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Research article

Salmonellosis in Ukraine: An analysis of food products contamination, Salmonella transmission, and serovar diversity during 2012–2023

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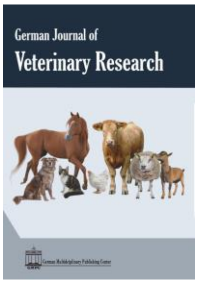

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Abstract

A laboratory-based surveillance was conducted to study the transmission of Salmonella infection in Ukraine during the period 2012-2023. The study focused on the different categories of food products, feed, and animals as the main transmission factors and tried to analyze the relationship between them. The serological profile of Salmonella was predominantly observed in samples from objects of veterinary control, including biological/pathological material from animals and biomaterials from poultry within the National Poultry Salmonellosis Control Program. The study found that the most frequently isolated serovars were *S. Enteritidis* (20.03%), followed by *S.* Typhimurium (14.76%), *S.* Pullorum (without biovar identification;10.71%), *S.* Pullorum biovar Pullorum (10.50%), *S.* Pullorum var. Gallinarum (6.62%), *S.* Choleraesuis (5.79%), *S.* Livingstone (2.53%), and *S.* Infantis (1.70%). In 2021, an isolate of monophasic *S.* Typhimurium was identified for the first time in pathological material from pigs. The study also found that the most frequent *Salmonella*-positive categories of food products in Ukraine were meat and meat products (78.16%), eggs and egg products (11.75%); dairy products (3.319%), fish products (2.71%), ready-to-eat food products (1.96%). The largest specific share of *Salmonella* isolates from food products and feed was *S.* Enteritidis, followed by serotypes such as *S.* Infantis*,* *S.* Typhimurium*,* *S.* Livingstone, *S.* Virchow*,* and rare serotypes such as *S.* Nigeria and *S.* Thompson. The dominance of certain serovars such as *S.* Enteritidis*,* *S.* Typhimurium*,* *S.* Infantis*,* *S.* Livingstone, and *S.* Virchow in biomaterials from sick animals indicates their primary role in the infection of food products of animal origin. Hence, a stress to enhance diagnostic and monitoring frameworks at animal herd levels. The findings of this study can be used as a basis for evidence-based epidemiology, as well as for the implementation of joint steps to improve the effectiveness of control measures against salmonellosis in each region.

Keywords: *Salmonella,* Food safety, Ukraine, Disease control, Zoonoses

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Introduction

Human and animal health, food safety, and nutrition are closely linked within the "One-Health" framework. Salmonellosis is one of the four major causes of diarrheal diseases in the world and the most common from consuming contaminated food (Brenner et al., 2024; Lee and Yoon, 2021). Salmonellae are bacterial pathogens affecting a wide range of hosts and possess many pathogenicity factors (Tanner and Kingsley, 2018; Velge et al., 2005). Updates of the Kaufman-White scheme include new Salmonellae serovars each year (Grimont and Weill, 2007). In the EU, Salmonella remains the second most common cause of food poisoning outbreaks and a significant cause of hospitalizations (9,631 accounting for 36.9%) and deaths (0.2% of outbreak deaths) (European Food Safety Authority (EFSA) and European Centre for Disease Prevention and Control (ECDC), 2023). In the US, more than 95% of salmonellosis outbreaks are foodborne (Ehuwa et al., 2021; Thomas et al., 2015), with similar trends in countries of America (Godínez-Oviedo et al., 2020; Lee and Yoon, 2021), Asia (Gong et al., 2022), Africa (Gelaw et al., 2018; Ramtahal et al., 2022) and Australia (Munck et al., 2020) and Europe (Alba et al., 2020; Nagy et al., 2020; Wielinga and Schlundt, 2013). Since 2003, EU member states have implemented National Salmonella Control Programs and, as part of annual zoonoses monitoring, submit relevant reports to the ECDC, the World Health Organization (WHO), the EFSA, the Rapid Alert System for Food and Feed (RASF) (Latif et al., 2023). A declining trend in confirmed cases of human salmonellosis since 2001 stalled during 2014-2016. Indeed, confirmed salmonellosis outbreaks and "strong evidence outbreaks" have had the largest specific weight during 2010-2017 (22.1% of all outbreaks), hospitalizations (49.0% of all hospitalizations), and mortality (33.3% of all deaths). Additionally, salmonellosis was the most frequent cause of confirmed outbreaks based on the criterion "causing agent of a toxic infection outbreak" of all food intoxications during 2010-2017 (Boelaert, 2019).

In Ukraine, human salmonellosis cases are recorded in all regions with varying intensity (Bubalo, 2013; Kislyak et al., 2017). In almost 90% of all salmonellosis cases, the pathogen's transmission factor was products of animal origin, including eggs and egg products, indicating that the epizootic situation of poultry salmonellosis in Ukraine during 2012–2021 has distinct spatial and temporal characteristics (Chechet et al., 2022; Yakubchak et al., 2014). The highest rates of positive samples for poultry salmonellosis were found in the Sumy and Luhansk regions (Klishchova, 2018; Kozytska et al., 2023). Baharev, 2019 identified the functioning of ecologically personalized anthropology Salmonella reservoirs in the urbanized territories of the North-Western Black Sea coast, which combined anthropogenic strains of 25-35 serovars with *S. enteritidis*, *S.* Typhimurium, *S.* Infantis, being dominant. These reservoirs are independent and independent of zoogenic sources, and the zoonotic nature of their influence is exclusively related to poultry products. A team of scientists studying the epidemiology of salmonellosis caused by non-typhoidal Salmonellae established that this infection is an urgent problem for the Zaporizhzhia region because the rates of morbidity, particularly in children, significantly exceed the corresponding rates in the country; the dominant serovars are *S.* Enteritidis (40%), *S.* Blegdam (28%) and *S.* Typhimurium (18%). Similarly, in the east of Ukraine, *S.* Enteritidis remains the main cause of food poisoning over the past decade (Garkavenko et al., 2021; Klishchova, 2018). Many authors insist that monitoring the spread of Salmonella infection is one of the important measures for its prevention (Brenner et al., 2024; Cohen et al., 2022; Gonçalves-Tenório et al., 2018).

Therefore, the prevalence of Salmonella as the causative agent of foodborne zoonosis in many countries of the globe points out the importance of its bacteriological, serological, and molecular genetic monitoring. Periodic surveillance reports, such as those provided by EFSA, CDC, and other disease control organizations worldwide, could be useful practices for Ukraine.

Materials and methods

Sampling and evaluation criteria for *Salmonella* spp.

In the current report, we used statistical data from the Ministry of Agrarian Policy of Ukraine, which included annual reports on infectious diseases in Ukraine from 2012 to 2023. Our first criterion for selecting the data was to assess the laboratory's ability to conduct bacteriological research on salmonellosis. In this study, we focused on the reports of state-authorized laboratories accredited by the National Accreditation Agency of Ukraine in accordance with the international standard EN ISO/IEC 17025 "General requirements for the competence of testing and calibration laboratories". These laboratories were a part of the State Veterinary Medicine Service from 1991 to 2014, and since 2014, they have been a part of the State Production and Consumer Service. The number of these laboratories ranged from 173 in 2012 to 103 in 2014 and 77 in 2021. However, due to the invasion of Ukraine by the Russian Federation, the number of authorized laboratories decreased to 51 in 2023.

Our second criterion for selecting the reporting data was the methodological approach to the protocols of Salmonella microbiological detection in specimens. The laboratories used two ISO methods for the detection and identification of Salmonella recommended by national poultry salmonellosis control programs: ISO 6579-1 "Microbiology of the food chain - Horizontal method of detection, counting and serotyping of Salmonella. Part 1: Detection of *Salmonella* spp." and the State Ukrainian Standard DSTU EN 12824:2004, based on the EN 12824:1998 "Microbiology of food and animal feed - Horizontal method for the detection of *Salmonella*" (which was withdrawn in EU countries since 2002).

***Salmonella* spp. identification**

The laboratory protocols were performed in accordance with the following steps: first, the samples were pre-enriched in buffered peptone water for 18-24 hours at a temperature of 37°C. Then, they underwent selective enrichment in two liquid media, Rappaport-Vassiliadis and Muller-Kauffmann tetrathionate with novobiocin or Selenite Cysteine Broth at 37°C for 24 hours. In the case of processing swabs from poultry houses and bird feces, the samples were enriched in semisolid Rappaport-Vassiliadis with novobiocin at 42°C for 24 to 48 hours. Subsequently, subcultures from the enrichment media were carried on two selective solid media, Xylose Lysine Deoxycholate agar and Salmonella Differential agar (RajHans Medium) at 37 °C for 18-48 hours. The biochemical identification of the isolated bacterial colonies was performed using commercial reagents and special media. The identification involved tests such as determining oxidase, catalase, acetylmethylcarbinol (Voges-Proskauer test), the methyl red test, assimilation of citrate salts (on Simmons agar), detection of gelatinase, lysedecarboxylase, arginidecarboxylase, phenylalanine deaminase, urea, indole, and hydrogen sulfide (on a Triple Sugar agar or Kligler agar), and fermentation of sugars such as glucose, mannitol, maltose, galactose, xylose, dulcinea, sucrose, lactose, salicin, and adonite. To identify *Salmonella* serovars, serological identification was carried out using sera specific for O-somatic antigens and H-flagellar antigens, including phase I and II ciliary (Sifin, Germany).

National control program (NCP) of poultry salmonellosis

In Ukraine, since 2004, there have been three national programs for the control of poultry salmonellosis: "Program of State Veterinary and Sanitary Control of Salmonellosis" for broilers, meat turkeys, laying hens, and breeding birds. Each NCP had been developed 5-year duration: 2004-2008, 2009-2013, 2014-2018. Since 2019, all three NCPs have been replaced by single ones for all species of agricultural and zoo birds. Instruction on the Prevention and Elimination of Poultry Salmonellosis (the Order of the Ministry of Agriculture and Forestry dated June 19, 2016, No. 310).

This Instruction establishes the procedure for preventive measures by veterinary medicine workers to prevent salmonellosis in poultry (the framework of samples collection), the procedure for veterinary sanitary measures in cases of outbreaks of salmonellosis in poultry and is mandatory for all poultry farms and zoos, regardless of the form of ownership. Among the European Member States and Non-Member States Countries, all NCP for *Salmonella* aim to control the target *Salmonella enterica* subsp. *Enterica* serovars five for breeding flocks of *Gallus gallus* (*Salmonella enterica* subsp. *Enterica* serovars Enteritidis, Typhimurium including monophasic variant, Hadar, Infantis, Virchow), and two serovars for laying hens and broilers (Enteritidis, Typhimurium including monophasic variant) in accordance with Regulation (EC) No 2160/2003 (Leati et al., 2021)

Results and discussion

The study of the epidemic (epizootic) process helps us understand how infectious diseases occur and spread and how to control them. The classical approach to the epidemic process involves three links - the source of the infection-causing agent, the method of transmission, and the presence of susceptible animals. Others suggest that the epizootic process occurs and progresses according to four factors: a) the source of the infection-causing agent; b) the mechanism of transmission from sick to healthy animals; c) susceptible animals; and d) specific environmental conditions (Koivu-Jolma and Annila, 2018). The epizootic process is a complex phenomenon of infectious disease emergence and spread related to the chain transmission of pathogens from infected to susceptible animals

(Yarchuk et al., 2002). The severity of the disease depends on the duration of parasite-host coevolution and environmental factors. When studying salmonellosis, we assumed that the epizootic process is an evolutionarily formed biological phenomenon involving two specific factors - the infectious process and the pathogen's spread mechanism. An important aspect of our research was the analysis of the results from microbiological tests of food products, feed, and biological material from animals conducted at the laboratories of the State Production and Consumer Service of the Ministry of Agrarian Policy of Ukraine. Specialists of laboratories for the implementation of the State Veterinary and Sanitary Control Program for salmonellosis in broilers, meat turkeys, laying hens, and breeding poultry (chickens and turkeys) in poultry farms of Ukraine carry out the diagnosis of salmonellosis in animals and monitoring of safety indicators (including the criterion "presence of *Salmonella*") in food products and feed. Table 1 shows data on the total number of carried out bacteriological studies according to the microbiological criterion "Salmonella in 25 grams" or "Presence of Salmonella" and positive results in food samples, fodder, and biological materials from animals obtained by the laboratories of the State Production and Consumer Service for the period 2012–2023.

Table 1: Comparison of proportions (%) of Salmonella-positive samples from the categorized samples, according to data received by laboratories of the State Consumer Protection Service supervision in Ukraine, 2012-2023.

Year	Food		Feed		Pathological/biological materials from animals		National Control Program of Poultry Salmonellosis	
	Tested samples No.	Positive samples No (%)	Tested samples No.	Positive samples No (%)	Tested samples No.	Positive samples No (%)	Tested samples No.	Positive samples No (%)
2012	183,644	58 (0.03)	26,786	25 (0.09)	187,997	309 (0.16)	208,973	62 (0.03)
2013	172,990	124 (0.07)	20,344	9 (0.04)	141,921	258 (0.18)	224,296	142 (0.06)
2014	147,164	57 (0.04)	18,090	6 (0.03)	107,144	285 (0.27)	151,075	48 (0.03)
2015	130,957	36 (0.03)	16,241	11 (0.07)	104,406	232 (0.22)	145,002	58 (0.04)
2016	120,686	18 (0.01)	14,703	11 (0.07)	98,712	139 (0.14)	137,567	66 (0.05)
2017	114,759	32 (0.03)	13,899	9 (0.06)	74,000	146 (0.20)	161,673	19 (0.01)
2018	130,521	110 (0.08)	15,683	16 (0.10)	124,862	103 (0.08)	209,632	119 (0.06)
2019	131,310	60 (0.05)	9,862	9 (0.09)	56,250	32 (0.06)	224,837	28 (0.01)
2020	150,120	65 (0.04)	10,003	8 (0.08)	51,923	86 (0.17)	228,179	44 (0.02)
2021	133,315	74 (0.06)	17,642	10 (0.06)	21,176	47 (0.22)	216,512	24 (0.01)
2022	71,233	11 (0.02)	15,435	0 (0.00)	21,510	1 (0.00)	165,307	27(0.02)
2023	75,578	19 (0.03)	10,992	32 (0.29)	15,163	11 (0.07)	168,475	10 (0.01)
Total	1,562,277	664 (0.04)	189,680	146 (0.08)	1,005,064	1649 (0.16)	2,241,528	647(0.03)

Based on the data, the following trends can be noted: in terms of the number of examined samples, the highest numbers came from the samples of poultry products and biological materials from poultry, which were selected and examined within the framework of the National Poultry Salmonellosis Control Program. A total of 2,241,528 samples were examined; the average annual number of samples was more than 186,000 samples per year. In second place in terms of the number of samples tested for the presence of Salmonella are food products and raw materials (in total - 1,562,277 samples, an average of 130,000 samples/year). Biological/pathological materials from all species of animals suspected of salmonellosis or carriers were examined twice as few (1,005,064 studies) as studies within the framework of the National Poultry Salmonellosis Program. The total and annual number of researched feed samples (189,680) remained consistently the lowest of all categories, and the average annual indicator was 15,807 samples /year. It is worth noting two periods in which we observed significant declines in the number of samples taken and microbiological studies carried out: the first from 2014 to 2018, in which the number of studies decreased by an average of 2.9 times compared to 2012-2013; and the second – from 2022 to today, in which the number of studies decreased by 1.7 times compared to 2019-2020 in all sample categories. This is due to the two waves of the Russian invasion of Ukraine in 2014 and 2022.

As for the obtained positive results (Table 1), during the studied period, the largest number of positive results regarding the detection and identification of Salmonella was observed in the pathological material from animals: a total of 1,647 cases were established during the period. 2.5 times less *Salmonella* strains were isolated from food products within the scope of poultry salmonellosis in the NPC: 664 and 647 positive cases, respectively. The least amount of Salmonella was isolated from feed - 146 cases. It is also possible to note a significant decrease (by 4.9 times) in the number of positive cases of diagnosed salmonellosis in animals starting from 2018 to 2023 (an average of 46.67 cases), compared to the period of 2012-2017 when the average annual number of positive cases was 227.17. This may be due to a decrease in the number of livestock and productive animals on farms. However, if we compare and contrast the number of positives obtained from animals (including poultry) and within the framework of the NPC, we can note a trend from large gaps to an average of 4.4 times more Salmonella isolated from animals at the beginning of the period (2012-2017) to practically balancing the number of positives. It is obvious that the Nation Control Program of Poultry Salmonellosis has become more effective and has found feedback and understanding from poultry businesses. Ukraine followed the positive experience of the EU countries, the majority of which, starting from the 2000s, developed and implemented their own NPC of animal salmonellosis, including birds.

The proof of effectiveness and importance of these programs consisted in the reduction and overall control of human Salmonella associated with food products. Thus, by 2004, more than 200,000 cases of human disease were registered annually in 15-member states. As a result of the use of PPE, this figure was reduced to less than 90,000 cases in 2014 in 28 Member States, according to the European Centre for Disease Prevention and Control in 2009 (ECDC, 2009) and the European Food Safety Authority (EFSA, 2015). As in cases of salmonellosis in the population and cases of salmonellosis in animals, the establishment of the prevalence of Salmonella serotypes as the main pathogen infectious process is an important criterion that can be of scientific and practical importance for predicting the intensity of the epidemic and epizootic situation both in the regions and in the country as a whole.

Table 2 summarizes data on the identified *Salmonella* serotypes in Ukraine for the period 2012–2023, which were isolated from biological and pathological materials from animals, food products, and feed.

As can be seen from the data given in Table 2, out of 3106 *Salmonella* isolates, unidentified isolates are the most numerous groups for both categories of studied objects: 40.86% for food products and feed and 19.64% for biomaterials from animals and poultry. The main reason for such a large number of unidentified isolates was that, due to objective circumstances, laboratory specialists were unable to purchase type-specific salmonellosis agglutinating O- and H-sera. Analyzing the group of identified *Salmonella* isolated from food products and feed, we note that *S.* Enteritidis occupies the largest specific share of isolates: 187 isolates were isolated, which is 23.09% of all positives. The remaining positives, not exceeding the 10% threshold, include *S.* Infantis (55 -6.79%), *S.* Typhimurium (39 - 4.81%), *S.* Livingstone (29 -3.58%), *S.* Virchow (19 – 2.35%), and rare serotypes (20 – 2.47%).

The most frequent detection and identification of *S.* Enteritidis in food products and feed is evidence of their secondary infection, i.e., *Salmonella* infection of products and feed occurs from salmonellosis (humans or animals). Thus, it is important from the point of view of prevention of secondary *Salmonella* contamination of food and feed to ensure screening monitoring of employees of all establishments related to the production or preparation of food and feed for salmonellosis. Analyzing the groups of identified *Salmonella* isolated from animals suffering from salmonellosis and *Salmonella* carriers, it should be noted that the largest share here is occupied by *Salmonella* of serotypes *S.* Enteritidis (460 - 20.03%), *S.* Typhimurium (339 - 14.76%). *S.* Pullorum both biovars: *S.* Gallinarum, *S.* Pullorum (246 – 10.71), *S.* Pullorum biovar Pullorum (241 – 10.50), *S.* Pullorum var. Gallinarum (152 - 6.62%), *S.* Choleraesuis (133 - 5.79%), *S.* Livingstone (58 - 2.53%), *S.* Dublin (16 - 0.70%). The rest were rare *Salmonella* (22 serotypes), the share of which did not exceed 1%.

Isolation and identification *of S.* Typhimurium, *S.* Enteritidis, and *S.* Dublin from pathological material usually indicate primary infection of beef meat products, *S.* Enteritidis, *S.* Pullorum biovar Pullorum, *S.* Pullorum var. Gallinarum, *S.* Livingstone on primary infection

Table 2: *Salmonella* serotypes, isolated from biological/pathological materials from animals and food/feed in Ukraine 2012-2021.

Serotype	Food		Feed		Serotype	Pathological material from animals		NCP of poultry Salmonellosis	
	No	%	No	%		No	%	No	%
S. spp. (untyped species)[a]	224	34	107	73	S. spp. (untyped species)[1]	304	18	147	23
Enteritidis	180	27	7	5	Typhimurium	315	19	24	4
Infantis	52	8	3	2	Typhimurium monophasic	1	0	0	0
Livingstone (Eismbuettel)	29	4	0	0	Pullorum (biovar Pullorum)	241	15	0	0
Typhimurium	36	5	3	2	Pullorum/Gallinarum	228	14	18	3
Virchow	16	2	3	2	Enteritidis	170	10	290	45
Rare serotypes (group F-67b	19	3	1	1	Pullorum (biovar Gallinarum)	126	8	26	4
Nigeria	12	2	0	0	Choleraesuis	133	8	0	0
Thompson	8	1	1	1	Livingstone (Eismbuettel)	35	2	23	4
Brandenburg	6	1	0	0	Dublin	15	1	1	0
Nohanga	5	1	1	1	Rare serotype (group F-67)[2]	11	1	12	2
London	5	1	0	0	Typhisuis	11	1	0	0
Vuadens	5	1	0	0	London	6	0	2	0
Essen	4	1	7	5	Djugu	1	0	2	0
Derby	4	1	0	0	Infantis	6	0	33	5
Arizonae (Choleraesuis)	4	1	0	0	Virchow	6	0	3	0
Dublin	3	0	0	0	Paratyphi	4	0	0	0
Heidelberg	3	0	1	1	Typhi	0	0	1	0
Stanley	2	0	0	0	Oranienburg	2	0	0	0
Altendorf	2	0	0	0	Moscow	2	0	0	0
Kisangani	2	0	1	1	Saint Paul	1	0	0	0
Reading	2	0	0	0	Suberu	1	0	5	1
*Pullorum (*biovar *Gallinarum)*	2	0	0	0	Heidelberg	1	0	0	0
Virginia	2	0	0	0	Eko	1	0	0	0
Adabraca	2	0	0	0	Muenchen	1	0	5	1
Haifa	2	0	2	1	California	1	0	0	0
Agona	2	0	0	0	Konstanz	1	0	0	0
Colindale	2	0	0	0	Othmarsen	1	0	0	0
Blegdam	2	0	0	0	Nohanga	1	0	0	0
Othmarschen	2	0	1	1	Pankow	2	0	0	0
Montevideo	2	0	0	0	Abortus-equi	1	0	0	0
Seftendberg	2	0	3	2	Eastbourne	1	0	2	0
Tenessee	1	0	0	0	Essen	1	0	1	0
Millesi	1	0	0	0	Agona	1	0	1	0
Amsterdam	1	0	0	0	Cambole	1	0	4	1
Suberu	1	0	0	0	Coeln	1	0	0	0
Typhi	1	0	0	0	Kisii	0	0	2	0
Paratyphi	1	0	0	0	Isangi	4	0	4	1
Moskow	1	0	0	0	*Hato*	6	0	0	0
Jamaica	1	0	0	0	*Give*	1	0	21	3
Potsdam	1	0	0	0	*Eschweiler*	1	0	0	0
Legon	1	0	0	0	*Schwarzengrund*	1	0	0	0
Westhampton	1	0	0	0	*Porland*	1	0	0	0
Bury	1	0	0	0	*Thompson*	0	0	3	0
Ruzizi	1	0	0	0	*Derby*	0	0	4	1
Glastrup	1	0	0	0	*Porland*	0	0	2	0
Menston	1	0	1	1	*Irumu*	1	0	2	0
Papuana	1	0	0	0	*Antum*	0	0	5	1
Isangi	1	0	0	0	*Indiana*	0	0	1	0
Lagos	1	0	1	1	*Hindmarsh*	0	0	1	0
Eko	1	0	1	1	*Postdam*	0	0	1	0
Rissen	1	0	0	0	*Hamburg*	0	0	1	0
Schwarzengrund	1	0	0	0					
Bispebjerg	0	0	1	1					
Goeteborg	0	0	1	1					
Total	**664**		**146**		**Total**	**1649**		**647**	

a) means that these isolates were only serologically typed by serum A-67 without further subtyping to serovars. b) means that these isolates were only serologically typed to F-67 serum without further subtyping to serovar of poultry products and *S.* Choleraesuis and *S.* Livingstone - on primary infection of pork meat products. Therefore, the primary diagnosis of salmonellosis at the level of practicing doctors and diagnostic laboratories of veterinary medicine is the key to the timely identification of animals with salmonellosis and their isolation, which makes it possible to stop the epizootic process already at the level of the source of the causative agent of infection (the first link of the epizootic process). On the other hand, in each case of the establishment of an outbreak of salmonellosis in groups or herds of animals, it is necessary to introduce serological screening for salmonellosis (Pundyak, 2015). It can also be important to carry out *Salmonella* serological screening of humans involved in professions linked with animals. By identifying the source of *Salmonella* (sick or carrier animals or people), we can prevent the contamination of food/feed.

Table data 2, on the one hand, testify the great diversity of *Salmonella* serotypes circulating in Ukraine, and, on the other hand, we see that the largest specific weight in the infection of food and feed, as well as acting as an etiological factor of animal salmonellosis, is about a dozen serotypes, including *S.* Enteritidis, *S.* Typhimurium, *S.* Pullorum both biovars, *S.* Livingstone, *S.* Choleraesuis, *S.* Dublin. The first two are the main ones in the infectious pathology of food-toxic infections of a salmonellosis nature.

The establishment of this fact shows that in Ukraine, the primary Salmonella infection of products of animal origin is the main one and plays a decisive role in the occurrence of food-toxic infections. On the other hand, this once again confirms our conclusions that the prevention of toxic infections of salmonellosis origin should, first of all, be aimed at a timely and accurate diagnosis of salmonellosis and salmonellosis in herds of productive animals.

Table 3 shows data on the categories of food products tested for the presence of Salmonella and their recent contamination in Ukraine during 2012–2023.

Table 3: Contribution of major food categories to Salmonella spread in Ukraine, 2012–2021. The specific portion of the main categories of food products in terms of the total number of samples tested for the presence of Salmonella and the positive samples isolated from them according to the data of the laboratories of the State Production and Consumer Service in Ukraine, 2012 - 2023.

Name of food category	No. of tested samples	%	No. of positive samples	%
Meat and meat products	747,844	47.87	519	78.16
Milk and dairy products	386,076	24.71	22	11.75
Fish and fish products	186,962	11.97	18	3.31
Eggs and egg products	116,637	7.47	78	2.71
Other uncategorized products	46,771	2.99	6	1.96
Ready-to-eat food products	37,047	2.37	13	0.90
Food of plant origin	24,328	1.56	5	0.75
Drink water/ready-to-drink beverages	10,355	0.66	0	0.45
Confectionary products	5,713	0.37	3	0.00
Honey and bee products	544	0.03	0	0.00
Total	**1,562,277**		**664**	

During the period 2012-2023, the most samples of meat and meat products were examined - 747,844 (47.87%); in second place - milk and milk products - 386,076 (24.71%); on the third - fish and fish products - 186,962 (11.97%); on the fourth - eggs and egg products - 116,637 (7.47%). In terms of the number of *Salmonella*-contaminated samples, we observe a slightly different picture: in the first place - also meat and meat products (518 positive samples, which is 78.13%); in second place - eggs and egg products - 78 (11.76%); on the third - milk and milk products - 22 (3.32%) and on the fourth - fish and fish products - 18 (2.71%). The obtained data are evidence that in Ukraine, the main factors of *Salmonella* transmission are two categories of products - meat and meat products and eggs and egg products, which account for a total of 89.9% of all positives. Both categories are products of animal origin, regardless of whether they were contaminated with Salmonella during the life of productive animals (primary contamination) or the processing of meat or eggs (secondary contamination). Secondary contamination with Salmonella can be controlled more easily and effectively, while salmonellosis in animals is difficult to detect, even in cases of targeted monitoring of this type of infectious process in herds of productive animals.

According to the results of our research and statistical data of the National Control Program of Poultry Salmonellosis in Ukraine, since 2018, contamination with salmonellosis pathogens in the samples under study has been showing a downward trend in these indicators. However, the epidemiological situation for the period 2012-2023 remains consistently dangerous in terms of salmonellosis infection in humans, animals, and poultry, as its level annually fluctuates on average within 0.01-0.02% of isolates, and salmonellosis pathogens are constantly isolated. Often, even the clinical manifestation of salmonellosis in animals remains undiagnosed, which leads to the spread of the disease in the herd and the dispersion of the pathogen in the environment. The reason for this is a number of subjective factors, in particular, the need for a more professional level of doctors at the primary level of veterinary care for animals, unwillingness or inability to correctly select biomaterial and send it to the laboratory for bacteriological research, etc. All this negatively affects the safety and quality of livestock products and is one of the important factors in the functioning of the epizootic process of salmonellosis in the populations of productive animals and the epidemic process in the population of the regions, Ukraine, and the countries of the world, and in general supports the indestructibility and ubiquity of Salmonella.

Conclusions

Salmonella is a bacterial pathogen that causes salmonellosis, a common infectious disease resulting in diarrhea. It is usually associated with consuming contaminated food products. *Salmonella* has many pathogenicity factors and hosts and is characterized by a wide range of sources, reservoirs, and factors of pathogen transmission. This makes it highly ubiquitous and persistent, leading to constant outbreaks of salmonellosis worldwide. According to the annual reports of State laboratories for the Food Safety and Consumer Protection Service of Ukraine from 2012 to 2023, meat and meat products are the most frequently contaminated food products with Salmonella, accounting for 78.13% of cases. Eggs and egg products are second with 11.76%, followed by milk and dairy products at 3.32%, fish and fish products at 2.71%, ready-to-eat food products (including confectionery) at 2.41%, unclassified food products at 0.9%, and products of plant origin with 0.75%.

After analyzing the group of *Salmonella* isolates from food products and feed, it was observed that the largest specific share was occupied by *S.* Enteritidis (23.09%). The rest of the isolates were serotypes such as *S.* Infantis (6.79%), *S.* Typhimurium (4.81%), *S.* Livingstone (3.58%), *S.* Virchow (2.35%), and rare serotypes (2.47%), such as *S.* Nigeria (1.48%) and *S.* Thompson (1.11%). In the group of identified *Salmonella* isolated from animals with salmonellosis and *Salmonella* carriers, the dominance of serovars Enteritidis (20.3%) and Typhimurium (14.76%) can be considered consistent. Specific host serovars such as *S.* Pullorum (without biovar identification - 10.71%; *S.* Pullorum biovar Pullorum - 10.50%) and *S.* Pullorum var. Gallinarum (6.62%) and *S.* Choleraesuis (5.79%) were also identified. The portion of *S.* Livingstone was less than 5% of the threshold (2.53%), and the rest were rare *Salmonella* (23 serotypes), the portion of which was 1%. In 2021, the Volyn Regional State Laboratory of Food Safety and Consumer Protection Service isolated monophasic *S.* Typhimurium for the first time from pathological material from pigs. The predominance of *S.* Enteritidis and *S.* Typhimurium serotypes in biomaterials from sick animals and *Salmonella*-carrying animals indicates the primary role of food products of animal origin in the epidemic process. Therefore, the diagnosis of salmonellosis at the level of both veterinary practitioners and diagnostic laboratories is essential in the system of prevention measures for *Salmonella* spread.

Challenges in detecting salmonellosis impede animal health monitoring. Moreover, controlling infection in live animals/birds is difficult. Hence, our study highlights the importance of animal health monitoring and management practices, which means a special focus on controlling the spread of salmonellosis within the herds and a subsequent focus on transmission via food products.

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