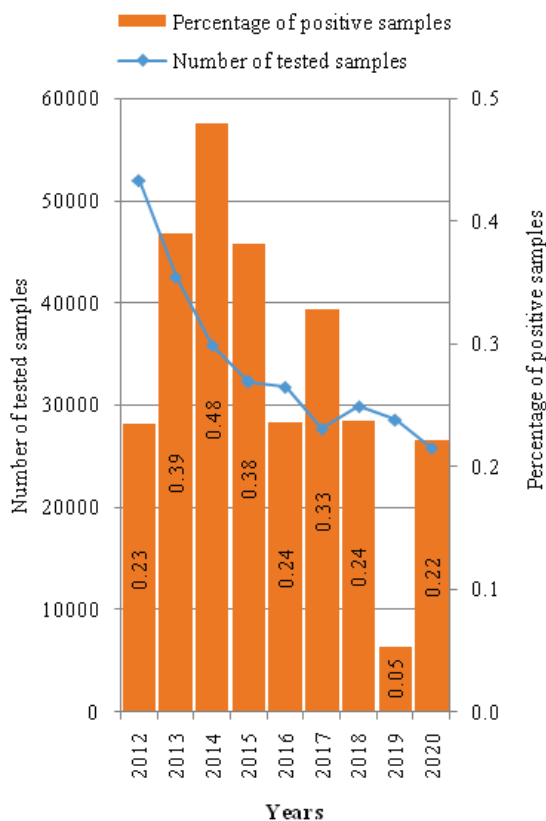


Fig. 4. Dynamics of the number of detected cases of salmonellosis among poultry in Ukraine (2012–2020)

Research on the spread of staphylococcosis among poultry in Ukraine. During the analyzed period, 516 positive samples for staphylococcosis were detected, which is 7.8% of the total number of positively responding poultry. This disease plays a leading role in the etiological structure of bacterial diseases of poultry in Ukraine (Fig. 5). The morbidity of poultry for staphylococcosis in the analyzed period was the highest in 2020 – 2.0%, and the lowest in 2012, 2015 and amounted to 0.4% and 0.3%, respectively. During the analyzed period, two periods were observed: the first – from 2012 to 2017 when there were slight fluctuations in indicators of the poultry disease staphylococcosis from 0.3% in 2015 to 1.1% in 2013; second – from 2017 to 2020 there was a steady annual increase in cases of infection of poultry with staphylococcosis from 0.5% in 2017 to 2.0% in 2020. In general, during the analyzed period, we observed a steady trend of increasing rates of infection of poultry with staphylococcosis. In absolute terms (the number of positive samples per year), we observed a variety of indicators – fluctuations over the years from 40 to 88 positive samples.

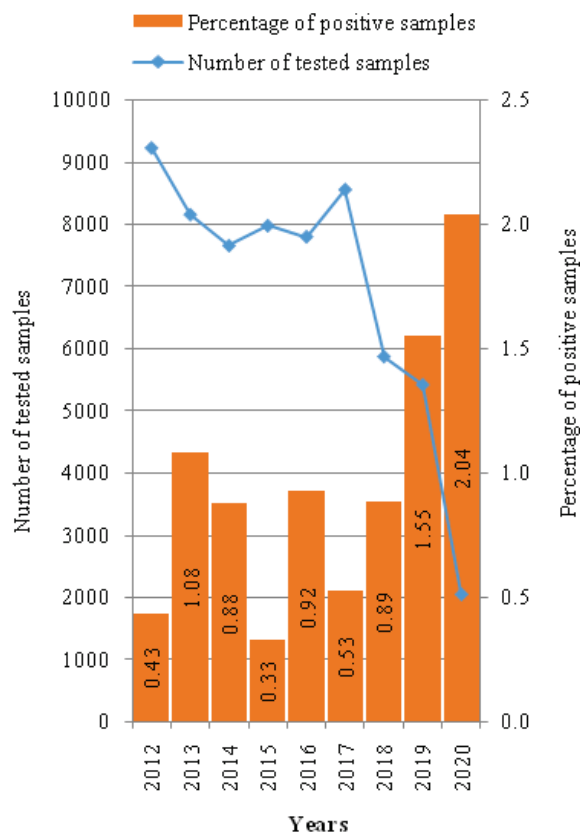
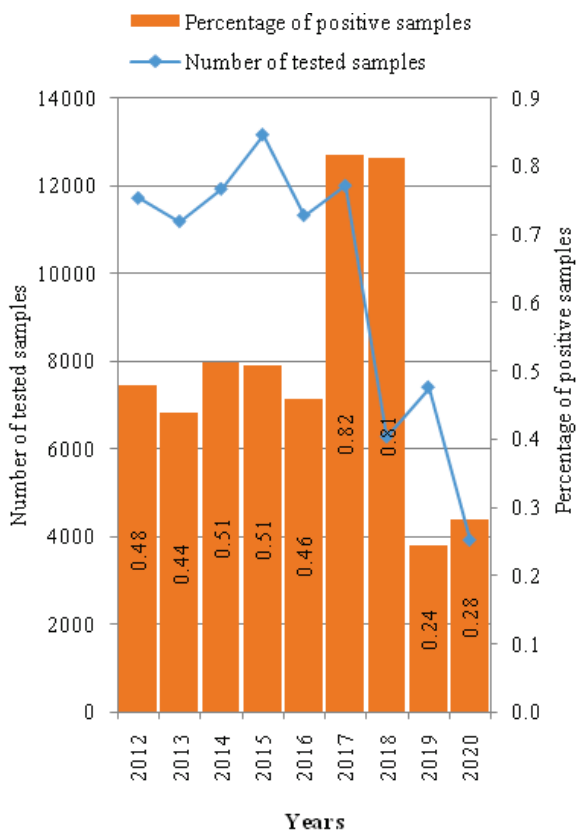


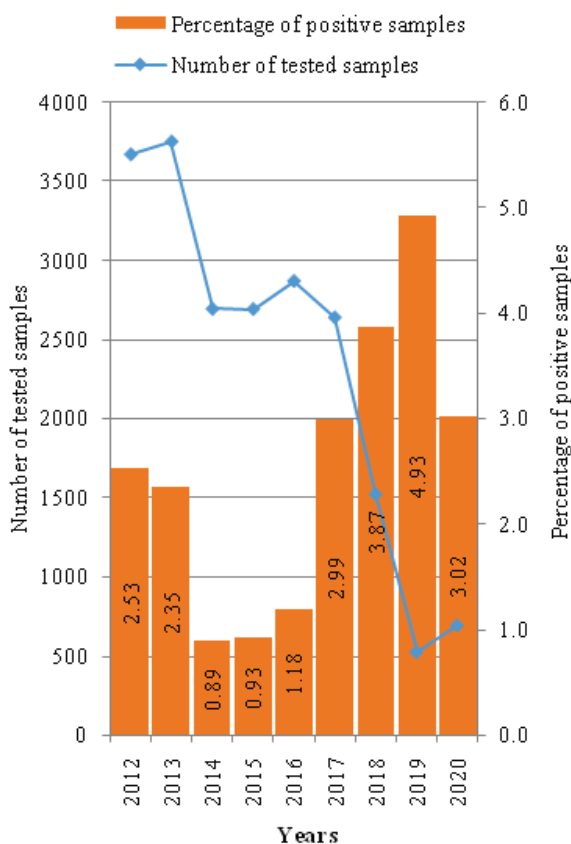
Fig. 5. Dynamics of the number of detected cases of staphylococcosis among poultry in Ukraine (2012–2020)

Research on the spread of pasteurellosis among poultry in Ukraine. During the analyzed period, veterinary laboratories received 463 positive samples for pasteurellosis, which is 7.0% of the total number of positive samples from poultry. This disease is widespread in Ukraine among poultry, and ranks fourth (in the number of positive samples) in the etiological structure of bacterial diseases of poultry in Ukraine (Fig. 6). Infection of poultry with pasteurellosis for the analyzed period was the highest in 2017 and 2018 – 0.82% and 0.81%, respectively, and the lowest in 2019 and 2020 – 0.2% and 0.3%, respectively. In general, from 2012 to 2020, as evidenced by the trend line, there is a slight tendency to reduction in the incidence of infection of poultry with pasteurellosis.

Research on the spread of pseudomonosis among poultry in Ukraine. During the research period, 449 positive samples for pseudomonosis were received, which is 6.8% of the total number of positively responding poultry (Fig. 7). Infection with pseudomonosis for the analyzed period was the highest in 2019 – 4.9%. The lowest number of infections were in 2014, 2015 and 2016 and amounted to 0.90%, 0.93% and 1.20%, respectively. In general, from 2012 to 2020, there was a steady trend to increase in the incidence of infection of poultry with pseudomonosis.



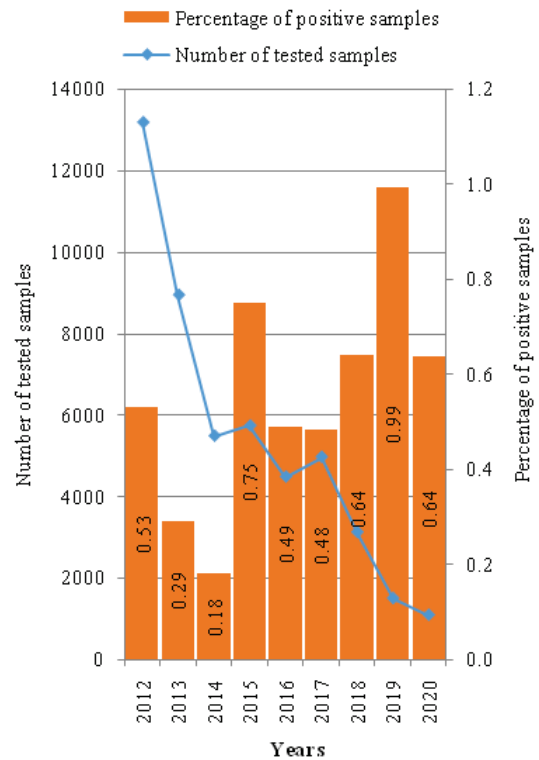
**Fig. 6.** Dynamics of the number of detected cases of pasteurellosis among poultry in Ukraine (2012–2020)



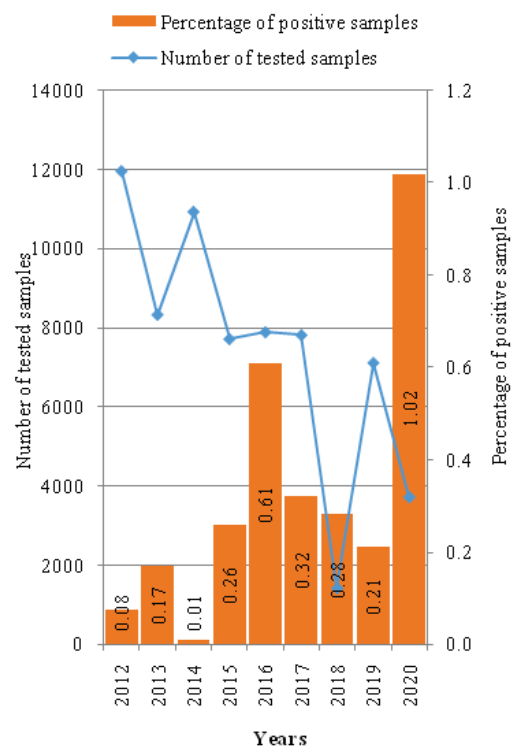
**Fig. 7.** Dynamics of the number of detected cases of pseudomonosis among poultry in Ukraine (2012–2020)

Research on the spread of pullorosis among poultry in Ukraine. During the experimental period, 237 positive samples for pullorosis were received, which is 3.6% of the total number of all positive samples.

This disease ranks sixth (in the number of positive samples) in the etiological structure of bacterial diseases of poultry in Ukraine (Fig. 8). The incidence of pullorosis in poultry for in the analyzed period was the highest in 2019 – 1.0%. The lowest infection rate was in 2014 – 0.2%. In general, during the analyzed period, we observed heterogeneity in the rates of infection of poultry with pullorosis. From 2012 to 2020, as evidenced by the trend line, there was a tendency to increase in the share of poultry infection with pullorosis. But in absolute terms, there was a tendency to reduction in infections.



**Fig. 8.** Dynamics of the number of detected cases of pullorosis among poultry in Ukraine (2012–2020)



**Fig. 9.** Dynamics of the number of detected cases of streptococcosis among poultry in Ukraine (2012–2020)



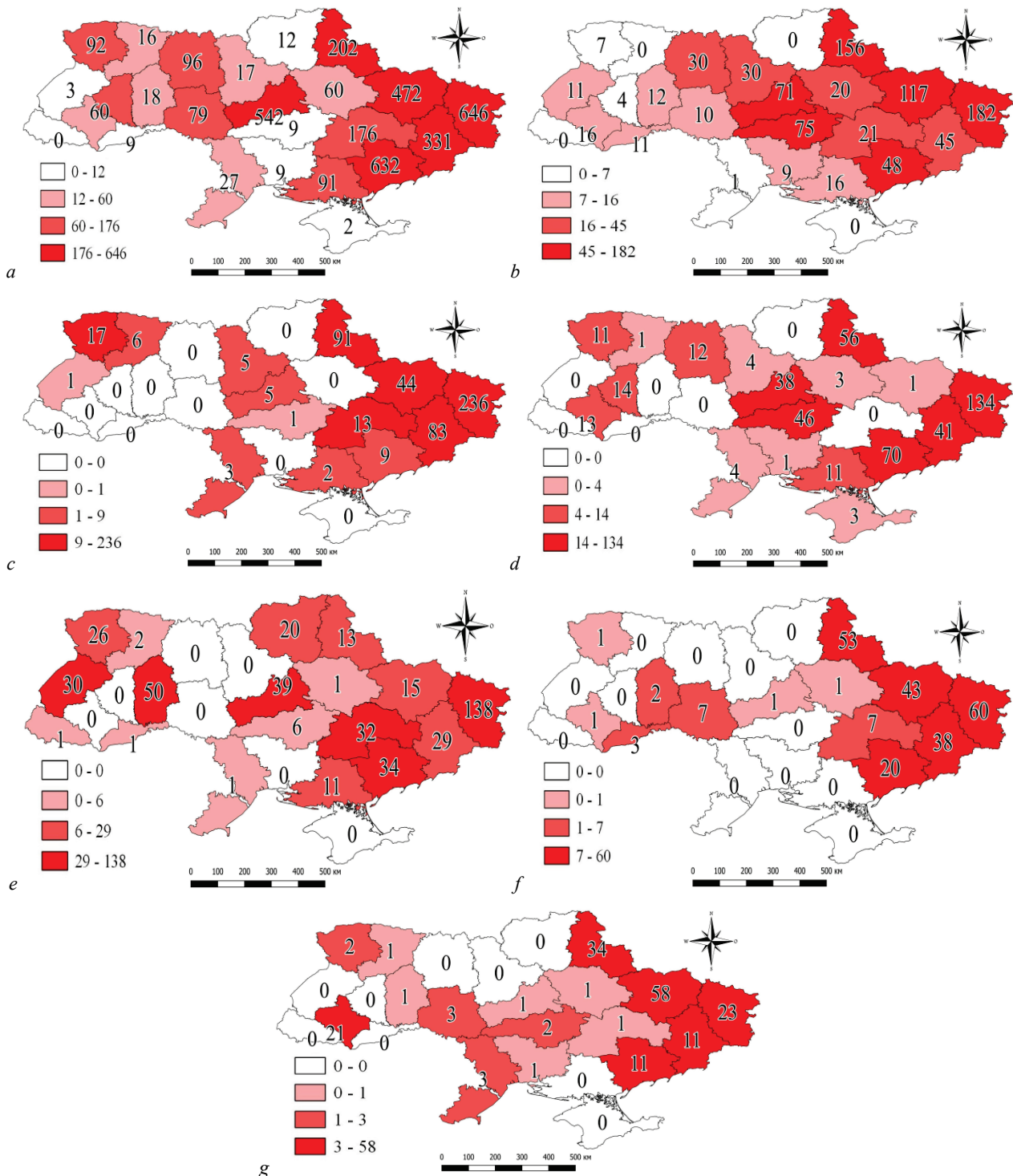
*Research on the spread of streptococcosis among poultry in Ukraine.*

During the period subjected to analysis, 174 positive samples for streptococcosis were received, which is 2.6% of the total number of positive samples from poultry. By the number of positive samples detected, this disease ranks seventh in the etiological structure of bacterial diseases of poultry in Ukraine (Fig. 9). Infection of poultry with streptococcosis in the analyzed period was the highest in 2020 – 1.0%, and the lowest in 2014 – 0.01%. In general, from 2012 to 2020, as evidenced by the trend line, there was a steady increase in the share of infection of poultry with this disease.

Territorial spread of the main bacterial diseases of poultry on the territory of Ukraine. We have also performed an ecological and geographical analysis of the spread of poultry diseases in Ukraine for each of the seven most common bacterial diseases of poultry: colibacteriosis, salmonellosis, staphylococcosis, pasteurellosis, pseudomonosis, pullorosis and streptococcosis.

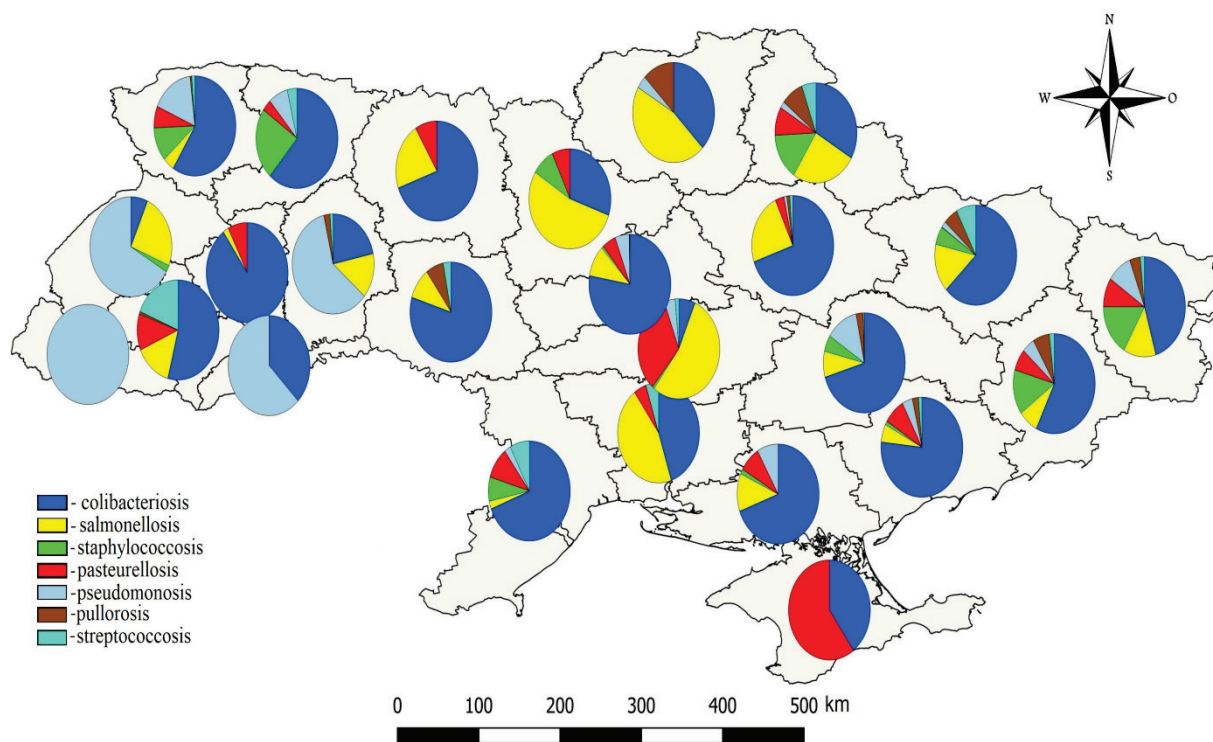
Based on the data on the results of bacterial examination of poultry samples, using the software “QGIS 3.16.0”, we created “Maps of the spread of bacterial diseases of poultry” (Fig. 10), on which the density of the number of positive samples for the most common bacterial diseases of poultry in the context of the regions of Ukraine is visualized with the help of different color intensities of each region.

For the purpose of territorially analyzing the etiological structure of bacterial diseases of poultry, a map of the etiological structure of poultry diseases in all regions of Ukraine was drawn up (from 2012 to 2020), which shows the percentage of the seven most common poultry diseases with the help of pie charts, according to the results of bacteriological investigation conducted by state laboratories of veterinary medicine Figure 11.



**Fig. 10.** Maps of the spread of bacterial diseases of poultry in Ukraine (2012–2020):

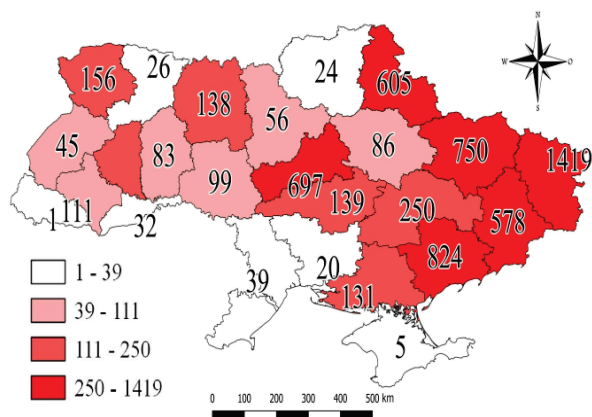
*a* – colibacteriosis, *b* – salmonellosis, *c* – staphylococcosis, *d* – pasteurellosis, *e* – pseudomonosis, *f* – pullorosis, *g* – streptococcosis



**Fig. 11.** Map of the nosological profile of bacterial diseases of poultry in Ukraine (2012–2020)

As can be seen from the map of the nosological profile of bacterial diseases of poultry, the etiological factors of bacterial diseases in different regions of Ukraine are not homogeneous. So, for example, in the Luhansk region the nosological profile is varied and is represented by all seven diseases: colibacteriosis – 45.5%, salmonellosis – 12.8%, staphylococcosis – 16.6%, pasteurellosis – 9.4%, pseudomonosis – 9.7%, pullorosis – 4.2% and streptococcosis – 1.6%. The following regions are also heterogeneous in terms of nosological profile: Volynj, Sumy, Cherkasy, Kharkiv and others. However, there are areas where the nosological profile is monotonous, for example in Mykolajiv it is represented by only a few diseases: colibacillosis – 45.0%, salmonellosis – 45.0%, pasteurellosis – 5.0% and streptococcosis – 5.0%. The following districts are also homogeneous in terms of etiological structure: Vinnytsija, Zakarpattja, Ivano-Frankivsk, Chemihiv, Chemivtsi and other districts.

Territorial spread of bacterial diseases of poultry in Ukraine. Based on the results of the investigations of poultry for bacterial diseases, for nine years (2012–2020), an epidemiological ranking of the territory of Ukraine was conducted and a map of the density of bacterial diseases of poultry in Ukraine was prepared (Fig. 12). Depending on the number of detected positive samples from poultry, all regions of the country were divided into four zones of risk of infection: high, medium, low and very low risk of infection.



**Fig. 12.** Density map of positive cases of bacterial diseases of poultry in Ukraine (2012–2020)

The zone of high risk of the disease includes six regions: Luhansk, Zaporizhia, Kharkiv, Cherkasy, Sumy and Donetsk. The total share of positive samples from poultry in this area is 75.0%. For this zone, the districts with borderline indicators are: Luhansk – 21.8% and Donetsk – 8.9% of cases. Areas with a medium risk of bacterial disease include: Dnipropetrovsk, Ternopil, Volyno, Kirovohrad, Zhytomyr and Kherson. The total number of positive samples from poultry detected in this area is 15.3%. From this zone, the greatest share of positive reactions were observed in Dnipropetrovsk – 3.9%, and the least in Kherson – 2.0%. The zone of low risk of the disease includes: Ivano-Frankivsk, Vinnytsia, Poltava, Khmelnytskyo, Kyiv and Lviv. The total share of positive samples from poultry in this area is 7.4%. For this zone, the districts with limit indicators are: Ivano-Frankivsk – 1.70% and Lviv – 0.69% of positive samples.

In such districts as Odesa, Chemivtsi, Rivne, Chemihiv, Mykolaiv, Transcarpathian and the Autonomous Republic of Crimea for the nine years (2012–2020), the lowest number of positive samples of poultry for bacterial diseases was observed, and therefore they are classified as having very low risk of infection, the total share of positive samples in this area is 2.3%. In the data range of this zone, the highest indicators are in Odesa region – 0.6%, and the lowest (in this zone and in Ukraine in general) in Transcarpathian 0.02% of the total number of all positive poultry samples for 2012–2020.

## Discussion

Control of bacterial factor infections in poultry is one of the leading tasks of veterinary services around the world. Thus, in 2003, the European Commission adopted Law 2160/2003/EC (EC, 2003) on the prevention of *Salmonella* and other specific food zoonotic agents. This directive and several protocols cover the adoption of targets aimed at reducing the incidence of specific zoonoses at the level of primary production in broilers, laying hens and turkeys. After approval of the relevant control act, even food industry workers must take samples and analyze them for the presence of zoonotic agents (Hafez & Attia, 2020). Now European researchers are currently studying the development of “prebiotic-like” feed additives to reduce the amount of *Campylobacter* in broiler chickens before slaughter (meat Campybro, to control this pathogen), because the problem of detecting this pathogen in broiler meat is now faced by many European countries. It is considered that a concentration of 4 CFU/g of poultry meat

is already an epidemic danger to humans. The problem with this pathogen is that there are no effective remediation mechanisms of *Campylobacter* in live poultry (Kaakoush et al., 2015). One of the methods that improve the microbiological safety of fresh chicken eggs for incubation and human consumption is reliable disinfection and decontamination of their shells (Turtoi & Borda, 2014).

For a long time, the prevention and struggle against bacterial diseases of poultry was carried out with the use of antibiotics. The latter has eventually led to the circulation of antibiotic-resistant strains among poultry (Williams, 2005; Barrow & Freitas Neto, 2011).

At present, epidemiological monitoring with obligatory bacteriological tests is used in Ukraine to control bacterial infections of poultry, immunomodulatory, prebiotic, probiotic, antibacterial preparations are used, and sanitary measures are constantly taken (disinfection, dissection, de-ratization). In poultry farming, the requirements for industrial hygiene and biosecurity are constantly being raised, and specific prophylaxis (vaccines) is being used for prophylactic purposes. Also in our country since 2012 a system of HACCP was introduced – a system of analysis and control of critical points and risks that may arise during any production process related to food. For example, the use of the HACCP system in primary poultry processing is a science-based and obligatory measure in the EU and the USA. The introduction of this system allows one to ensure the epizootic well-being of farms, and thus to obtain products safe from pathogens of factorial bacterial infections. Control of bacterial diseases also involves the prevention of possible diseases in humans, because meat and eggs from infected poultry are factors in the transmission of these pathogens (Pires et al., 2014; Skarp et al., 2016; Walker & Baum, 2022).

In general, control over the epizootic situation with regard to bacterial diseases in poultry enterprises of Ukraine is carried out using a full range of veterinary and sanitary and specific and non-specific prevention measures. Scientists note that the use of antibacterial substances in poultry only leads to the formation of polyresistant strains of bacteria, which eventually enter the human body with meat or eggs. Thus, *Enterococcus faecalis* isolated from poultry was resistant to lincomycin, tetracycline and gentamicin (Maasjost et al., 2015), coagulase-negative staphylococci isolated from healthy turkeys were insensitive to tetracycline, ampicillin, penicillin, sulfamethoxazole/trimethoprim (Moawad et al., 2019), *Staphylococcus aureus* (ESBL) strains resistant to many groups of antibiotics were found in poultry (Richter et al., 2012), *Campylobacter jejuni* were insensitive to amoxicillin, neomycin, metronidazole, sulfamethoxazole/trimethoprim, nalidixic acid, ciprofloxacin, tetracycline (El-Adawy et al., 2012, 2015; Nguyen et al., 2016), reported the occurrence of *Escherichia coli*, which produces  $\beta$ -lactamase with an extended spectrum of action resistant to colistin (Moawad et al., 2018), as well as multiresistance of this pathogen isolated from broiler chickens (Azad et al., 2019; Xu et al., 2019). *Salmonella* isolated in poultry farms has been shown to be insensitive to many antibiotics. *S. infantis* strains had the MDR phenotype in 94.4% of isolates. Strains of *S. typhimurium* had a reduced phenotype of antimicrobial resistance, and 50% showed resistance to one antimicrobial compound. One of the atypical strains of *S. enterica* had an MDR profile for 11 of the 20 antibiotics examined (eight groups), two atypical strains of *S. enterica* showed resistance to two and three antibiotics, respectively (Sánchez-Salazar et al., 2020).

The complete abandonment of the use of antibacterial preparations requires the use of other approaches in the prevention and treatment of bacterial diseases in poultry. For this purpose it is necessary: to increase the number of controlled diseases through monitoring investigations; use commercial vaccines against bacterial diseases and develop vaccines from local strains of microorganisms and implement them in the practice of poultry farms; to use bacteriophages; to introduce into the practice of poultry enterprises preparations for the normalization of the microbiocenosis of the gastrointestinal tract (the use of probiotic and prebiotic preparations, oligosaccharides); to develop programs for the prevention and control of factor diseases in poultry.

Our research has shown that the nosological profile of bacterial diseases, the causative agents of which circulate in poultry farms in Ukraine is quite wide and is represented by 17 diseases: *Escherichia coli* (56.9%), salmonellosis (13.5%), staphylococcosis (7.8%), pasteurellosis (7.0%), pseudomonosis (6.8%), pullorosis (3.6%), streptococcosis (2.6%), pneu-

mococcosis (0.5%), tuberculosis (0.4%), infectious enterotoxemia (0.3%), pathogenic proteus (0.2%), erysipelas septicemia (0.1%), klebsiellosis (0.1%), listeriosis (0.1%), neisseriosis (0.08%), coligranulomatosis (0.05%), hemophilosis (0.02%). It should be noted as a positive that for the period 2012–2020 in the materials of poultry pathogens of yersiniosis, campylobacteriosis and mycoplasmosis were not isolated – no positive test was detected for the entire analyzed period.

As a negative it should be noted the fact that during the analyzed period the number of bacteriological studies decreased significantly. The downward trend was steady, and it happened every year. For example, the number of investigations in 2012 was 137,807, and in 2020 – only 58,320. It should be noted that fluctuations in the number of poultry in Ukraine did not exceed 15.0%. The analysis of graphic trends also shows that the number of cases of staphylococcosis, pseudomonosis, pullorosis and streptococcosis increased during the analyzed period. The number of cases of colibacillosis and salmonellosis has slightly decreased. The graphic trend of pasteurellosis cases remains at approximately the same level for the analyzed period. The largest number of infected poultry is registered in regions with significant livestock: Sumy, Kharkiv, Luhansk, Donetsk, Transcarpathian, Dnipropetrovsk, Mykolajiv, Kherson and Poltava.

According to similar investigations described in the scientific literature, in Russia during bacteriological investigations on diseases of poultry of bacterial etiology, streptococcosis accounted for 13.0% of cases, salmonellosis – 12.5%, staphylococcus – 6.2%, pseudomonosis – 6.0%, pasteurellosis – 2.0%, other pathogens of factor diseases were – 0.5% (Shurahova et al., 2010). During the research in 2007–2011 it was confirmed that bacterial etiology accounted for more than 60.0% of infected poultry, of which the mass share of *Escherichia coli* was 63.0%, salmonellosis – 11.7%. In 2012, the incidence of *E. coli* was 53.9%, the death rate was 92.0%. It was indicated that in the research on bacterial diseases at poultry farms, *E. coli* accounted for 49.8%, salmonellosis – 15.7%, pasteurellosis – 15.0%, spirochetosis – 13.9%, staphylococcosis – 5.6%. During bacteriological examination of clinically healthy poultry, pathological material, air of incubator cabinets, dead embryos, *E. coli* were isolated in 39.6% of cases, *Staphylococcus aureus* – 13.9%, *Proteus vulgaris* – 14.2%, *Pseudomonas aeruginosa* – 6.9% (Bobyleva, 2013).

Given the information on the formation of polyresistance to antibiotics in pathogens of factor infections, it is necessary to use alternative elements for the prevention of bacterial diseases, which are based on the timely use of preventive and compulsory disinfection with the use of reliable measures and means of remediation of poultry premises, including in the presence of poultry.

Thus, the industry requires the development and implementation in the practice of industrial poultry farming of modern disinfectants that could significantly improve the epizootic situation of bacterial diseases of poultry. The prospect of further research will be the creation and justification of the introduction of such disinfectants in order to prevent bacterial factor infections in poultry.

## Conclusions

The epidemiological analysis of the nosological profile of bacterial diseases of poultry in Ukraine for the period 2012–2020 showed that it was formed by 17 diseases. Of the diseases registered in our country, a significant number (14 of 17) are pathogens of so-called factor infections, namely: *Escherichia coli*, salmonellosis, staphylococcosis, pasteurellosis, pseudomonosis, pullorosis, streptococcosis, pneumococcosis, infectious enterotoxemia, pathogenic proteus, erysipelas septicemia, neisseriosis, coligranulomatosis, hemophilia. It is found that bacterial diseases of poultry are significantly common in Ukraine, the average rate of infection of poultry with bacterial diseases for the period from 2012 to 2020 is 0.8%. The leading role in the etiological structure of pathogens of bacterial diseases of poultry is played by colibacillosis – 56.9% of the total number of all positive samples. Also, the dominant bacterial diseases of poultry in Ukraine during the analyzed period were: salmonellosis (13.5%), staphylococcosis (7.8%), pasteurellosis (7.0%), pseudomonosis (6.8%), pullorosis (3.6%) and streptococcosis (2.6%). Significantly fewer positive samples were registered in the bacteriological examination of other diseases – 1.8%. The heterogeneity of the etiological structure of bacterial diseases of



poultry in different regions of Ukraine has been established. It was found that the nosological profile of bacterial diseases of poultry in Ukraine has pronounced differences both in the set of diseases and their importance in the total pathology of bacterial diseases. Measures to prevent factor diseases should include alternatives to antibiotics – the use of bacteriophages, vaccines, reliable sanitation of premises with the use of modern disinfectants, etc.

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