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Analysis of the prevalence of antibiotic-resistance in coliform isolates recovered from food products

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ABSTRACT

Introduction. The global incidence of the diseases caused by antibiotic-resistant microorganisms is increasing annually. At present, measures are being developed and implemented to combat the spread of bacteria resistance to antibiotics. A key strategy in this effort is the systematic monitoring of microbial resistance.
Objective. To study the prevalence of antibiotic-resistance in *Escherichia coli* and other coliform isolates recovered from food product samples.
Materials and methods. Coliform isolates recovered from food and water samples were used for this study. The bacteria were identified by biochemical methods using API 20 E kit and time-of-flight mass spectrometry. Antibiotic resistance was determined with disc diffusion method.
Results. A total of 2,667 tests of food and water samples for coliforms were carried out at the Vladimir Testing Laboratory of the Federal Centre for Animal Health in 2024; 134 coliform isolates were recovered. Tests of the recovered isolates for their antibiotic resistance showed high resistance rates to nalidixic acid, levofloxacin, cefalotin, ciprofloxacin, and tetracycline. Additionally, data on *Escherichia coli* isolates resistant to third-generation and fourth-generation cephalosporins are presented.
Conclusion. Coliform isolates showed 100% susceptibility to carbapenems. The recovered isolates exhibited the highest resistance to quinolones, fluoroquinolones, cephalosporins, and tetracyclines. *Escherichia coli* isolates demonstrated high resistance to quinolones, fluoroquinolones, and tetracyclines. *Citrobacter* spp. and *Enterobacter* spp. isolates were resistant to penicillins and cephalosporins, while *Cronobacter* spp. isolates were resistant to penicillins, quinolones, and fluoroquinolones. Polyresistant coliforms were isolated during the study, they were predominantly detected in products of animal origin.

Keywords: food products, coliforms, *Enterobacteriaceae*, antibiotics, antibiotic resistance, polyresistance

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Анализ распространения антибиотикорезистентности среди изолятов бактерий группы кишечной палочки, выделенных из пищевой продукции

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РЕЗЮМЕ

Введение. Ежегодно в мире увеличивается количество случаев заболеваний, вызванных антибиотикорезистентными микроорганизмами. В настоящее время разрабатываются и реализуются меры, направленные на противодействие распространению устойчивости бактерий к антибиотикам. Одной из ключевых стратегий является систематический мониторинг резистентности микроорганизмов.
Цель работы. Изучить распространенность устойчивости к антибактериальным препаратам у изолятов *Escherichia coli* и других представителей бактерий группы кишечной палочки (БГКП), выделенных из образцов пищевой продукции.
Материалы и методы. В работе использовали изоляты БГКП, выделенные из образцов пищевой продукции и воды. Идентификацию бактерий проводили биохимическим методом с использованием набора API 20 E и методом времяпролетной масс-спектрометрии. Устойчивость к антимикробным препаратам определяли диско-диффузионным методом.
Результаты. В течение 2024 г. во Владимирской испытательной лаборатории ФГБУ «ВНИИЗЖ» было проведено 2667 исследований образцов пищевой продукции и воды по показателю «содержание бактерий группы кишечной палочки». Выделено 134 изолята БГКП. При изучении антибиотикорезистентности выделенных изолятов установлен высокий процент резистентности к налидиксовой кислоте, левофлоксацину, цефалотину, ципрофлоксацину и тетрациклину. Представлены данные по изолятам *Escherichia coli*, обладающим устойчивостью к цефалоспоринам III и IV поколения.
Заключение. Установлена 100%-я чувствительность изолятов БГКП к антибиотикам группы карбапенемов. Наибольшую резистентность выделенные изоляты показали к хинолонам, фторхинолонам, цефалоспоринам и тетрациклинам. Среди изолятов *Escherichia coli* высокий уровень устойчивости

отмечен к антибиотикам группы хинолонов, фторхинолонов и тетрациклинов. Изоляты *Citrobacter* spp. и *Enterobacter* spp. проявили резистентность к антибактериальным препаратам из группы пенициллинов и цефалоспоринов. Изоляты *Cronobacter* spp. обладали устойчивостью к антибиотикам группы пенициллинов, хинолонов и фторхинолонов. В ходе работы выделены изоляты БГКП, обладающие полирезистентностью к антимикробным препаратам, которые были обнаружены главным образом в продукции животного происхождения.

Ключевые слова: пищевая продукция, бактерии группы кишечной палочки, БГКП, энтеробактерии, антибиотики, антибиотикорезистентность, полирезистентность

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INTRODUCTION

One of the most important inventions of mankind is penicillin, the first antibiotic, developed by Alexander Fleming, British bacteriologist, in 1928 [1, 2, 3]. By the mid-20th century, other antibacterial drugs, such as erythromycin, streptomycin, and tetracycline, had also been discovered [4, 5]. Since their discovery, antibiotics have been widely used in medicine, manufacturing, and animal farming [6, 7, 8, 9, 10].

As early as 1940, at the very beginning of penicillin use, the first reports began to appear that some microorganisms were capable of developing resistance to this antibiotic [2, 5]. Every year, the number of bacteria resistant to previously developed antimicrobial agents continues to increase [7, 9, 10, 11, 12]. There is a trend for increase in the number of diseases, including food-borne infections caused by antimicrobial resistant microorganisms [13, 14, 15, 16, 17].

In 2024, the World Health Organization was published an updated Bacterial Priority Pathogens List comprising the microorganisms that pose the greatest threat to the human life and health. This list includes three categories of bacteria according to the degree of the threat posed. The first category, comprising high-priority microorganisms, includes poly-antimicrobial resistant bacteria. Bacteria of the *Enterobacteriaceae* family are classified to this category due to their resistance to carbapenems and third-generation cephalosporins [18].

Currently, efforts are being made to reduce the use of antibiotics [19]. The World Health Organization has developed an action plan designed to optimize antimicrobial use, thereby ensuring its rational application [18]. In the Russian Federation, as part of the strategy to counter the spread of antibiotic-resistant bacteria, several regulations have been adopted to govern the use of antimicrobials and to implement measures aimed at combating antimicrobial resistance in bacteria [19]. Thus, Decree No. 97 of the President of the Russian Federation of 11 March 2019 approved the "On the principles of State policy of the Russian Federation in the area of chemical and biological safety for the period to 2025 and beyond". In November 2021, the Order of the Ministry of Agriculture of the Russian Federation "On approval of the list of medicinal products intended for the treatment of infectious and parasitic diseases of animals caused by pathogenic microorganisms and opportunistic microorganisms, in respect of which a restriction on the use for medicinal purposes is imposed, in including for the treatment of farm animals" was issued. By Decree No. 2214-r of the Government of the Russian Federation of 16 August 2024 the Action Plan for implementation of the Strategy for Antimicrobial Resistance Spread Prevention in the Russian Federation for the period up to 2030 was approved. A key component of this plan is the systematic monitoring of the spread of antibiotic resistance among microorganisms. Ongoing antibiotic resistance surveillance enables the detection of changes in bacteria susceptibility to antibiotics [20, 21]. As indicated in the analytical report on the antibiotic resistance of bacterial pathogens in the Russian Federation (28 December 2024), *Enterobacteriaceae* spp. constituted 55.6% of all detected bacterial pathogens in 2019–2024. Within the analysed period, the following coliforms were most common detected in the country: *Klebsiella pneumoniae* (45.4%), *Escherichia coli* (37.47%), *Proteus mirabilis* (4.15%), *Enterobacter cloacae* (3.02%) and *Klebsiella oxytoca* (2.04%) [22].

The data given above indicate the importance of testing microorganisms detected in animal products, raw food materials and food products for their antibiotic resistance.

The frequency of detection of antibiotic-resistant bacteria of the family *Enterobacteriaceae* isolated from diseased patients was as follows: ampicillin-resistant bacteria – 86.34%; amoxicillin/clavulanic acid-resistant bacteria – 66.62%; piperacillin/tazobactam-resistant bacteria – 43.71%; cephalosporins (cefotaxime, ceftazidime and cefepime)-resistant bacteria – 60.54, 52.6 and 49.08%, respectively; aztreonam-resistant bacteria – 54.15%, ceftazidime/avibactam and aztreonam/avibactam-resistant bacteria – 15.84 and 1.24%, respectively; carbapenems (ertapenem, imipenem and meropenem)-

resistant bacteria – 33.97, 21.78 and 23.02%, respectively; imipenem/relebactam-resistant bacteria – 21.34%; fluoroquinolones (ciprofloxacin)-resistant bacteria – 55.88%; aminoglycoside (amikacin and gentamicin)-resistant bacteria – 21.16 and 34.88%, respectively; trimethoprim/sulfamethoxazole-resistant bacteria – 52.07%; chloramphenicol-resistant bacteria – 37.2%; colistin-resistant bacteria – 10.91% [22, 23, 24, 25, 26].

The novelty of this study lies in isolating novel antibiotic-resistant enterobacteria exhibiting polyresistance, as well as analysing the types of food products that serve as sources of antibiotic resistance dissemination.

The aim of this study was to isolate coliforms from food and water samples, test them for antibiotic resistance, and analyse the antibiotic resistance prevalence among the recovered isolates.

MATERIALS AND METHODS

A total of 134 coliform isolates recovered from food and water at the Department for Microbiological Testing of the Vladimir Testing Laboratory of the Federal Centre for Animal Health in 2024 were used. The samples were tested in accordance with the following regulatory documents: GOST 31747-2012 "Food products. Methods for detection and quantity determination of coliforms"; GOST 30726-2001 "Food-stuffs. Methods for detection and determination of *Escherichia coli*"; GOST 31955.1-2013 "Drinking water. Detection and enumeration of and coliform bacteria. Part 1. Membrane filtration method".

Nutrient media, reagents, and test systems. Kessler medium (State Research Center for Applied Microbiology and Biotechnology, Russia) was used for primary sample inoculation. Chromocult Coliform Agar (Merck, Germany) was used for coliform differentiation. Isolated colonies were inoculated on tryptone soy agar (State Research Center for Applied Microbiology and Biotechnology, Russia) for their identification. Coliform isolates were re-inoculated onto Mueller – Hinton agar (HiMedia, India) to determine their susceptibility to antimicrobials.

Isolated microorganisms were identified based on their biochemical properties using the API 20 E kit (bioMérieux, France).

Mass spectrometric analysis was performed with MALDI Autof MS 1000 mass spectrometer (Autobio Diagnostics Co., Ltd., China). The analysis parameters were optimized for the mass range from 2,000 to 20,150 m/z (mass/time), and the spectrum obtained by summing 20 single spectra was recorded. Autof Acquirer v2.0.130 software (Autobio Diagnostics Co., Ltd., China) was used for recording, processing the obtained mass spectra and statistical analysis thereof.

Tests for susceptibility to antimicrobials were carried out with disc-diffusion method according to the Russian Guidelines for determination of the susceptibility of microorganisms to antimicrobial drugs (IACMAC) and Methodical Guidelines (MG) 4.2.1890-04 "Determination of susceptibility of microorganisms to antibacterial drugs". Paper disks with antibiotics (Saint-Petersburg Pasteur Institute, Russia) of the following groups were used:

1) penicillins with beta-lactamase inhibitors: ampicillin/sulbactam (10/10 μg per disc), amoxicillin/clavulanate (20/10 μg per disc), ticarcillin/clavulanate (75/10 μg per disc);

2) first-generation cephalosporins: cephalotin (30 μg per disc), cefazolin (30 μg per disc);

3) second-generation cephalosporins: cefaclor (30 μg per disc), cefuroxime (30 μg per disc), cefoxitin (30 μg per disc), cefamandole (30 μg per disc);

4) third-generation cephalosporins: ceftriaxone (30 μg per disc), ceftazidime (30 μg per disc), cefotaxime (30 μg per disc);

5) fourth-generation cephalosporins: cefepime (30 μg per disc);

6) carbapenems: imipenem (10 μg per disc), meropenem (10 μg per disc);

7) aminoglycosides: kanamycin (30 μg per disc), gentamicin (10 μg per disc), amikacin (30 μg per disc);

8) quinolones: nalidixic acid (30 μg per disc);

9) fluoroquinolones: ofloxacin (5 μg per disc), ciprofloxacin (5 μg per disc); levofloxacin (5 μg per disc);

10) tetracyclines: tetracycline (30 μg per disc), doxycycline (30 μg per disc);

11) amphenicols: chloramphenicol, or levomycetin (30 μg per disc);

12) sulfonamides: trimethoprim/sulfamethoxazole, or co-trimoxazole (1.25/23.75 μg per disc).

To determine antibiotic resistance, bacterial suspension (0.5 according to the McFarland turbidity standard) was evenly distributed on the agar surface. Discs with antibiotics were placed onto the agar surface inoculated with the test culture (no more than 4 discs per dish). Then, the Petri dishes were inverted and placed into a laboratory incubator and incubated at 35 °C for 18–24 hours.

The results were assessed based on presence of microorganism growth inhibition zones around the discs in accordance with the recommendations of MG 4.2.1890-04. The diameters of the growth inhibition zones, taking into account the diameter of the disc itself, were measured with an accuracy of 1 mm.

Interpretation and analysis of the results. Bacterial isolates were divided based on their susceptibility to antibiotics into the following groups: susceptible, intermediate, resistant to one and two antibiotics, polyresistant – resistant to three or more antibiotics. Extremely resistant isolates, i.e. isolates resistant to 10 or more antimicrobials, were identified in the group of polyresistant isolates.

Data laid down in MG 4.2.1890-04 (Table 1) were used for classification of the isolates into susceptible (S), intermediate (In) and resistant (R) groups.

Statistical processing of the data was carried out using the Microsoft Excel application and standard statistical techniques.

RESULTS AND DISCUSSION

In 2024, 2,667 tests for coliforms were carried out at the Department for Microbiological Testing of the Vladimir Testing Laboratory of the Federal Centre for Animal Health. A total of 134 coliform isolates were recovered including: 11 isolates recovered from water samples, 22 isolates – from dairy products, 94 isolates – from meat and meat products, 3 isolates – from fish products, 2 isolates – from ready-to eat products, 1 isolate – from spices and 1 isolate – from egg melange. The percentage of coliform detections in various food product groups ranged from 0.5% in spices to 13.1% in water (Fig. 1).

Food product samples were initially inoculated in Kessler medium. Cultures from the test tubes, in which gas formation and/or medium turbidity developed, were

inoculated onto Chromocult Coliform Agar medium. Colonies of pink (red) and blue (purple) colour were selected for identification after incubation for 24 hours at 37 °C. Examination of microorganisms using API 20 E biochemical identification kits has shown that the recovered isolates belonged to the family *Enterobacteriaceae*. The following bacteria species were identified among the recovered cultures: *E. coli* – 81.3%, *Citrobacter* spp. – 6.0%, *Enterobacter* spp. – 5.2%, *Cronobacter* spp. – 2.2%, *Raoultella* spp. – 2.2%, *Leclercia adecarboxylata* – 1.5%, *Serratia* spp. – 0.7%, *Klebsiella* spp. – 0.7%.

Biochemical identification results showed that all *E. coli* isolates fermented glucose and mannitol, exhibited no urease activity, did not utilize citrates, did not produce hydrogen sulphide, and did not ferment tryptophan deaminase, gelatinase, inositol, or amygdalin. Among the isolates, 99.1% demonstrated beta-galactosidase fermentation and lacked acetoin production, whereas 95.4% were positive for indole formation. More than 91% of the isolates fermented sorbitol, rhamnose, melibiose, and arabinose. Also, 85.3 and 54.1% of isolates did not produce arginine dihydrolase and ornithine decarboxylase fermentation, respectively. Among the isolates, 51.4% did not ferment sucrose. While 84.4% of *E. coli* isolates were positive lysine decarboxylase fermentation.

The results of the biochemical identification of *E. coli* and other coliforms were consistent to the data presented in the Bergey's Manual of Systematic Bacteriology.

Additionally, the isolated cultures were identified by time-of-flight mass spectrometry. Mass spectrometry and biochemical identification (API 20 E kit) yielded consistent results for 100% of the bacterial isolates. All coliform isolates were identified by MALDI Autof MS 1000 mass spectrometry, yielding accuracy scores between 9.0 and 9.72, which indicates a high level of identification reliability.

Tests of coliform isolates for their susceptibility to antimicrobials (Fig. 2) showed that 100% of the isolates were susceptible to carbapenems (meropenem, imipenem), 94% of the isolates were susceptible to ticarcillin/clavulanate and amikacin, 92.5% of the isolates were susceptible for cefaclor, 91.8% of the isolates were susceptible to cefepime and gentamicin, 88.8% of the isolates were susceptible to ceftazidime, 85.1% of the isolates were susceptible to ceftriaxone, 83.6% of the isolates were susceptible to cefotaxime, 82.8% of the isolates were susceptible to cefuroxime.

Coliform isolates exhibited greatest resistance to nalidixic acid (45.5% of isolates), levofloxacin (38.1% of isolates), cefalotin (37.3% of resistant isolates, 20.1% of intermediately susceptible isolates), ciprofloxacin (36.6% of resistant isolates), tetracycline (34.3% of resistant isolates, 29.1% of intermediately susceptible isolates).

The findings of our study are supported by several scientific publications. The study published in 2024 demonstrated high resistance of *E. coli* isolates recovered in China in 2022 to ciprofloxacin (61.4%) and cefepime (25.1%); 9.7% of the isolates exhibited resistance to ceftriaxone. Resistance to imipenem and meropenem increased from 1.0% in 2019 to 1.6% in 2022 [16]. In 2021, *E. coli* isolates resistant to chloramphenicol (5.6%) were recovered from food products in Chile [17]. In Italy, isolates resistant to gentamicin, chloramphenicol, co-trimoxazole, tetracycline and nalidixic acid were recovered from food products in 2010–2018. In Brazil, enterobacteria isolates resistant to aminoglycosides,

Table 1
Growth inhibition zone diameter according to Methodical Guidelines (MG) 4.2.1890-04

Antibiotic	Antibiotic resistance groups		
	susceptible (S), mm	intermediate (In), mm	resistant (R), mm
Ampicillin/sulbactam	≥ 17	14–16	≤ 13
Amoxicillin/clavulanate	≥ 18	14–17	≤ 13
Ticarcillin/clavulanate	≥ 20	15–19	≤ 14
Cephalotin	≥ 18	15–17	≤ 14
Cefazolin	≥ 18	15–17	≤ 14
Cefaclor	≥ 18	15–17	≤ 14
Cefuroxime	≥ 18	15–17	≤ 14
Cefoxitin	≥ 18	15–17	≤ 14
Cefamandole	≥ 18	15–17	≤ 14
Ceftriaxone	≥ 18	15–17	≤ 14
Ceftazidime	≥ 18	15–17	≤ 14
Cefotaxime	≥ 23	15–22	≤ 14
Cefepime	≥ 18	15–17	≤ 14
Imipenem	≥ 16	14–15	≤ 13
Meropenem	≥ 16	14–15	≤ 13
Kanamycin	≥ 18	14–17	≤ 13
Gentamicin	≥ 15	13–14	≤ 12
Amikacin	≥ 17	15–16	≤ 14
Nalidixic acid	≥ 17	15–16	≤ 14
Ofloxacin	≥ 16	13–15	≤ 12
Ciprofloxacin	≥ 21	16–20	≤ 15
Levofloxacin	≥ 17	14–16	≤ 13
Tetracycline	≥ 19	15–18	≤ 14
Doxycycline	≥ 16	13–15	≤ 12
Chloramphenicol (levomycetin)	≥ 18	13–17	≤ 12
Trimethoprim/ sulfamethoxazole (co-trimoxazole)	≥ 16	11–15	≤ 10

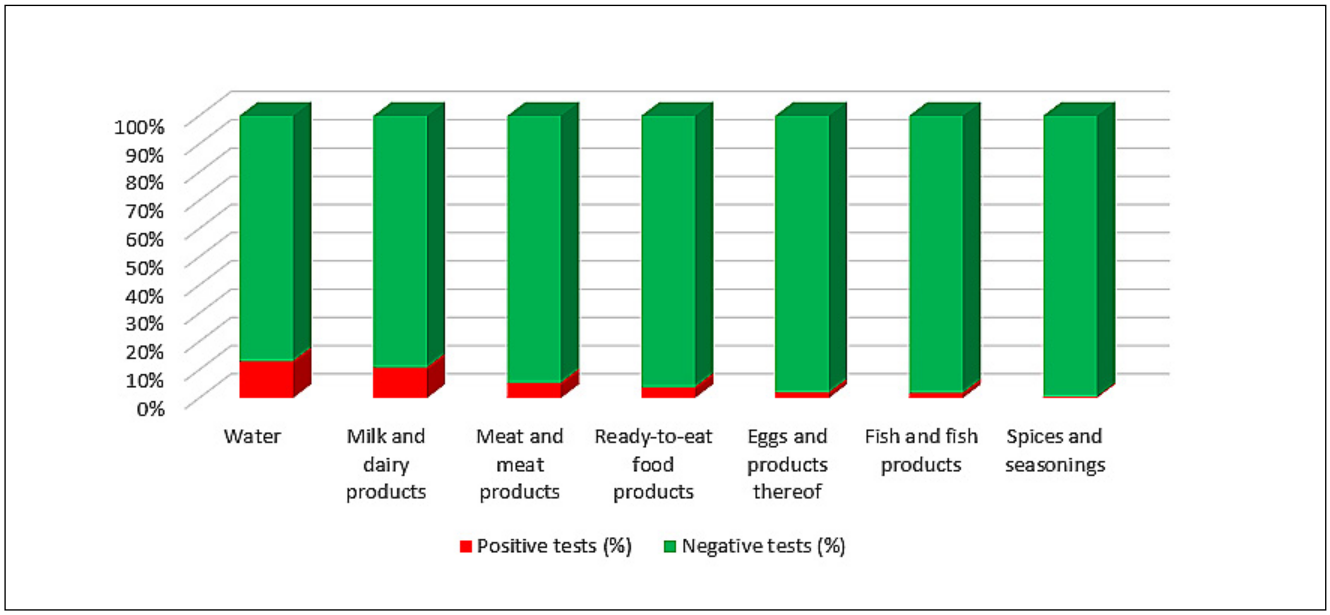

Fig. 1. Detection of coliforms in products of various types in 2024 (n = 134)

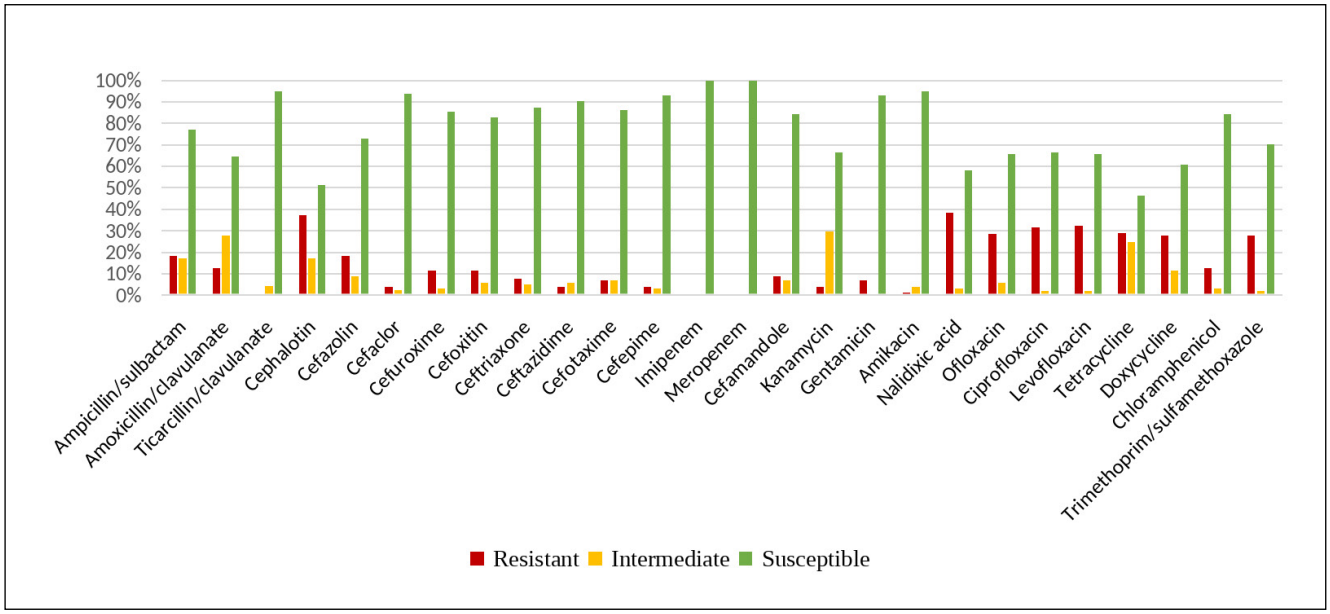

Fig. 2. Resistance of coliform isolates (n = 134) to antibiotics

beta-lactams, tetracyclines, and quinolones were recovered from meat in 2010–2019. In Korea, isolates resistant to nalidixic acid, ciprofloxacin, tetracycline, chloramphenicol, co-trimoxazole, and gentamicin were recovered from poultry meat in 2019 [27].

In 2018, S. A. Sheveleva published the results of tests of the isolates recovered from meat and dairy products for their antimicrobial resistance. *Enterobacteria* isolates exhibiting resistance to tetracyclines (45–63%), ampicillin (42%), and fluoroquinolones (up to 20%) were isolated from food samples during the study [28].

In 2022, M. M. Sibirkina et al. presented the findings of the study on antimicrobial resistance of the bacteria detected in food products of animal origin presented on the markets located in Moscow region. *Enterobacteriaceae* family isolates, resistant to antibiotics of the penicillin, quinolone, and aminoglycoside groups, were recovered from food samples. The authors of the study also noted the susceptibility of the recovered isolates to carbapenems [29].

The results of the analysis of the antimicrobial resistance prevalence among isolates of various genera of the family *Enterobacteriaceae* are presented in Table 2.

E. coli isolates showed the greatest resistance to nalidixic acid (53.2%), levofloxacin (45.0%), ciprofloxacin (43.1%) and tetracycline (40.4%).

Citrobacter spp. isolates exhibited resistance to amoxicillin/clavulanate (37.5%), cephalotin (37.5%), cefoxithin (37.5%) and cefazolin (25.0%).

Enterobacter spp. isolates were found to be resistant to cephalotin (85.7%), amoxicillin/clavulanate (71.4%), cefazolin (71.4%) and cefoxitin (71.4%).

Cronobacter spp. isolates demonstrated resistance to ticarcillin/clavulanate (66.7%), as well as to antibiotics such as ampicillin/sulbactam, amoxicillin/clavulanate, nalidixic acid, ofloxacin, ciprofloxacin and levofloxacin.

Raoultella spp. and *Leclercia adecarboxylata* isolates demonstrated susceptibility to all antimicrobials included in the study.

Currently, *Enterobacteriaceae* resistance to cephalosporins, in particular to third-generation and fourth-generation cephalosporins, is a matter of great concern [30, 31]. According to the data presented in Table 2, *E. coli* isolates exhibited resistance to first-generation cephalosporins (26.15 ± 5.95%) of the isolates to second-generation cephalosporins (10.3 ± 4.1%) of isolates, to third-generation cephalosporins (8.6 ± 2.8%) of isolates, to fourth-generation cephalosporins – 5.5% of isolates. Thus, the proportion of resistant *E. coli* isolates was shown to decrease depending on the generation of the antibiotic used. Notably, the detection of *E. coli* resistant to third-generation and fourth-generation cephalosporins in food products should serve as grounds for tightening control over the veterinary medicinal products used in livestock industry.

No *Citrobacter* spp., *Enterobacter* spp., *Cronobacter* spp., *Raoultella* spp., *Leclercia adecarboxylata*, *Serratia* spp. and *Klebsiella* spp. isolates resistant to third-generation and fourth-generation cephalosporins were found.

Testing the isolates for antibiotic resistance revealed the coliform isolates that were resistant to three or more antibiotics (polyresistant) and resistant to 10 or more antibiotics (extremely resistant).

Data presented in Table 3 show that *E. coli*, *Citrobacter* spp., *Enterobacter* spp., *Cronobacter* spp., and *Serratia* spp. isolates demonstrated polyresistance. However, extremely resistant isolates are found only among *E. coli* bacteria.

Analysis of the products from which polyresistant bacteria were isolated (Fig. 3) showed that 88.7% of the isolates were recovered from the products of animal origin, of which 76.1% were detected in poultry meat products. Polyresistant isolates were also recovered from drinking water (9.9%), dairy products (7.0%) and spices (1.4%).

The study findings show that food products of animal origin, especially poultry products, are one of the main routes of transmission of antibiotic-resistant microorganisms. These data are consistent with the results of many authors [27, 28, 30, 32] and suggest that the high prevalence of antimicrobial-resistant coliform bacteria in poultry meat may be attributed to the specific broiler meat production characteristics, whereby zoo-technical methods alone do not always yield effective outcomes.

In 2019, several studies published in Germany reported that up to 71.9% of *E. coli* isolates recovered from poultry meat harbored extended-spectrum beta-lactamases (ESBL) conferring resistance to cephalosporins. The rate of ESBL-producing escherichia detection in beef and pork was significantly lower and amounted to 12.1%.

Table 2
Antimicrobial resistance prevalence among isolates of various genera of the family *Enterobacteriaceae*

Antibiotic	Group of antimicrobials	Proportion of resistant isolates, %					
		E. coli (*n* = 109)	*Citrobacter* spp. (*n* = 8)	*Enterobacter* spp. (*n* = 7)	*Cronobacter* spp. (*n* = 3)	*Raoultella* spp. (*n* = 3)	*Leclercia adecarboxylata* (*n* = 2)
Ampicillin/sulbactam	Penicillins + beta-lactamase inhibitors	24.8	12.5	0	33.3	0	0
Amoxicillin/clavulanate		8.3	37.5	71.4	33.3	0	0
Ticarcillin/clavulanate		0.9	0	0	66.7	0	0
Cephalotin	First-generation cephalosporins	32.1	37.5	85.7	0	0	0
Cefazolin		20.2	25.0	71.4	0	0	0
Cefaclor	Second-generation cephalosporins	5.5	0	0	0	0	0
Cefuroxime		15.6	0	0	0	0	0
Cefoxitin		7.3	37.5	71.4	0	0	0
Cefamandole		12.8	0	0	0	0	0
Ceftriaxone	Third-generation cephalosporins	11.0	0	0	0	0	0
Ceftazidime		5.5	0	0	0	0	0
Cefotaxime		9.2	0	0	0	0	0
Cefepime	Fourth-generation cephalosporins	5.5	0	0	0	0	0
Imipenem	Carbapenems	0	0	0	0	0	0
Meropenem		0	0	0	0	0	0
Kanamycin	Aminoglycosides	5.5	0	0	0	0	0
Gentamicin		10.1	0	0	0	0	0
Amikacin		0.9	12.5	0	0	0	0
Nalidixic acid	Quinolones	53.2	0	0	33.3	0	0
Ofloxacin	Fluoroquinolones	38.5	0	0	33.3	0	0
Ciprofloxacin		43.1	0	0	33.3	0	0
Levofloxacin		45.0	0	0	33.3	0	0
Tetracycline	Tetracyclines	40.4	0	0	0	0	0
Doxycycline		39.4	0	0	0	0	0
Chloramphenicol (levomycetin)	Amphenicols	17.4	12.5	0	0	0	0
Trimethoprim/sulfamethoxazole (co-trimoxazole)	Sulfonamides	38.5	0	0	0	0	0

Colour scale				
0–20%	20–40%	40–60%	60–80%	80–100%

Table 3
Classification of the coliform isolates based on their resistance to antibiotics

Microorganism	Antibiotic resistance			
	Susceptible, %	Resistant, %	Polyresistant, %	Extremely resistant, %
E. coli ($n = 109$)	36.7	8.3	37.6	17.4
Citrobacter spp. ($n = 8$)	37.5	37.5	25.0	0
Enterobacter spp. ($n = 7$)	0	14.3	85.7	0
Cronobacter spp. ($n = 3$)	33.3	0	66.7	0
Raoultella spp. ($n = 3$)	100	0	0	0
Leclercia adecarboxylata ($n = 2$)	100	0	0	0
Klebsiella spp. ($n = 1$)	100	0	0	0
Serratia spp. ($n = 1$)	0	0	100	0

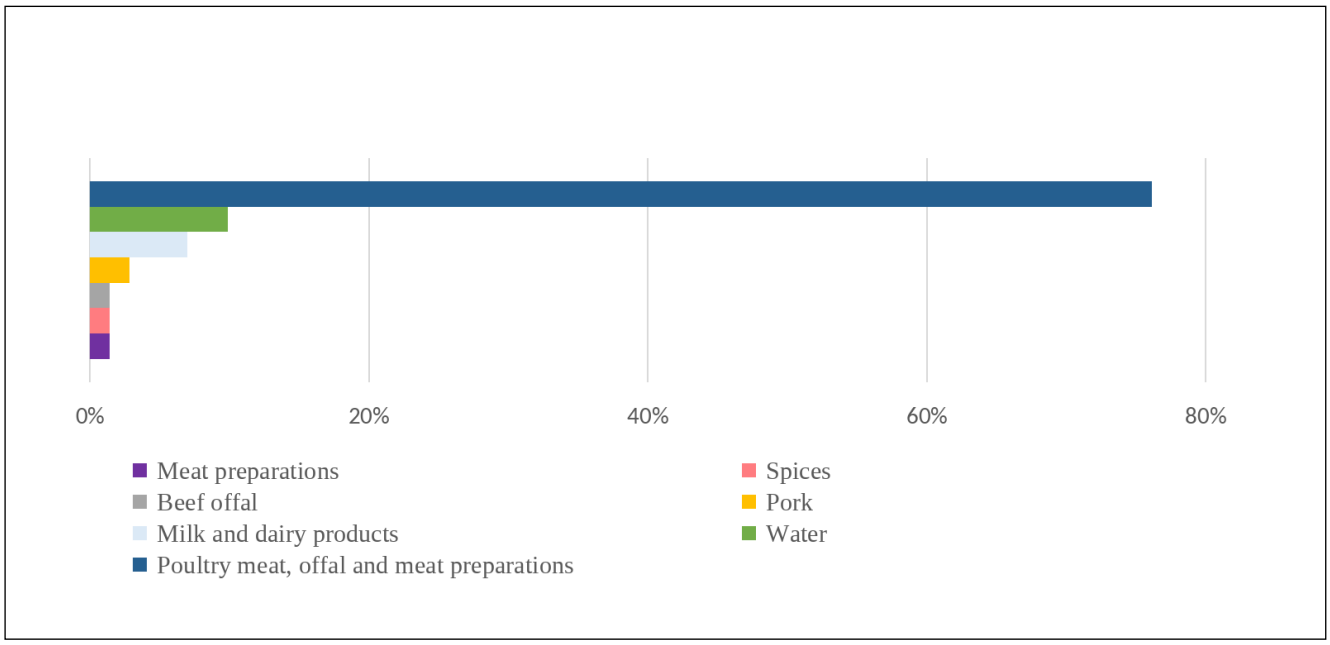

Fig. 3. Distribution of polyresistant coliform isolates depending on the source of isolation (n = 76)

In 2019–2021, I. Donnik carried out a study of livestock facilities in Russia to analyse the prevalence of antibiotic-resistant enterobacteria isolates. During this study, enterobacteria were found to be resistant to tetracyclines (up to 92% of isolates) and penicillins (up to 67% of isolates) as well as third-generation cephalosporins, carbapenems, fluoroquinolones, and aminoglycosides [7].

CONCLUSION

A total of 134 isolates of coliforms were recovered during tests of 2,667 food product and water samples at the Department for Microbiological Testing of the Vladimir Testing Laboratory of the Federal Centre for Animal Health. Microorganism identification tests showed that the isolated enterobacteria belonged to the genera *Escherichia*, *Enterobacter*, *Citrobacter*, *Cronobacter*, *Leclercia*, *Serratia*, *Klebsiella*, *Raoultella*.

Testing for antimicrobial resistance showed 100% susceptibility of the coliform isolates to carbapenems. The recovered isolates exhibited the greatest resistance to the following groups of antimicrobial drugs: quinolones, fluoroquinolones, cephalosporins and tetracyclines.

E. coli isolates exhibited the greatest resistance to quinolones, fluoroquinolones, and tetracyclines. *Citrobacter* spp. and *Enterobacter* spp. isolates demonstrated resistance to penicillins and cephalosporins. *Cronobacter* spp. isolates exhibited resistance to penicillins, quinolones, and fluoroquinolones.

Tests for antibiotic resistance showed that *E. coli*, *Citrobacter* spp., *Enterobacter* spp., *Cronobacter* spp., *Serratia* spp. isolates demonstrated polyresistance. Only *E. coli* isolates were classified as extremely resistant. *Raoultella* spp., *Leclercia adecarboxylata* and *Klebsiella* spp. isolates demonstrated susceptibility to all the antibiotics used for the study.

The study showed that polyresistant isolates were mainly recovered from poultry meat samples. This fact indicates that the high detection rate of antibiotic-resistant coliform bacteria in poultry meat may be associated with the specific characteristics of production of broiler meat.

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