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Peculiarities of rearing poultry by floor method on deep bedding

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Abstract. In poultry rearing on deep bedding systems, microorganisms that cause infectious diseases develop within the bedding. This study aimed to determine the physical properties and microbial accumulation capacity of different types of bedding. Methods used included thermo-programmed desorption mass spectrometry, microbiological methods, and scanning electron microscopy. The hygroscopic properties of straw bedding deteriorated by 269.90% from the seventh to the forty-second day. In the experimental room, where a dry disinfectant was added to the straw

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bedding, the hygroscopic capacity was 86.70% at the end of the experiment, a difference of 183.2%. Wood shavings bedding, with the addition of disinfectant, exhibited a water absorption capacity 102.82% higher than the control on the forty-second day. Granulated bedding with disinfectant retained moisture 150.33% better compared to the control. At the end of the experiment, the pH of straw bedding was 8.13 in the control group compared to 7.56 in the treated group; for wood shavings was 7.95 versus 7.16; and for granule was 7.35 versus 6.35, due to the use of the disinfectant. At the conclusion of the experiment, granulated bedding exhibited the lowest pH compared to straw and wood shavings, affecting the growth and reproduction of microorganisms. Monitoring of microorganisms in the bedding revealed the presence of bacteria: *Escherichia coli*, *Salmonella typhimurium*, *Salmonella pullorum*, *Clostridium perfringens*, *Staphylococcus aureus*, *Klebsiella pneumonia*, *Listeria monocytogenes*, as well as microscopic fungi: *Fusarium sporotrichioides*, *Aspergillus niger*, and *Eimeria* oocysts. The use of disinfectant reduced bacterial contamination of straw bedding by 12.35-199.19%, fungal contamination by 633.91-1959.14%, and *Eimeria* by 676.50%. In the wood shavings bedding, bacterial contamination was reduced by 32.84-257.93%, fungal contamination by 487.08-1098.4%, and *Eimeria* by 570.21%. Granulated bedding showed reduced bacterial accumulation by 50.93-228.87%, fungal accumulation by 169.89-500.9%, and *Eimeria* by 301.56%. The practical significance of this study lies in the improved physical properties of poultry bedding and the reduction in bacterial, fungal, and *Eimeria* oocyst accumulation

Keywords: hygroscopic properties; bedding pH; bacteria; microscopic fungi; *Eimeria*

INTRODUCTION

The environment plays a crucial role in poultry productivity. When selecting bedding materials, factors such as cost-effectiveness, moisture absorption capacity, and environmental safety must be considered. The European Union's initiative to ban caged poultry by 2027 (European Commission, 2021) has prompted producers to adopt floor-keeping systems for broiler production. Rearing poultry on the floor necessitates the use of high-quality bedding materials. The intensive broiler production system has raised concerns about poultry welfare, leading to a search for alternative rearing systems (Çavuşoğlu & Petek, 2019; Kwon *et al.,* 2024).

In the management of pigs on the floor, researchers O. Shkromada *et al.* (2022) identified bacteria such as *A. Thiooxidans, S. aureus, E. coli, S. enteritidis, S. Choleraesuis, C. Perfringen* and fungi including *Cladosporium, Fusariums, Aspergillus*. Their research demonstrated that a dry disinfectant exhibited antimicrobial properties against field isolates of bacteria and fungi from the pig farm. While the experiment was conducted in a pigsty, poultry farming has unique conditions and requirements. Bacteria and fungi can lead to secondary infections, contamination of products, and environmental pollution in poultry houses. Studies by H.K. Sorour *et al.* (2023) found that methicillin-resistant coagulase-negative staphylococci caused polyserositis of internal organs, hepatic and myocardial necrosis.

Bacteria of the *Escherichia sp.* family have been linked to diseases such as enteritis, salpingitis, peritonitis, and septicaemia in poultry (Swelum *et al.,* 2021). These microorganisms have demonstrated high pathogenicity and resistance to a range of antibiotics, necessitating preventative measures to reduce the risk of poultry infection. The indiscriminate and frequent use of antibiotics to treat infectious diseases has led to the emergence of antibiotic-resistant strains of microorganisms, which can spread among poultry via bedding (Oxendine *et al.,* 2023). Additionally, researchers M. Kyakuwaire *et al.* (2019) determined that poultry bedding can serve as a source of infection and allergic reactions in both animals and humans. Consequently, there is a pressing need for research into the efficacy of preventive disinfection.

Floor-based poultry systems offer both advantages and disadvantages. A variety of materials, often agricultural by-products, are used as bedding (Brochu *et al.,* 2021). Wood shavings have been the most common bedding material in farms (70.2%). In an experiment conducted by T.L. Crippen *et al.* (2019), it was found that straw, sawdust, and wood bark are frequently used as poultry bedding. Changes in the bedding can affect the quantity and types of microorganisms present on the floor.

Research has also revealed the use of hulls of sunflower, legumes, straw, and other plant-based materials as bedding (Sieńkowska *et al.,* 2019). These materials have been found to contain pesticides, lead, cadmium, and toxins produced by fungi and bacteria. Therefore, when selecting bedding materials, it is crucial to consider factors such as toxicological and biological safety. Scientists M.H. Seyedtaghiya *et al.* (2021) explored the potential of using *Satureja hortensis L.* as a medicinal plant to eliminate bacteria. However, their study focused solely on the bactericidal properties of *Satureja hortensis L.* against *E. Coli* and *Salmonella*, which is insufficient to eliminate the associated microbiota. In the research of S.I. Cuevas-Cianca *et al.* (2023), the antimicrobial activity of extracts from Latin American medicinal plants was investigated as a solution to the problem of antibiotic resistance in microorganisms. However, the researchers did not propose a method for treating bedding with these extracts or essential oils.

This study aimed to conduct a comparative assessment of poultry bedding materials for safe

floor-based rearing. To achieve this objective, the following tasks were undertaken: to investigate the moisture-holding capacity of different bedding types; to determine the pH of each bedding type; and to examine the microorganisms and *Eimeria* content in various bedding materials.

MATERIALS AND METHODS

Cobb-500 broiler chickens were kept in the veterinary clinic of Sumy National Agrarian University for a period of 40 days, from January 1 to February 9, 2024. The birds were divided into 6 groups: 3 control and 3 experimental (Table 1).

Table 1. *Experiment design*

Control		Experiment	
1C	Straw	1E	Straw + dry disinfectant
2C	Wood shavings	2E	Wood shavings + dry disinfectant
3C	Granule	3E	Granule + dry disinfectant

Note: *C – control; E – experimental*
Source: *developed by the authors*

The chicks were housed in a room with a concrete floor and bedded on: wood shavings (Fig. 1a), straw (Fig. 1b), and granule (Fig. 1c). For bedding, wood shavings from coniferous and soft deciduous species of 0.05-0.1 × 6-8 mm; chopped wheat and rye straw were used. The granules used in the experiment were a mixture of coniferous and deciduous wood, measuring up to 6.8 × 50 mm. The different types of bedding were spread on the floor to a depth of 20-30 cm before the birds were placed in the house. In the experimental groups, a dry powdered disinfectant was spread twice a week at a rate of 50 g/m^2. The experimental disinfectant, produced and supplied for testing by LLC "Brovapharma", contained kaolin, calcium sulphate dihydrate, chloramine, copper sulphate, thymol, iron sulphate, and zeolite.

Figure 1*. Image of poultry housing on the floor with bedding*
Note: *a – wood shavings; b – straw; c – granule*
Source: *author's photo*

The primary objective of the experiment was to investigate the varying performance characteristics of different bedding materials. Laboratory analyses were conducted in the Department of Veterinary Expertise, Microbiology, Zoohygiene and Safety and Quality of Livestock Products of the Faculty of Veterinary Medicine in the "Veterinary Pharmacy" laboratory of the Sumy National Agrarian University.

Investigation of hygroscopic properties of bedding samples using TPD MS. The Thermo-Programmed Desorption Mass Spectrometry (TPD MS) MX-7304 (SELMI OJSC, Sumy, Ukraine) was used to determine the moisture content of the bedding samples. Samples weighing 5-10 mg were heated from 40 to 200°C at a rate of 15°C/min, with the release of moisture being recorded every minute. The mass spectrometer was used to determine the H_2O content (Murphy *et al.,* 2021).

Determination of the pH of the bedding. The selected bedding samples were kept for 60 minutes in distilled water, and the pH of the bedding was measured using a pH meter. Measurements were taken at the beginning and end of the experiment, after 42 days.

Investigation of bedding contamination with microorganisms and Eimeria. Weekly, samples of each bedding type were collected along with faecal matter into sterile containers to which 250 ml of water was added for a ten-fold dilution. The resulting suspension was added to selective media. Endo agar was used for the isolation of enterobacteria, and salt agar for staphylococci (Hanišáková *et al.,* 2022). Sabouraud agar was used to cultivate microscopic fungi (Suwannarach *et al.,* 2022). For the cultivation of clostridia, Wilson-Blair agar was used. After the cultivation of the microorganisms in a thermostat, the number of colony-forming units per

gram of sample (CFU/g) was counted using an automatic counter Scan 4000 Ultra HD (Interscience, China). Samples of bedding and faeces were examined for *Eimeria* using the Fülleborn method. The number of *Eimeria* oocysts per gram of sample (OPG index) was counted using the method of S.K. Sadhukhan (2022).

Scanning electron microscopy. Microscopy of straw, wood shaving, and granules bedding samples was performed using a REM 106 (SELMI OJSC, Sumy, Ukraine) at electron-optical magnification ranging from 200 to 5,000 times.

Statistical analysis. Statistical analysis of the data was performed using the Fisher-Student method (Fisher & Mosteller, 1948), considering a significance level of greater than 95% ($p < 0.05$). The research was conducted by DSTU EN ISO/IEC 17025:2019 (2019), adhering to the rules of bioethics and humane treatment of vertebrate animals 2010/63/EU (Hartung, 2010), the European Convention for the Protection of Vertebrate Animals… (1986) and Law of Ukraine No. 249 (2012).

RESULTS AND DISCUSSION

Results of determining the hygroscopic properties of bedding samples using TPD MS. At the first stage of the research, the hygroscopic properties of the bedding were determined (Table 2). In the first control room, the moisture content of the straw bedding increased by 38.76% on the seventh day, 81.07% on the fourteenth ($P < 0.05$), 111.76% on the twenty-first, 140.07% on the twenty-eighth, 205.78% on the thirty-fifth, and 269.90% on the forty-second, compared to the beginning of the experiment.

Table 2. *Moisture content in different types of bedding of control rooms, M ± m, n = 5*

Bedding type	Hygroscopic property, %						
	Start of the experiment	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42 end of the experiment
1C straw	15.22 ± 0.06	21.12 ± 0.09	27.56 ± 1.12*	32.23 ± 1.16*	36.54 ± 1.20*	46.54 ± 3.21*	56.30 ± 3.35*
2C wood shavings	15.35 ± 0.04	19.42 ± 0.08	24.18 ± 1.10*	26.48 ± 1.15*	32.25 ± 1.13*	39.12 ± 2.14*	43.48 ± 3.36*
3C granule	10.14 ± 0.07	12.10 ± 0.06	16.14 ± 0.03	20.35 ± 1.34*	24.76 ± 1.17*	30.23 ± 1.15*	33.18 ± 2.20*

Note: **P < 0.05 – results are significant compared to the start of the experiment*
Source: *developed by the authors*

Straw bedding has a sufficient level of water absorption capacity for the first two weeks. However, with prolonged use, even with the periodic addition of fresh straw, the moisture content increases severalfold. In the control room with wood shavings, the hygroscopic property of the bedding increased by 26.51% on the seventh day, 57.52% on the fourteenth (*P < 0.05), 72.50% on the twenty-first, 110.09% on the twenty-eighth, 154.85% on the thirty-fifth, and 183.25% on the forty-second. Wood shavings, as bedding, demonstrate a higher water absorption capacity compared to straw.

In the case of granulated bedding, the hygroscopic properties gradually deteriorated by 19.32% on the seventh day, 59.17% on the fourteenth (*P < 0.05), 100.69% on the twenty-first, 144.18% on the twenty-eighth, 198.12% on the thirty-fifth, and 227.21% on the forty-second, compared to the initial value. In the experimental rooms, where a dry powdered disinfectant was added twice a week, the moisture-retention capacity of the bedding decreased relatively slowly compared to the control rooms (Table 3).

Table 3. *Moisture content in different types of bedding in the experimental rooms, M ± m, n = 5*

Bedding type	Hygroscopic property, %						
	Start of the experiment	Day 7	Day 14	Day 21	Day 28	Day 35	Day 42 end of the experiment
1E straw	15.19 ± 0.04	18.43 ± 0.08	20.26 ± 0.15	22.45 ± 0.22	26.13 ± 1.22*	27.43 ± 1.25*	28.36 ± 1.35*
2E wood shavings	15.18 ± 0.05	17.40 ± 0.07	18.22 ± 0.14	20.07 ± 0.19	22.25 ± 1.13*	25.12 ± 1.34*	27.39 ± 1.36*
3E granule	10.34 ± 0.04	11.15 ± 0.05	12.09 ± 0.19	13.22 ± 0.21	14.05 ± 1.15*	15.45 ± 1.23*	18.29 ± 1.32*

Note: **P < 0.05 – results are significant compared to the start of the experiment*
Source: *developed by the authors*

In the experimental room with straw bedding, humidity increased by 21.32% on the seventh day, 33.37% on the fourteenth, 47.79% on the twenty-first, 72.02% (*P < 0.05) on the twenty-eighth, 80.57% on the thirty-fifth, and 86.70% on the forty-second, compared to the beginning of the experiment. Straw with the addition of a powdered disinfectant loses its hygroscopic properties twice as slowly as the control.

In the second experimental room, the bedding lost its water absorption capacity by 14.62% on the seventh day, 20.02% on the fourteenth, 32.21% on the twenty-first, 46.57% (*P < 0.05) on the twenty-eighth, 65.48%

on the thirty-fifth, and 80.43% on the forty-second. In the room where shavings with added disinfectant were used as bedding, the increase in moisture occurred more slowly than in the control and straw. The hygroscopic properties of the bedding in the third experimental room decreased by 7.83% on the seventh day, 16.92% on the fourteenth, 30.37% on the twenty-first, 35.88% (*P < 0.05) on the twenty-eighth, 49.41% on the thirty-fifth and 76.88% on the forty-second, compared to the beginning of the experiment. The water absorption capacity of the granulated bedding with added disinfectant was maintained at a high level for almost the entire experimental period, compared to other types of bedding.

Results of bedding pH determination. The average pH value of the bedding on the fourteenth day increased in 1C by 5.30%, in 2C by 3.92%, and in 3C by 5.69% compared to the seventh day (Fig. 2).

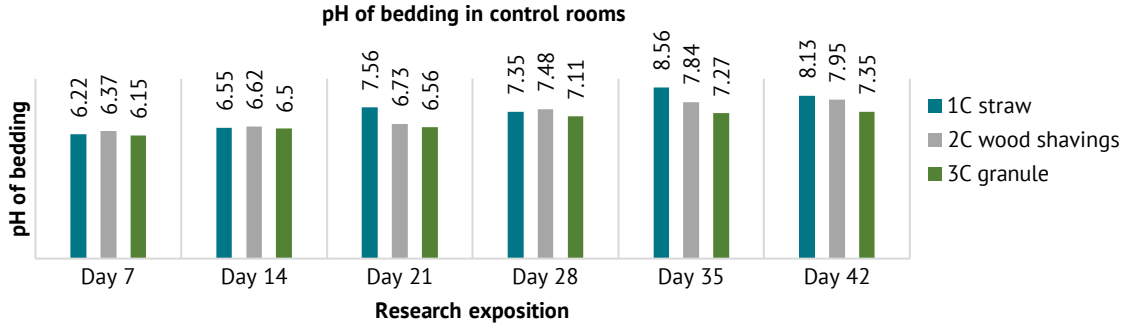

Figure 2*. pH of bedding in control rooms for keeping poultry on deep bedding of different types*
Source: *developed by the authors*

By the twenty-first day of the experiment, the pH of the bedding increased by 21.54% in 1C, 5.65% in 2C, and 6.66% in 3C. The pH value on the twenty-eighth day increased by 18.16% in the first control room, 17.42% in the second, and 15.60% in the third. The pH values in all types of bedding gradually shifted towards the alkaline side, which led to an increase in the spectrum of microorganisms.

The average pH of the bedding on the thirty-fifth day of the experiment increased by 37.62% in the first experimental room, 23.07% in the second, and 18.21% in the third. At the end of the experiment, the pH of the bedding had increased by 30.70% in 1C, 24.80% in 2C, and 19.51% in 3C. Granulated bedding had the lowest average pH on the forty-second day compared to straw and shavings. In experimental rooms where a powdered disinfectant was added to the bedding in the presence of poultry, the pH tended to increase throughout the experiment (Fig. 3).

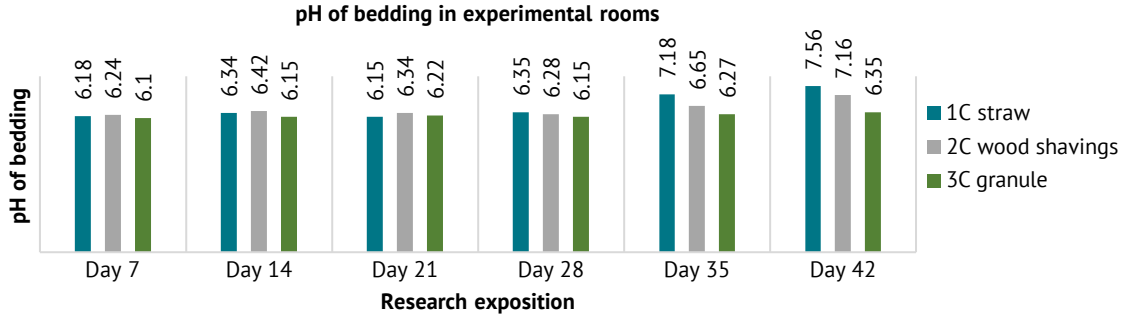

Figure 3*. pH of bedding in experimental rooms for keeping poultry on deep bedding of different types*
Source: *developed by the authors*

By the fourteenth day of the experiment, the pH of the bedding increased by 2.58% in the first experimental room, 2.88% in the second, and 0.81% in the third, compared to the seventh day. The pH value on the twenty-first day decreased by 0.48% in the first room, increased by 1.60% in the second, and 1.96% in the third. The addition of disinfectant to the bedding slowed down the shift of pH towards the alkaline side. On the twenty-eighth day, the pH increased by 2.75% in 1E, 0.64% in 2E, and 0.81% in 3E. The average pH on the thirty-fifth day increased by 16.18% in the first room, 6.57% in the second, and 2.78% in the third. At the end of the experiment, the pH had increased by 22.33% in the first experimental room, 14.74% in the second, and 4.09% in the third. On the forty-second day, the pH of the granulated bedding with added powdered dry disinfectant had hardly increased.

Results of the study of bedding contamination by microorganisms and Eimeria. In the poultry house, as a result of prolonged use, the bedding became soaked with moisture and faeces. A large number of microorganisms harmful to poultry also accumulated in the room. During the experiment, the accumulation of microflora in different types of bedding was determined (Figs. 4-10). In the straw bedding of the control room, the content of *Escherichia coli* increased by 18.72% on the fourteenth day, 31.84% on the twenty-first, 49.76% on the twenty-eighth, 99.2% on the thirty-fifth, and 146.88% on the forty-second, compared to the seventh day of the study (Fig. 4).

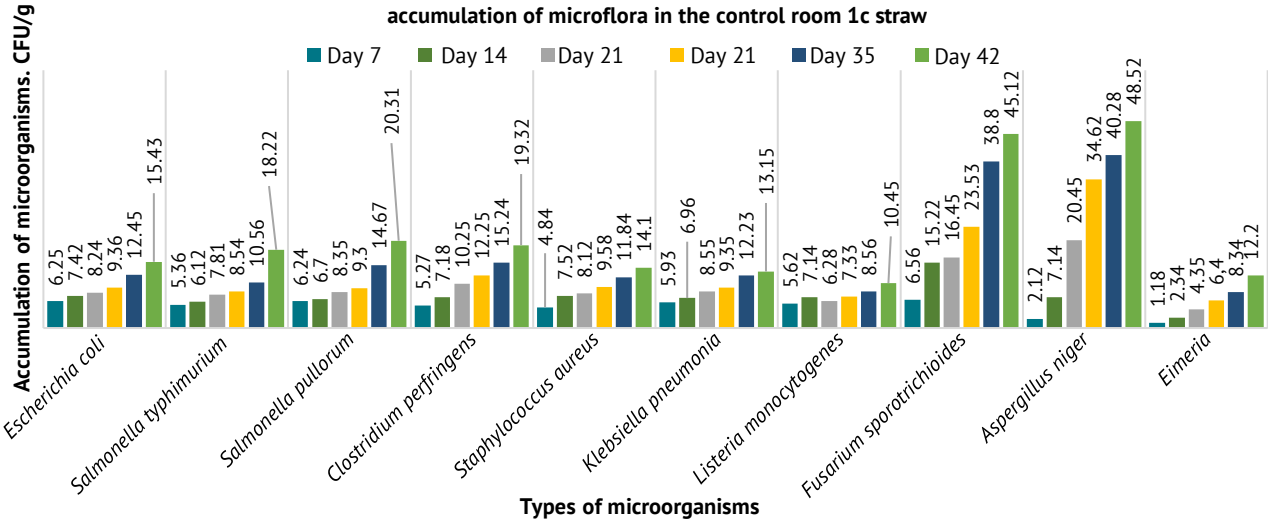

Figure 4*. Accumulation of microorganisms in the control room with straw bedding*
Source: *developed by the authors*

The concentration of *Salmonella typhimurium* increased by 14.17% on the fourteenth day, 45.70% on the twenty-first day, 59.32% on the twenty-eighth day, 97.01% on the thirty-fifth day, and 239.92% on the forty-second day. After the twenty-first day, the number of intestinal microorganisms in the straw bedding increased by nearly 50%. Specifically, the concentration of *Salmonella pullorum* increased by 7.37% on the fourteenth day, 33.81% on the twenty-first day, 49.03% on the twenty-eighth day, 135.09% on the thirty-fifth day, and 225.48% on the forty-second day. On the fourteenth day of the experiment, the concentration of *Clostridium perfringens* increased by 36.24%, 94.49% on the twenty-first day, 132.44% on the twenty-eighth day, 189.18% on the thirty-fifth day, and 266.60% on the forty-second day.

The concentration of *Staphylococcus aureus* increased by 55.37% on the fourteenth day, 67.76% on the twenty-first day, 97.93% on the twenty-eighth day, 144.62% on the thirty-fifth day, and 191.32% on the forty-second day. The accumulation of *Klebsiella pneumoniae* increased by 17.36% on the fourteenth day, 44.18% on the twenty-first day, 57.67% on the twenty-eighth day, 106.23% on the thirty-fifth day, and 121.75% on the forty-second day. The microbial count of *Listeria monocytogenes* increased by 27.04% on the fourteenth day, 11.74% on the twenty-first day, 23.60% on the twenty-eighth day, 52.31% on the thirty-fifth day, and 85.94% on the forty-second day.

Microscopic fungi thrive in the moist environment of straw bedding (Fig. 5). Spores of the fungus *Fusarium sporotrichioides* enter the bedding in two ways: through feed and in untreated straw. The concentration of *Fusarium sporotrichioides* increased by 132.0% on the fourteenth day, 150.76% on the twenty-first day, 258.68% on the twenty-eighth day, 491.46% on the thirty-fifth day, and 711.51% on the forty-second day. With a significant accumulation of microscopic fungi in the bedding, it becomes a hazardous source of spores that can infect poultry, leading to disease and mortality. The growth of *Aspergillus niger* colonies increased by 236.79% on the fourteenth day, 864.62% on the twenty-first day, 1,533.01% on the twenty-eighth day, 1,800% on the thirty-fifth day, and 2,174.52% on the forty-second day.

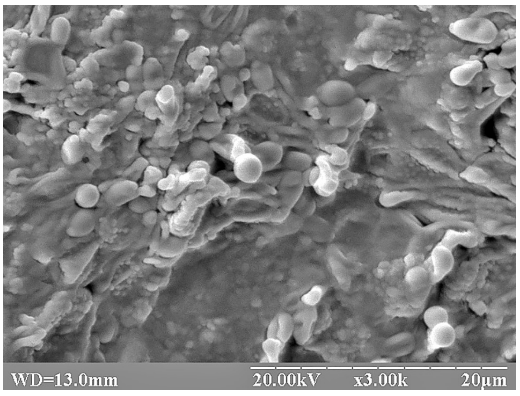

Figure 5*. Scanning electron microscope image of microscopic fungal colonies in a sample of straw bedding*
Source: *developed by the authors*

Infected birds release *Eimeria* oocysts into the bedding along with their faeces, which leads to the disease known as coccidiosis. On the fourteenth day, the number of *Eimeria* oocysts had increased by 98.30%, 268.64% on the twenty-first day, 442.37% on the twenty-eighth day, 606.77% on the thirty-fifth day, and by 933.89% on the forty-second day. In the control room with wood shavings bedding, the amount of *Escherichia coli* increased by 40.36% on the fourteenth day, 61.69% on the twenty-first day, 88.07% on the twenty-eighth day, 109.86% on the thirty-fifth day, and 132.56% on the forty-second day, compared to the start of the experiment (Fig. 6).

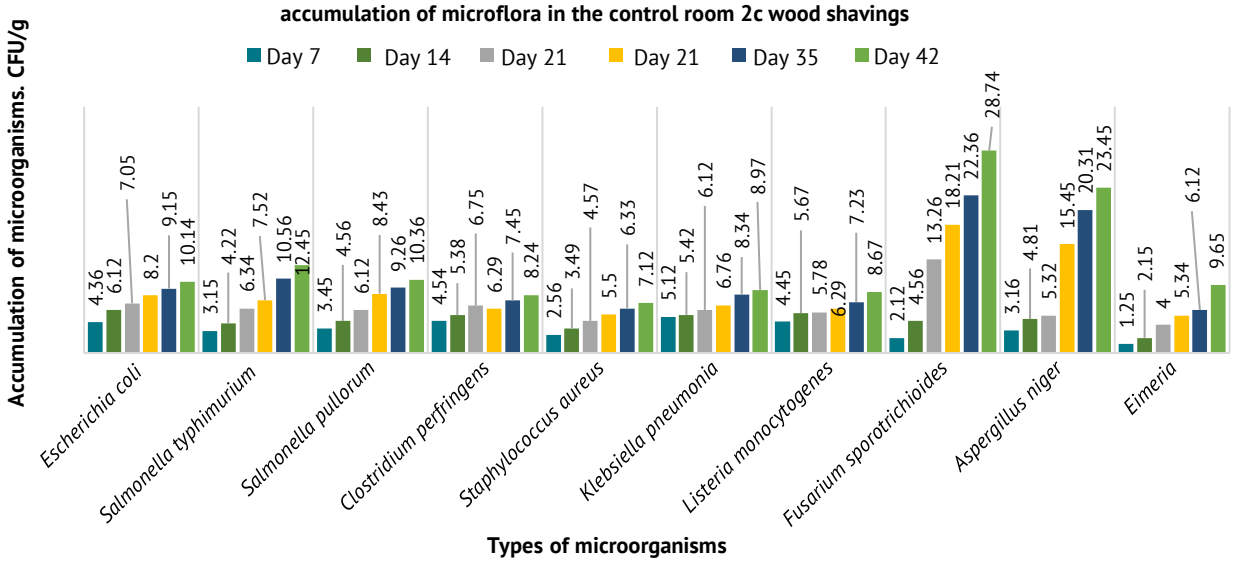

***Figure 6**. Accumulation of microorganisms in the control room with wood shaving bedding*
***Source:** developed by the authors*

In the second control room, the level of *Salmonella typhimurium* increased by 33.96% on the fourteenth day, 101.26% on the twenty-first day, 138.73% on the twenty-eighth day, 235.23% on the thirty-fifth day, and 295.23% on the forty-second day. The accumulation of *Salmonella pullorum* in the wood shavings bedding increased by 32.17% on the fourteenth day, 77.39% on the twenty-first day, 144.34% on the twenty-eighth day, 168.40% on the thirty-fifth day, and 200.28% on the forty-second day, compared to the seventh day. Thus, on the twenty-first day of the study, there was a rapid increase in the number of colonies of intestinal microflora (*E. coli* and *Salmonella*) in the wood shavings bedding.

The content of *Clostridium perfringens* increased by 18.50% on the fourteenth day of exposure, 48.67% on the twenty-first day, 38.54% on the twenty-eighth day, 64.09% on the thirty-fifth day, and 81.49% on the forty-second day. On the fourteenth day, *Staphylococcus aureus* had increased by 36.32%, 78.51% on the twenty-first day, 114.84% on the twenty-eighth day, 147.26% on the thirty-fifth day, and 178.12% on the forty-second day. Results indicated that colonies of *Klebsiella pneumoniae* and *Clostridium perfringens* constituted a relatively small percentage throughout the study period in the wood shavings bedding. On the fourteenth day of the experiment, the level of *Klebsiella pneumoniae* had increased by 5.85%, 19.53% on the twenty-first day, 32.03% on the twenty-eighth day, 62.89% on the thirty-fifth day, and 75.19% on the forty-second day. The content of *Listeria monocytogenes* increased by 27.41% on the fourteenth day, 29.88% on the twenty-first, 41.34% on the twenty-eighth, 62.47% on the thirty-fifth, and 94.83% on the forty-second. The growth of the microscopic fungus *Fusarium sporotrichioides* showed a tendency to increase by 115.09% on the fourteenth day, 525.47% on the twenty-first, 758.96% on the twenty-eighth, 954.71% on the thirty-fifth, and 1,355.66% on the forty-second. Even though wood shavings are a mixture of deciduous and coniferous wood species, which contain resins and essential oils, the number of microscopic fungi increased by a thousand per cent by the end of the experiment. The content of *Aspergillus niger* increased by 52.21% on the fourteenth day, 68.35% on the twenty-first, 388.92% on the twenty-eighth, 542.72% on the thirty-fifth, and 642.08% on the forty-second. The number of *Eimeria* oocysts in the wood shavings increased by 72.0% on the fourteenth day, 220.0% on the twenty-first, 327.2% on the twenty-eighth, 389.6% on the thirty-fifth, and 672.0% on the forty-second, compared to the initial values.

Despite heat treatment of the wood shavings before use as bedding, the number of bacteria, microscopic fungi, and coccidia oocysts was very high. The accumulation of microorganisms in granulated bedding in the third experimental room over a period of forty-two days was also determined (Fig. 7).

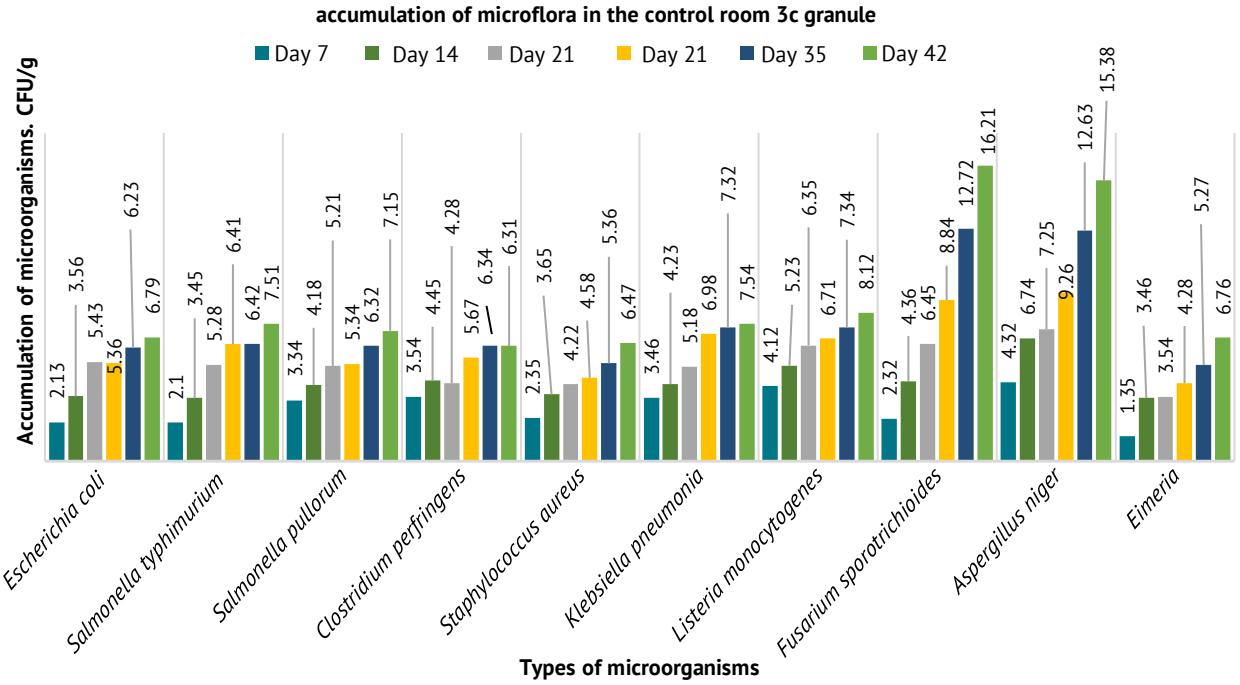

***Figure 7**. Accumulation of microorganisms in the control room with granulated bedding*
***Source:** developed by the authors*

By the fourteenth day of the experiment, the content of *Escherichia coli* had increased by 67.13%, 154.92% on the twenty-first, 151.64% on the twenty-eighth, 192.48% on the thirty-fifth, and 218.77% on the forty-second, compared to the beginning. The content of *Salmonella typhimurium* increased by 64.28% on the fourteenth day, 151.42% on the twenty-first, 205.23% on the twenty-eighth, 205.71% on the thirty-fifth, and 257.61% on the forty-second. At the same time, the number of *Salmonella pullorum* microbial cells in the granulated bedding increased by 25.14% on the fourteenth day, 55.98% on the twenty-first, 59.88% on the twenty-eighth, 89.22% on the thirty-fifth, and 114.07% on the forty-second. At the end of the experiment, the content of intestinal bacteria in the granulated bedding was lower compared to straw and wood shavings.

By the fourteenth day of exposure, the content of *Clostridium perfringens* increased by 25.70%, 20.90% on the twenty-first, 60.16% on the twenty-eighth, 79.09% on the thirty-fifth, and 78.24% on the forty-second. The content of *Staphylococcus aureus* increased by 55.31% on the fourteenth day, 79.57% on the twenty-first, 94.89% on the twenty-eighth, 128.08% on the thirty-fifth, and 175.31% on the forty-second. The accumulation of *Klebsiella pneumoniae* occurred by 22.25% on the fourteenth day, 54.1271% on the twenty-first, 101.73% on the twenty-eighth, 111.56% on the thirty-fifth, and 117.91% on the forty-second.

In the third experimental room, the content of *Listeria monocytogenes* increased by 26.94% on the fourteenth day, 54.12% on the twenty-first, 62.86% on the twenty-eighth, 78.15% on the thirty-fifth, and 97.08% on the forty-second. The growth of microscopic fungi in the granulated bedding was lower compared to straw and wood shavings throughout the experiment. The quantity of *Fusarium sporotrichioides* increased by 87.93% on the fourteenth day, 178.01% on the twenty-first, 281.03% on the twenty-eighth, 448.27% on the thirty-fifth, and 598.7% on the forty-second. The content of *Aspergillus niger* increased by 56.01% on the fourteenth day, 67.82% on the twenty-first, 114.35% on the twenty-eighth, 192.36% on the thirty-fifth, and 256.01% on the forty-second.

The quantity of *Eimeria* oocysts in the granulated bedding increased by 156.29% on the fourteenth day, 162.22% on the twenty-first, 217.03% on the twenty-eighth, 290.37% on the thirty-fifth, and 400.74% on the forty-second compared to the beginning of the study. A similar room with straw bedding but with the addition of a dry disinfectant was studied for the content of microorganisms over a period of forty-two days (Fig. 8).

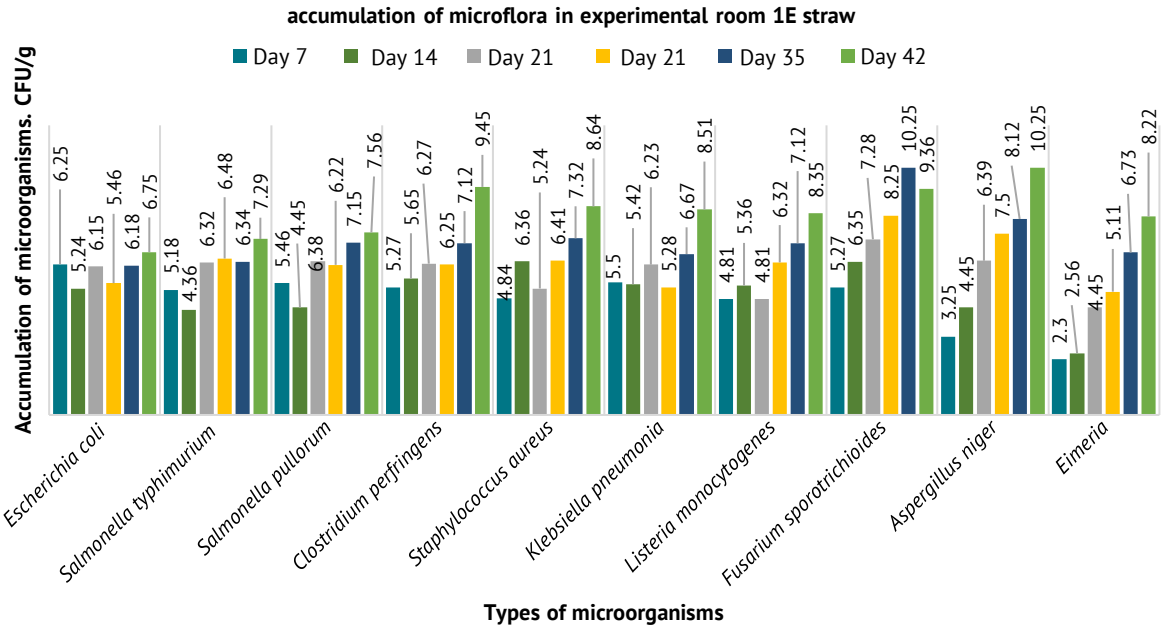

***Figure 8**. Accumulation of microorganisms in the experimental room with straw bedding*
***Source:** developed by the authors*

By the fourteenth day of the experiment, the content of *Escherichia coli* decreased by 16.16%, 1.6% on the twenty-firs, 12.64% on the twenty-eighth, 1.12% on the thirty-fifth, and increased by 8.0% on the forty-second compared to the beginning. However, the level of accumulation of *E. coli* in the control room with straw bedding was 146.88%. The quantity of *Salmonella typhimurium* decreased by 15.83% on the fourteenth day, increased by 22.00% on the twenty-first, 25.09% on the twenty-eighth, 22.39% on the thirty-fifth, and 40.73% on the forty-second (versus 239.92% in the control). Similarly, the content of *Salmonella pullorum* decreased by 18.49% on the fourteenth day, increased by 16.84% on the twenty-first, 13.91% on the twenty-eighth, 30.95% on the thirty-fifth, and 38.46% on the forty-second. For comparison, in the first control room, the content of *Salmonella pullorum* increased by 225.48% at the end of the experiment.

By the fourteenth day of the experiment, the content of *Clostridium perfringens* increased by 7.21%, 18.97% on the twenty-first, 18.59% on the twenty-eighth, 35.10% on the thirty-fifth, and 79.31% on the forty-second (compared to 266.60% in the control). The content of *Staphylococcus aureus* increased by 31.40% on the fourteenth day, 8.26% on the twenty-first, 32.43% on the twenty-eighth, 32.43% on the thirty-fifth, and 78.51% on the forty-second (compared to 191.32% in 1C). The level of *Klebsiella pneumoniae* decreased by 1.45% on the fourteenth day and 4.0% on the twenty-eighth, increased by 13.27% on the twenty-first, 21.27% on the thirty-fifth, and 54.72% on the forty-second (compared to 121.75% in 1C). By the fourteenth day, the content of *Listeria monocytogenes* increased by 11.43%, but returned to the initial values by the twenty-first day, however, on the twenty-eighth it increased again by 19.92%, 35.10% on the thirty-fifth, and 73.59% on the forty-second (as opposed to 85.94% in the control).

The growth of the microscopic fungus *Fusarium sporotrichioides* increased by 20.49% on the fourteenth day, 38.14% on the twenty-first, 56.54% on the twenty-eighth, 94.49% on the thirty-fifth, and 77.60% on the forty-second, compared to 711.51% in the control. The content of *Aspergillus niger* increased by 36.92% on the fourteenth day, 96.61% on the twenty-first, 130.76% on the twenty-eighth, 149.84% on the thirty-fifth, and 215.38% on the forty-second (versus 2,174.52% in 1C). The addition of a dry disinfectant to the bedding also affected the reduction in the number of oocysts in the straw bedding. The content of *Eimeria* oocysts increased by 11.30% on the fourteenth day, 93.47% on the twenty-first, 122.17% on the twenty-eighth, 192.60% on the thirty-fifth, and 257.39% on the forty-second, compared to 933.89% in the control. The microflora in the second experimental room with wood shavings bedding and the addition of an experimental dry powdered disinfectant was monitored (Fig. 9).

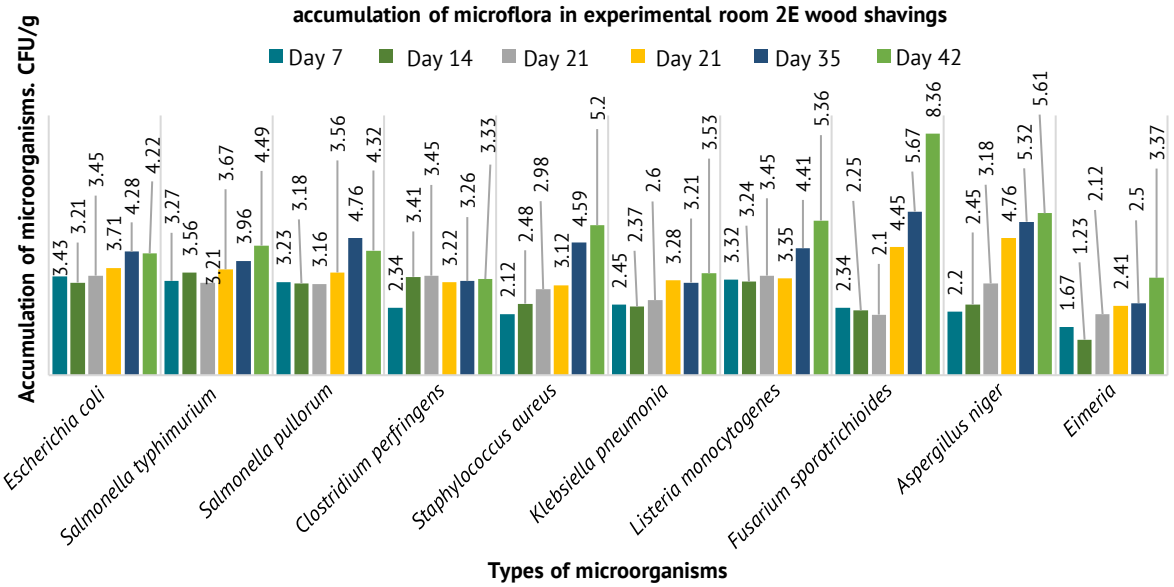

***Figure 9**. Accumulation of microorganisms in the experimental room with wood shavings bedding*
***Source:** developed by the authors*

By the fourteenth day, the content of *Escherichia coli* decreased by 6.41%, returned to the initial values on the twenty-first, increased by 8.16% on the twenty-eighth, 24.78% on the thirty-fifth, and 23.03% on the forty-second (compared to 132.56% in 2C). In the second experimental room, the content of *Salmonella typhimurium* increased by 8.86% on the fourteenth day, decreased by 1.83% on the twenty-first, and increased by 12.23% on the twenty-eighth, 21.10% on the thirty-fifth, and 37.30% on the forty-second, compared to 295.23% in the second control. The content of *Salmonella pullorum* remained at the same level on the fourteenth, twenty-first, and twenty-eighth days, increased by 47.36% on the thirty-fifth, and 33.74% on the forty-second, compared to 200.28% in 2C.

The results obtained show that the levels of *E. coli* and *Salmonella* decreased when a dry disinfectant was added to the wood shavings bedding. The level of *Clostridium perfringens* gradually increased by 45.72% on the fourteenth day, 47.43% on the twenty-first, 37.60% on the twenty-eighth, 39.31% on the thirty-fifth, and 42.30% on the forty-second, compared to 81.49%. The content of *Staphylococcus aureus* increased by 16.98% on the fourteenth day, 40.56% on the twenty-first, 47.16% on the twenty-eighth, 116.50% on the thirty-fifth, and 145.28% on the forty-second, compared to 178.12% in the second control. By the fourteenth day of the experiment, the content of *Klebsiella pneumoniae* decreased by 3.26%, increased by 6.12% on the twenty-first, 33.87% on the twenty-eighth, 31.02% on the thirty-fifth, and 44.08% on the forty-second (versus 75.19% in 2C). By the fourteenth day, the accumulation of *Listeria monocytogenes* decreased by 2.40%, increased by 3.91% on the twenty-first, 0.90% on the twenty-eighth, 32.83% on the thirty-fifth, and 61.44% on the forty-second, compared to 94.83% in 2C. When using a disinfectant, the content of *Fusarium sporotrichioides* decreased by 3.84% on the fourteenth day, 10.25% on the twenty-first, increased by 90.17% on the twenty-eighth, 142.30% on the thirty-fifth, and 257.26% on the forty-second, compared to 1,355.66% in the second control. The quantity of *Aspergillus niger* gradually increased by 11.36% on the fourteenth day, 44.54% on the twenty-first, 116.36% on the twenty-eighth, 49.06% on the thirty-fifth, and 155.00% on the forty-second (versus 642.08% in the control).

The content of *Eimeria* oocysts in the wood shavings bedding decreased by 26.34% on the fourteenth day, increased by 26.94% on the twenty-first, 44.31% on the twenty-eighth, 49.70% on the thirty-fifth, and 101.79% on the forty-second, compared to 672.0% in the second control. The use of a dry disinfectant in the bedding reduced the level of *Eimeria* oocysts in the wood shavings bedding. In the third experimental room with granulated bedding and the addition of a disinfectant, the content of *Escherichia coli* decreased by 2.24% on the fourteenth day, increased by 7.17% on the twenty-first, 14.79% on the twenty-eighth, 39.91% on the thirty-fifth, and 43.94% on the forty-second (compared to 218.77% in 3C) (Fig. 10).

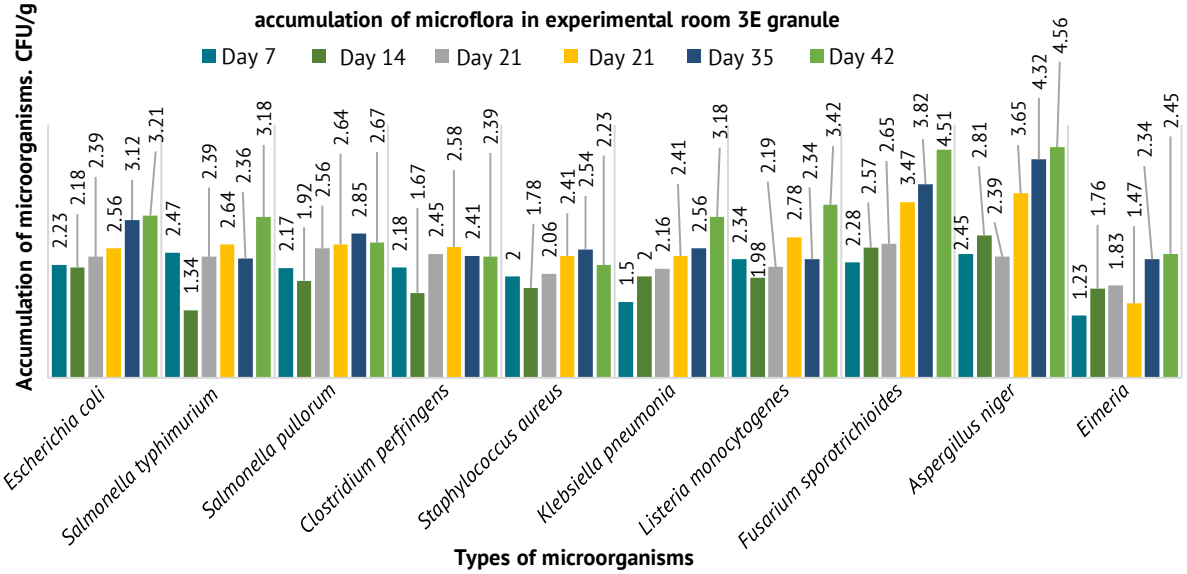

***Figure 9**. Accumulation of microorganisms in the experimental room with wood shavings bedding*
***Source:** developed by the authors*

The content of *Salmonella typhimurium* decreased by 45.74% on the fourteenth day, 3.23% on the twenty-first, and 4.45% on the thirty-fifth, but increased by 6.88% on the twenty-eighth and 28.74% on the forty-second, compared to 257.61% in the control. The quantity of Salmonella pullorum decreased by 11.52% on the fourteenth day but increased by 17.97% on the twenty-first, 21.65% on the twenty-eighth, 31.33% on the thirty-fifth, and 19.81% on the forty-second, compared to 114.07% in the control. The content of *Clostridium perfringens* increased by 23.39% after fourteen days of exposure, 12.38% on the twenty-first, 18.34% on the twenty-eighth, 10.55% on the thirty-fifth, and 9.63% on the forty-second (versus 78.24% in 3C). A decrease in *Staphylococcus aureus* was observed on the fourteenth day by 11.00%, but it increased by 3.00% on the twenty-first, 29.00% on the twenty-eighth, 20.5% on the thirty-fifth, and 11.5% on the forty-second, compared to 175.31% in the third control room.

Accumulation of *Klebsiella pneumoniae* increased by 33.33% on the fourteenth day, 44.00% on the twenty-first, 60.67% on the twenty-eighth, 70.66% on the thirty-fifth, and 112.00% on the forty-second, compared to 117.91% in the granule control. The content of *Listeria monocytogenes* decreased by 15.38% on the fourteenth day and 6.41% on the twenty-first, but increased by 18.80% on the twenty-eighth, returned to initial values on the thirty-fifth, and increased by 46.15% on the forty-second, versus 97.08% in the control. The quantity of *Fusarium sporotrichioides* increased by 12.71% on the fourteenth day, 16.22% on the twenty-first, 52.19% on the twenty-eighth, 67.54% on the thirty-fifth, and 97.80% on the forty-second, compared to 598.7% in the third control. The content of *Aspergillus niger* decreased by 2.44% on the twenty-first day, but increased by 14.69% on the fourteenth, 48.97% on the twenty-eighth, 76.32% on the thirty-fifth, and 86.12% on the forty-second, compared to 256.01% in the control. The quantity of *Eimeria* oocysts in granulated bedding with the added dry disinfectant increased by 43.08% on the fourteenth day, 48.78% on the twenty-first, 19.51% on the twenty-eighth, 90.24% on the thirty-fifth, and 99.18% on the forty-second (versus 400.74% in the control). The results of this experiment demonstrate that the application of a dry powdered disinfectant contributes to a reduction in the number of microorganisms in straw, wood shavings, and granulated bedding.

The research found that the hygroscopic properties of straw bedding deteriorated from the seventh to the forty-second day, reaching 269.90%. In the experimental room where a dry disinfectant was added to the straw bedding, the hygroscopicity at the end of the experiment was 86.70%, a difference of 183.2%. Wood shavings bedding with the addition of a disinfectant exhibited a water absorption capacity of 102.82% more on the forty-second day compared to the control. Granulated bedding with a disinfectant retained moisture 150.33% better compared to the control. The obtained results of the water absorption capacity of the bedding materials coincide with the findings of P. Gerber *et al.* (2020).

Research by A. Gutierrez and K. Schneider (2022) demonstrates that prolonged use of wet bedding leads to avian diseases such as contact dermatitis, intestinal infections, and reduced feed conversion. It was established that the addition of a dry powdered disinfectant inhibited the increase in bedding pH. At the end of the experiment, the pH levels in straw bedding were 8.13 in the control group compared to 7.56 in the experimental group; in wood shavings, 7.95 versus 7.16; and in granules, 7.35 versus 6.35. The results obtained show low pH levels for all bedding types at the beginning of the study and an increase at the end. The optimal pH range for bacterial growth is 6-8. Without the use of a disinfectant, the growth and multiplication of microorganisms in the bedding under favourable conditions of high humidity and neutral pH will increase. Similar results were obtained in studies by M.J. Rothrock *et al.* (2017) with rye straw bedding for poultry.

The contamination of straw bedding with *Escherichia coli* at the end of the experiment was reduced by 138.88% in the experimental group, *Salmonella typhimurium* by 199.19%, *Salmonella pullorum* by 187.02%, *Clostridium perfringens* by 187.29%, *Staphylococcus aureus* by 112.81% #, *Klebsiella pneumoniae* by 67.03%, *Listeria monocytogenes* by 12.35%, *Fusarium sporotrichioides* by 633.91%, *Aspergillus niger* by 1,959.14%, and *Eimeria* by 676.50% due to the use of a disinfectant. The obtained results coincide with the data of D. Milanov *et al.* (2019)when studying the accumulation of microflora in poultry manure and bedding.

On the forty-second day of the experiment, the levels of *Escherichia coli* in wood shavings bedding were reduced by 109.53% in the disinfectant-treated group, *Salmonella typhimurium* by 257.93%, *Salmonella pullorum* by 166.54%, *Clostridium perfringens* by 39.19%, *Staphylococcus aureus* by 32.84%, *Klebsiella pneumoniae* by 31.11%, *Listeria monocytogenes* by 33.39%, *Fusarium sporotrichioides* by 1098.4%, *Aspergillus niger* by 487.08%, and *Eimeria* by 570.21%. The trend of microbial accumulation, shown in the research of S. Winkler *et al.* (2017), coincides with the data obtained in this study. In all types of bedding, the majority of bacteria consisted of *E. coli* and *Salmonella* (Bindari *et al.,* 2021). The conducted studies have proven the rapid accumulation of microscopic fungi in the bedding. As established by researchers Y. Wang *et al.* (2020), fungi of the genus *Fusarium* affect cereal crops and cause toxicosis in animals and humans. Studies by J. Chu *et al.* (2017) have shown that microscopic fungi of the genus *Aspergillus* lead to severe pneumonia in poultry. The accumulation of *Escherichia coli* in granulated bedding was reduced by 174.83% in the disinfectant-treated group at the end of the experiment, *Salmonella typhimurium* by 228.87%, *Salmonella pullorum* was 94.26% lower, *Clostridium perfringens* was 68.61% lower, *Staphylococcus aureus* by 163.81%, *Klebsiella pneumoniae* by 5.91%, *Listeria monocytogenes* by 50.93%, *Fusarium sporotrichioides* by 500.9%, *Aspergillus niger* by 169.89%, and *Eimeria* by 301.56%.

In the experiment conducted by C. Mesa *et al.* (2021), bedding samples were analysed to determine the level of contamination with *Eimeria* oocysts on broiler farms. The studies revealed a significant concentration of *Eimeria* oocysts in various types of bedding, despite the use of coccidiostats in poultry. As a result of the experiment, the physical properties of different types of poultry bedding and the spectrum and trend of microbial accumulation were determined. Additionally, the effectiveness of using a dry powdered disinfectant to kill microorganisms and *Eimeria* oocysts was proven.

CONCLUSIONS

It was found that the addition of dry powdered disinfectant improved the hygroscopic properties of straw bedding by 183.2%, wood shavings by 102.82%, and granules by 150.33%. At the end of the experiment, the pH levels in straw bedding were 8.13 in the control group compared to 7.56 in the treated group; in wood shavings, 7.95 versus 7.16; and in granules, 7.35 versus 6.35, due to the use of the disinfectant. Additionally, by the end of the experiment, the levels of *Escherichia coli* in straw bedding were reduced by 138.88% with disinfectant use, *Salmonella typhimurium* by 199.19%, *Salmonella pullorum* by 187.02%, *Clostridium perfringens* by 187.29%, *Staphylococcus aureus* by 112.81%, *Klebsiella pneumoniae* by 67.03%, *Listeria monocytogenes* by 12.35%, *Fusarium sporotrichioides* by 633.91%, *Aspergillus niger* by 1959.14%, and *Eimeria* by 676.50%.

In the wood shavings bedding, the content of *Escherichia coli* was reduced by 109.53% in the experimental group with disinfectant, *Salmonella typhimurium* by 257.93%, *Salmonella pullorum* by 166.54%, *Clostridium perfringens* by 39.19%, *Staphylococcus aureus* by 32.84%, *Klebsiella pneumoniae* by 31.11%, *Listeria monocytogenes* by 33.39%, *Fusarium sporotrichioides* by 1,098.4%, *Aspergillus niger* by 487.08%, and *Eimeria* by 570.21%. The study also showed that the concentration of *Escherichia coli* in granulated bedding at the end of the experiment was lower by 174.83%, *Salmonella typhimurium* by 228.87%, *Salmonella pullorum* by 94.26%, *Clostridium perfringens* by 68.61%, *Staphylococcus aureus* by 163.81%, *Klebsiella pneumoniae* by 5.91%, *Listeria monocytogenes* by 50.93%, *Fusarium sporotrichioides* by 500.9%, *Aspergillus niger* by 169.89%, and *Eimeria* by 301.56%. Future research should focus on determining the quality of bedding for poultry rearing under production conditions.

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significant bacterial diseases of animals on the basis of use of innovative technologies".

CONFLICT OF INTEREST

None.

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Особливості вирощування птиці підлоговим способом на глибокій підстилці

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Анотація. При утриманні птиці на глибокій підстилці в ній розвиваються мікроорганізми, які є збудниками інфекційних захворювань. Метою дослідження було визначити фізичні властивості та здатність накопичення мікроорганізмів у різних типах підстилки. Використані методи: термопрограмована мас-спектрометрія; мікробіологічний метод; сканувальна електронна мікроскопія. Гігроскопічні властивості солом'яної підстилки погіршувались з сьомої до сорок другої доби на 269,90 %. У дослідному приміщенні, де до солом'яної підстилки додавали сухий дезінфектант гігроскопічність складала на момент завершення експерименту 86,70 % , різниця – 183,2 %. Підстилка стружка за додавання дезінфектанту проявляла водопоглинаючу здатність на сорок другу добу на 102,82 % більше ніж у контролі. Гранульована підстилка з дезінфектантом втримувала вологу на 150,33 % краще, порівняно з контролем. На момент завершення дослідження pH солом'яної підстилки складала у контролі 8,13 проти 7,56 у досліді; стружка – 7,95 проти 7,16; гранула – 7,35 проти 6,35, за рахунок застосування дезінфектанту. Підстилка гранула на період завершення експерименту мала найнижчий показник pH, порівняно з соломою та тирсою, що вплинуло на ріст та розмноження мікроорганізмів. При проведенні моніторингу мікроорганізмів в підстилці були виділені бактерії: *Escherichia coli*, *Salmonella typhimurium, Salmonella pullorum, Clostridium perfringens, Staphylococcus aureus, Klebsiella pneumonia, Listeria monocytogenes,* мікроскопічні гриби: *Fusarium sporotrichioides,Aspergillus niger* та ооцисти *Eimeria.* За використання дезінфектанту ураження солом'яної підстилки бактеріями зменшилось на 12,35-199,19 %, мікроскопічними грибами на 633,91-1959,14 %, *Eimeria* – на 676,50 %. Контамінація підстилки стружка у досліді була менше бактеріями на 32,84-257,93 %, мікроскопічними грибами на 487,08-1098,4 %, *Eimeria* – на 570,21 %. Накопичення у підстилці гранула бактерій було менше на 50,93-228,87 %, мікроскопічних грибів на 169,89-500,9 %, *Eimeria* – на 301,56 %. Практичною цінністю роботи є покращення фізичних властивостей підстилки для птиці та зниження накопичення в ній бактерій, мікроскопічних грибів та ооцист *Eimeria*

Ключові слова: гігроскопічні властивості; pH підстилки; бактерії; мікроскопічні гриби; *Eimeria*

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Formation of immunological memory of salmonella antigens in cows using different phenotypes of T-lymphocyte populations

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Abstract. The study aimed to investigate the formation of immunological memory to Salmonella antigens in cows using different phenotypes of T-lymphocyte populations. The study was conducted on farms in Kazakhstan and Latvia. As part of the study, blood samples were collected from cows vaccinated against Salmonella to analyse T-lymphocyte phenotypes. A comparative study of different phenotypes of T-cell populations, including CD4+, CD8+, γδ T-cells and effector T-cells (CD45RA+

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and CD45RA-), was conducted to assess their role in the formation of immunological memory. Flow cytometry and enzyme-linked immunosorbent assay (ELISA) were used to quantify T-cell populations and levels of specific antibodies. The main results showed that vaccination causes a significant increase in the population of CD4+ and CD8+ T-lymphocytes, which correlates with an increase in the level of specific antibodies to Salmonella antigens. The γδ T-cell population also showed significant activation, indicating their potential role in the formation of an immune response to Salmonella. Particular attention was devoted to effector cells of T-lymphocytes: CD45RA+ cells were actively involved in the primary immune response to Salmonella antigens, while CD45RA cells showed high activity during repeated exposure to the antigen, indicating their key role in maintaining long-term immunological memory. Comparative analysis of data from Kazakhstan and Latvia showed similar trends, indicating the universality of the observed immunological mechanisms. These findings highlight the importance of including different T-cell phenotypes in vaccination programmes to ensure more effective immunological memory in cows. Thus, this study provides valuable data on the role of different T-lymphocyte populations in the formation of immunological memory to Salmonella antigens in cows, which may contribute to the development of more effective vaccine programmes and improve the health and productivity of livestock in the regions of Kazakhstan and Latvia

Keywords: genetic immune response; farmers; T-cell analysis; flow cytometry; vaccine strategies; antibody levels

INTRODUCTION

In recent years, the problem of infectious diseases in farm animals has become increasingly important due to the growing population and the increasing demand for livestock products. Infections caused by pathogens such as salmonella significantly reduce animal productivity, degrade product quality and lead to serious economic losses. In the context of globalisation and the active international exchange of agricultural products, the problem of infectious diseases is becoming even more important. In this regard, the development of effective vaccine strategies aimed at preventing the spread of infections and reducing their negative impact on livestock production was prioritised. These issues were discussed by L.T. Midla *et al.* (2021).

Immunological memory is substantial in protecting the body from repeated infections, ensuring a quick and effective response of the immune system when it is exposed to a pathogen again. For farm animals, such as cows, the development of a robust immune response to pathogens such as Salmonella is critical. Salmonella is one of the most common pathogens causing significant economic losses in livestock production due to disease, reduced productivity and mortality (Mussayeva *et al.*, 2021). These aspects were also addressed by I. Azaldegui *et al.* (2024). In this context, an important aspect is the study of the formation of immunological memory using different phenotypes of T-lymphocyte populations. The need to conduct this study is determined by several important factors. Firstly, infectious diseases caused by Salmonella remain a serious problem in livestock production, leading to significant economic losses and poor animal health (Kirimbayeva *et al.*, 2023). Effective vaccination strategies significantly reduce morbidity and mortality and improve animal productivity. However, the development of such strategies requires a thorough interpretation of the mechanisms of immune response and immunological memory formation in cows, which was also being investigated by A. Facciuolo *et al.* (2020).

Existing research in the field of veterinary immunology has made significant strides in understanding the role of different T-cell populations in the immune response to infectious diseases. For instance, a study by N.N. Jarjour *et al.* (2022) showed that CD4+ and CD8+ T lymphocytes are significant in the adaptive immune response by coordinating the work of other immune cells and destroying infected cells. M.M. Um *et al.* (2022) γδ T cells have been identified as important participants in the early immune response, especially in the recognition and destruction of infected cells. CD45RA+ effector cells and CD45RA- memory cells have been described as key elements in the formation of primary and secondary immune responses, respectively.

Despite significant advances in this field, many unresolved issues remain. One of them is a detailed understanding of the mechanisms of immunological memory to Salmonella antigens in cows. In particular, it is necessary to find out what contribution different phenotypes of T-cell populations (CD4+, CD8+, γδ T-cells) make to the formation of the immune response in cows, how effector T-cells (CD45RA+ and CD45RA-) are activated upon initial and repeated exposure to the antigen, and what are the differences in immune responses in cows in Kazakhstan and Latvia. Regional differences can significantly affect the effectiveness of vaccination, and their consideration is necessary for the development of optimal vaccination strategies. An important aspect of this study is the assessment of regional peculiarities of the immune response in cows. Different geographical regions, such as Western Kazakhstan and Latgale, have different microbiota composition, animal husbandry conditions and prevalence of various pathogens. These factors influence the formation of immune responses and, consequently, the

effectiveness of vaccination. Research aimed at understanding these differences helps to develop adapted vaccine strategies that take into account the specific conditions of each region.

In addition, different phenotypes of T-lymphocyte populations interact differently with Salmonella antigens. CD4+ T-lymphocytes play a key role in coordinating the immune response, ensuring the activation of other immune cells and the production of antibodies. CD8+ T cells are responsible for destroying infected cells and controlling the spread of infection. γδ T cells are involved in the early immune response and can recognise a wide range of antigens, making them important for protection against various pathogens. Effector T lymphocytes (CD45RA+) and memory cells (CD45RA-) provide a rapid and effective response to repeated infections, which is a key element of immunological memory.

MATERIALS AND METHODS

The study was conducted on farms in two regions: Kazakhstan and Latvia. The choice of these regions (Western Kazakhstan and Latgale, respectively) was determined by their difference in climatic conditions and agricultural practices, which can be used to conclude the influence of regional factors on the immune response in cows. To achieve the research objectives, a sample of 200 cows was used, 100 in each region. Animals were randomly selected from different farms to ensure a representative sample. All cows were clinically healthy at the start of the study and had similar housing and feeding conditions. To fulfil the objectives of the study, the livestock was vaccinated, followed by blood sampling for flow cytometry and enzyme-linked immunosorbent analysis, and the results were then subjected to comparative analysis. A commercially available salmonella vaccine was used for the study. The vaccination was carried out according to the standard regimen recommended by the vaccine manufacturer. Blood samples were taken from cows at four-time points: before vaccination (zero), 14 days after vaccination, 28 days and 56 days. Blood samples were collected from the jugular vein using sterile vacutainers.

Immediately after collection, the blood samples were delivered to the laboratory, where they were separated into plasma and cell fractions by centrifugation at 1500 rpm for 10 minutes. Plasma was stored at -20°C for subsequent analysis of antibody levels. The cell fraction was used to analyze the phenotypes of T lymphocytes. Flow cytometry was used to analyse the phenotypes of T lymphocytes (CD4+, CD8+, γδ T cells, CD45RA+ and CD45RA-). The cells were incubated with fluorescently labelled antibodies against the corresponding markers for 30 minutes at room temperature in the dark. After incubation, the cells were washed, resuspended in PBS (phosphate-buffered saline) and analysed on a flow cytometer (BD FACSCalibur). At least 10,000 cells were analysed for each sample and the results were processed using FlowJo software.

This study evaluated the formation of immunological memory in cows in response to vaccination against Salmonella. The study focused on the phenotypes of T-cell populations, including CD4+, CD8+, γδ T-cells and effector cells CD45RA+ and CD45RA-. The study was conducted on farms in Kazakhstan and Latvia. A total of 200 blood samples were collected from cows at different time points: before vaccination, 14 days, 28 days and 56 days after vaccination. Flow cytometry and enzyme-linked immunosorbent assay (ELISA) were used to analyse T-cell populations and levels of specific antibodies. The levels of specific antibodies to Salmonella antigens in plasma were determined by ELISA. The microplates were coated with Salmonella antigen, incubated with diluted plasma samples, and then with a fluorescently labelled secondary antibody. The reaction was visualised using the TMB substrate and the optical density was measured using a spectrophotometer at 450 nm.

The methods of descriptive and inferential statistics were used to process and analyse the data obtained. The t-test (a common name for a class of statistical hypothesis testing methods based on the Student distribution) and ANOVA (analysis of variance) were used to compare the groups, followed by an analysis of the significance of the differences. Data are presented as mean values with standard deviations. The significance of the differences was considered statistically significant at $p < 0.05$. Comparative analyses were conducted between groups of animals from Kazakhstan and Latvia to identify regional differences in immune responses. This analysis included a comparison of the activity levels of different T-cell populations and levels of specific antibodies at different time points. These methods and materials were used to obtain comprehensive and reliable data on the formation of immunological memory to Salmonella antigens in cows. This study provides important data that can be used to optimise vaccine strategies and improve livestock health and productivity in different regions.

RESULTS

Immunological memory plays a key role in protecting the body from repeated infections. It ensures a quick and effective response of the immune system upon repeated exposure to the pathogen. For farm animals, such as cows, the development of a robust immune response to pathogens such as Salmonella is critical. Salmonella is one of the most common pathogens causing significant economic losses in livestock production due to disease, reduced productivity and mortality. In this context, an important aspect is the study of the formation of immunological memory using different phenotypes of T-lymphocyte populations.

T-lymphocytes are central in the adaptive immune response. Among them, effector cells are of particular importance, which can be classified by the expression of the CD45RA marker into effector cells of the first encounter with antigen (CD45RA+) and cells of repeated encounter (CD45RA-). These cells are responsible for the development and maintenance of immunological memory, which allows the body to respond effectively to repeated infections. However, despite significant advances in the study of the immune response in cows, there is still insufficient data on the role of different T-lymphocyte phenotypes in the formation of immunological memory to Salmonella antigens.

In recent years, the problem of infectious diseases in farm animals has become increasingly important due to the growing population and the increasing demand for livestock products. Infections caused by pathogens such as salmonella can significantly reduce animal productivity, degrade product quality and cause serious economic losses. In the context of globalisation and the active international exchange of agricultural products, the problem of infectious diseases is becoming even more important. In this regard, the development of effective vaccine strategies aimed at preventing the spread of infections and reducing their negative impact on livestock production was prioritised.

Immunological memory, a key component of the adaptive immune response, plays an important role in ensuring the long-term protection of animals against infectious diseases. The formation of a stable immunological memory allows the body to respond effectively to repeated infections, reducing the likelihood of their development and severity. Vaccination is one of the most effective methods of forming immunological memory and preventing infectious diseases. However, the effectiveness of vaccination depends on the correct choice and use of vaccines, as well as on understanding the mechanisms of immune response in animals.

Analysis of CD4+ and CD8+ T-lymphocyte populations showed that vaccination caused a significant increase in these cells. Similar trends were observed in Kazakhstan and Latvia: a significant increase in the number of CD4+ and CD8+ T-lymphocytes occurred between days 7 and 45 after vaccination. This confirms that these cells play a key role in the formation of an adaptive immune response. In Kazakhstan and Latvia, there were some differences in the number of these cells, which may be due to differences in environmental conditions and agricultural practices in these regions (Table 1). However, the general trends remained similar, which underlines the universality of immune mechanisms in cows.

***Table 1**. Comparative analysis of CD4+ and CD8+ T-lymphocyte populations in Kazakhstan and Latvia*

Time after vaccination	CD4+ cells (Kazakhstan)	CD4+ cells (Latvia)	CD8+ cells (Kazakhstan)	CD8+ cells (Latvia)
0 days	350	340	280	275
14 days	900	880	700	680
28 days	1,500	1,450	1,200	1,150
56 days	1,400	1,350	1,100	1,050

***Source:** compiled by the authors*

Analysis of γδ T cells showed a significant increase in them after vaccination. These cells are important participants in the immune response, especially in the early stages of infection. The results showed that the vaccination stimulated their activation and increase in numbers in both groups. Studies in other countries have also confirmed the importance of γδ T cells in the early immune response to infection (Table 2). These cells are significant in recognising and destroying infected cells, as well as in activating other components of the immune system.

***Table 2**. Comparative analysis of γδ T-cell populations in Kazakhstan and Latvia*

Time after vaccination	γδ T-cells (Kazakhstan)	γδ T-cells (Latvia)
0 days	100	95
14 days	350	330
28 days	600	570
56 days	550	520

***Source:** compiled by the authors*

CD45RA+ effector cells are indicators of the primary immune response. The results showed that these cells begin to accumulate as early as 7 days after vaccination, reaching a peak by day 45. This confirms that primary immunisation stimulates the formation of effector cells capable of an immediate response to an antigen. Additional analyses showed that after reaching the peak, the number of CD45RA+ cells began to gradually decline, which may be due to the transition of effector cells to a resting state or their differentiation

into memory cells. Table 3 demonstrates that both regions (Kazakhstan and Latvia) showed similar trends in antibody levels. This indicates that vaccination was equally effective in different climatic and environmental conditions. These results emphasise the importance of standardised vaccine strategies that can be successfully applied in different regions with equally good results.

***Table 3**. Changes in the number of CD45RA+ T-lymphocytes in response to vaccination*

Time after vaccination	Number of CD45RA+ cells (Kazakhstan)	Number of CD45RA+ cells (Latvia)
0 days	500	510
14 days	1,200	1,150
28 days	2,000	1,950
56 days	1,800	1,750

***Source:** compiled by the authors*

The results showed that after repeated vaccination, the number of CD45RA- cells increased significantly within a few days, indicating a rapid and effective response of the immune system (Table 4). This also confirms the importance of memory cells in providing long-term protection against infections.

***Table 4**. Changes in the number of CD45RA- T-lymphocytes in response to vaccination*

Time after vaccination	Number of CD45RA- cells (Kazakhstan)	Number of CD45RA- cells (Latvia)
0 days	200	210
14 days	700	680
28 days	1,800	1,750
56 days	1,600	1,550

***Source:** compiled by the authors*

The humoral response plays a key role in ensuring the defence against infections, and its most important component is specific antibodies that neutralise pathogens and prevent their spread. In the study, the ELISA method was used to quantify the levels of specific antibodies to Salmonella antigens. The results showed that the vaccination caused a significant increase in antibody levels, which peaked on day 28 and remained high until day 56. These data indicate the formation of a stable humoral response that provides long-term protection of animals against infection (Table 5).

***Table 5**. Levels of specific antibodies to Salmonella antigens*

Time after vaccination	Antibody level (Kazakhstan)	Antibody level (Latvia)
0 days	0.2	0.3
14 days	1.5	1.4
28 days	3.8	3.7
56 days	3.2	3.1

***Source:** compiled by the authors*

A comparative analysis of the data obtained in Kazakhstan and Latvia showed similar trends in the dynamics of the immune response. Although there were some differences in the quantitative indicators in both regions, the general trends pointed to the effective formation of immunological memory and activation of T-lymphocytes and antibodies in response to vaccination. These data highlight the universality of immune mechanisms in cows regardless of geographic region. Additional analysis has shown that differences in immune response levels between regions may be related to differences in animal husbandry, climatic factors and genetic characteristics of cow populations. However, the general mechanisms of immune memory formation and T-lymphocyte activation remained similar.

During the initial vaccination, a significant accumulation of CD45RA+ effector cells was observed. These cells play a key role in the formation of an immediate antigen response. As shown in Table 1, their number increased significantly over time after vaccination, reaching a peak by day 45. This confirms that primary immunisation is effective in stimulating a rapid immune system response. After reaching the peak, the number of CD45RA+ cells gradually decreased, which may be determined by the transition of some cells to a dormant state or their differentiation into memory cells. This also confirms the importance of primary vaccination to stimulate a rapid and effective immune response. Repeated vaccination caused a rapid accumulation of CD45RA--memory cells. These cells are key to the formation of

a stable immune memory and a rapid response when re-encountering an antigen. Observations have shown that repeated vaccination significantly accelerates the accumulation of these cells, indicating the formation of long-term memory and the body's readiness for rapid protection against repeated infections.

The results showed that repeated vaccination promotes a significant increase in the number of CD45RA cells within a few days after vaccination. This confirms that memory cells play a key role in ensuring a rapid and effective response of the immune system to repeated exposure to antigens. Repeated vaccination caused a faster and more significant increase in antibody levels compared to the initial vaccination. This indicates the formation of a memory of B-cells, which can quickly produce large amounts of antibodies upon repeated exposure to an antigen. This phenomenon is called a secondary humoral response and is an important aspect of long-term immune protection. The study showed that with repeated vaccination, antibody levels reached peak levels within 7-14 days, which is significantly faster than with the initial vaccination. This confirms the effectiveness of repeated doses of the vaccine in maintaining a high level of protection and a rapid response of the immune system to repeated infections.

During the initial vaccination, a significant accumulation of CD45RA+ effector cells was observed. These cells play a key role in the formation of an immediate antigen response. As shown in Table 1, their number increased significantly over time after vaccination, reaching a peak by day 45. This confirms that primary immunisation is effective in stimulating a rapid immune system response. Repeated vaccination caused a rapid accumulation of CD45RA- memory cells. These cells are key to the formation of a stable immune memory and a rapid response when re-encountering an antigen. Observations have shown that repeated vaccination significantly accelerates the accumulation of these cells, indicating the formation of long-term memory and the body's readiness for rapid protection against repeated infections. An analysis of the data 56 days after vaccination showed that the levels of specific antibodies and T-lymphocyte populations remained high. This indicates that the vaccination elicits a long-lasting immune response, which is particularly important for the protection of animals in the long term.

An analysis of temporal changes in T-cell populations showed that vaccination stimulated a significant increase in the number of CD4+ and CD8+ cells, as well as γδ T cells. These changes were observed in both Kazakhstan and Latvia, indicating the universality of immune mechanisms. The data presented in Table 4 confirm that memory effector cells with CD4+ and CD8+ markers show an increase in dynamics over time after immunisation. The study demonstrated that effector subpopulations accumulate only slightly in the primary response to an antigen. A significant increase occurs between days 7 and 45, which is consistent with the data presented in Table 1. With repeated immunisation, a rapid accumulation of these phenotypes is observed, which is associated with their persistence in the blood of animals. These data confirm that the immune system produces specific memory cells capable of rapid differentiation during a secondary immune response to an antigen. Additional analysis showed that after the initial vaccination, the number of CD45RA+ cells peaked on day 28 and then gradually decreased. At the same time, the number of CD45RA cells continues to increase after repeated vaccination, indicating the formation of a stable immune memory.

The findings of this study have important implications for the development of new vaccine strategies and the optimisation of existing ones. Determination of the role of different T-cell populations in the immune response can be used to develop more effective vaccines that can provide long-term protection of farm animals against infectious diseases. The inclusion of different T-lymphocyte phenotypes in vaccination programmes helps to create a stronger and more durable immune response. The development of new vaccine strategies should address the importance of primary and repeated vaccination for the formation of a stable immune memory. The initial vaccination stimulates the rapid accumulation of effector cells, while repeated vaccination increases the number of memory cells, which provides long-term protection. The results showed that vaccination caused a significant increase in the levels of specific antibodies to Salmonella antigens. The analysis of the data presented in Table 3 showed that antibody levels peaked on day 28 and remained high until day 56. This indicates that the vaccination stimulated the development of a sustained humoral response.

Additional analysis showed that antibody levels remained high even 56 days after vaccination, confirming a long-lasting immune response. This is especially important to ensure the long-term protection of animals from infections. Analysis of γδ T-cell populations showed a significant increase after vaccination. These cells play an important role in the early immune response to infection. The results showed that vaccination stimulated their activation and increase in number in both Kazakhstan and Latvia, highlighting the importance of γδ T cells in the formation of the primary immune response. Additional studies have shown that γδ T cells play an important role in activating other components of the immune system, such as macrophages and dendritic cells. This confirms that γδ T cells are an important link in the coordination of the immune response to infection. Another promising area is the use of vaccines against various diseases. Research may focus on combination vaccines that protect against multiple pathogens simultaneously. This will not only increase the effectiveness of immunisation but also simplify the vaccination process, which is especially important for

farmers and veterinarians. Thus, further research can cover a wide range of issues, from optimising vaccination methods and developing combination vaccines to studying genetic factors and the impact of the environment on the immune response. These studies will help to better understand the mechanisms of the immune system and develop effective strategies to protect farm animals from infectious diseases, which will lead to improved health and productivity.

DISCUSSION

In this study, a comprehensive assessment of the formation of immunological memory in cows in response to vaccination against Salmonella was carried out. The focus was on the analysis of the phenotypes of T-lymphocyte populations, including CD4+, CD8+, γδ T cells and effector cells CD45RA+ and CD45RA-. These results were used to draw several important conclusions about the mechanisms of the immune response to vaccination and the effectiveness of different T-lymphocyte phenotypes in the formation of a stable immune memory, which is also confirmed by B. Geckin *et al.* (2022).

Analysis of CD4+ and CD8+ T-lymphocyte populations showed that vaccination caused a significant increase in these cells. This is consistent with the results of A. Gillespie *et al.* (2021). This confirms the key role of these cells in the formation of an adaptive immune response. Vaccination stimulated the activation and proliferation of CD4+ T helper cells, which play an important role in coordinating the immune response, as well as CD8+ cytotoxic T lymphocytes responsible for killing infected cells, as mentioned in the studies by A.W. Yirsaw *et al.* (2021) and V. Berezin *et al.* (2008). In Kazakhstan and Latvia, similar trends in the number of these cells were observed, which emphasises the universality of immune mechanisms in cows. At the same time, some differences in quantitative indicators may be due to regional specifics, such as climatic conditions, genetic differences in cow populations and farming practices.

Analysis of γδ T cells showed a significant increase in them after vaccination. These cells are important participants in the immune response, especially in the early stages of infection. The results showed that the vaccination stimulated their activation and increased their number in both groups. γδ T cells play a key role in recognising and destroying infected cells, as well as in activating other components of the immune system, such as macrophages and dendritic cells (Liu *et al.*, 2023). CD45RA+ effector cells are indicators of the primary immune response. The results showed that these cells begin to accumulate as early as 7 days after vaccination, reaching a peak by day 45. This is consistent with the results of I.R. Tizard (2020) and H. Enul et al. (2024). This confirms that primary immunisation stimulates the formation of effector cells capable of an immediate response to an antigen. After reaching the peak, the number of CD45RA+ cells gradually decreased, which may be associated with the transition of some cells to the resting state or their differentiation into memory cells.

These results highlight the importance of primary vaccination to stimulate a rapid and effective immune response. CD45RA+ effector cells play a key role in providing immediate protection against infection, which is especially important in conditions of high risk of infection. CD45RA cells are memory cells that are activated upon repeated exposure to antigens. A significant increase in the number of these cells was observed with repeated vaccination. This indicates the formation of a stable immune memory, which allows the body to respond quickly to repeated infections. After repeated vaccination, the number of CD45RA- cells increases significantly after only a few days, indicating a rapid and effective immune system response.

The humoral response is an important component of the immune system that protects the body from pathogens (Alexyuk *et al.*, 2022). In the study, the ELISA method was used to quantify the levels of specific antibodies to Salmonella antigens. The results showed that the vaccination caused a significant increase in antibody levels, which peaked on day 28 and remained high until day 56. Such data were also mentioned in the study by H.H. Zheng *et al.* (2022), which indicates the formation of a stable humoral response that provides long-term protection of animals from infection. Comparative analyses showed that both regions (Kazakhstan and Latvia) showed similar trends in antibody levels. This indicates that vaccination was equally effective in different climatic and environmental conditions. Such results emphasise the importance of standardised vaccine strategies that can be successfully applied in different regions with similarly high results.

The study showed that the dynamics of the humoral response in both groups were characterised by a rapid increase in antibody levels after the initial vaccination. Antibody levels rose as early as 14 days after vaccination, indicating the onset of an active immune response. On day 28, the antibody level peaked, indicating the maximum activity of the humoral immune response. On day 56, the antibody levels remained high, although slightly lower than their peak values. These findings highlight the importance of choosing the optimal time intervals for repeat vaccinations to maintain high antibody levels and long-term protection against infection. Repeated vaccination caused a faster and more significant increase in antibody levels compared to the initial vaccination. This indicates the formation of a memory of B-cells, which can quickly produce large amounts of antibodies upon repeated contact with an antigen (Mussayeva *et al.*, 2023). This phenomenon is called the secondary humoral response and is a substantial aspect of long-term immune protection.

The data showed that with repeated vaccination, antibody levels reached peak levels within 7-14 days,

which is significantly faster than with the initial vaccination. This confirms the effectiveness of repeated doses of the vaccine in maintaining a high level of protection and a rapid response of the immune system to repeated infections. Comparative analysis between regions showed that despite similar trends, there were some quantitative differences in antibody levels. In Latvia, antibody levels were slightly higher than in Kazakhstan at all time points. These differences may be due to differences in animal husbandry, climatic conditions and the genetic background of cow populations. These findings highlight the importance of addressing regional specificities when developing and implementing vaccine strategies. A deeper understanding of the factors that influence the humoral response will help optimise vaccination in different settings and ensure maximum immune protection.

The humour response is also important for the overall performance of animals, which is also emphasised in the study by M.M. Appenheimer and S.S. Evans (2018). High levels of antibodies can help reduce morbidity and mortality, which has a positive impact on the productivity and economic efficiency of farms. This study showed that vaccination against Salmonella not only provides immune protection but also improves animal health, which in turn increases productivity. These results highlight the importance of regular vaccination and monitoring of antibody levels to maintain the health and productivity of farm animals. The development of effective vaccine strategies based on humoral response data can significantly improve farm outcomes and reduce economic losses associated with infectious diseases.

The results of the study showed that memory effector cells with CD4+ and CD8+ markers demonstrate an increase in dynamics over time after immunisation. This may serve as evidence that the immune system produces specific memory cells capable of rapid differentiation during a secondary immune response to an antigen. Observations have shown that CD45RA+ effector cells and CD45RA- -memory cells play a key role in the formation of a stable immune memory and a rapid response to repeated vaccination, which is consistent with the results of study A. Kandel *et al.* (2022). These data are important for the determination of the mechanisms of immune memory formation and for developing effective vaccine strategies. Memory effector cells provide long-term protection against repeated infections, which is especially important in conditions of high probability of infection (Busol *et al.*, 2024).

Data analysis showed that memory cells remain in the body for a long time after vaccination. This confirms the importance of repeated doses of the vaccine to maintain a high level of protection. Repeated vaccination contributes to a significant increase in the number of memory cells, which provides long-term immune protection. These results highlight the importance of regular vaccination to maintain a high level of protection against infections. Repeated doses of the vaccine help to maintain a high level of memory cells, which ensures a quick and effective response of the immune system to repeated infections. Further research could be directed at exploring a variety of vaccination methods. The development of new vaccine regimens that incorporate different adjuvants and methods of administration can significantly improve the immune response in animals. For example, the study of different dosing regimens and intervals between vaccinations can help determine the optimal conditions for maximising immune memory.

It is also necessary to address the genetic diversity of animals. Differences in genetic background can significantly affect the immune response to vaccination (Larsen *et al.*, 2022). Research into the influence of genetic factors on the effectiveness of vaccines will help to develop more personalised approaches to immunisation, which is especially relevant in large-scale livestock production. An important aspect of further research is the study of the duration of immune memory. Even though this study has obtained data on the formation of long-term immune memory, the question remains as to how long this memory persists and what factors may affect it. Long-term follow-up and subsequent vaccinations can provide valuable data on the persistence of memory cells and their ability to reactivate upon repeated exposure to antigens. In addition, research in other animal species can expand knowledge of the mechanisms of immune response and vaccine specificity. For instance, studying similar processes in other farm animals such as sheep, goats and pigs will allow the development of universal vaccine strategies applicable to different species, as can be observed in the studies of M. Simola *et al.* (2024), V. Fumagalli *et al.* (2023). This is especially important in mixed farms where different types of animals are kept.

Another promising area is the study of the impact of external factors on the immune response. Climatic conditions, feeding regimen, stress levels and other environmental factors can significantly affect the effectiveness of vaccination. Studies by S.H. Siddiqui *et al.* (2021) aimed at investigating these factors will help to develop recommendations for optimising animal conditions to maximise the effectiveness of immunisation. Particular attention should be paid to the development of new methods for diagnosing and monitoring the immune response. Current methods, such as flow cytometry and ELISA, are effective but can be labour-intensive and costly. The development of simpler and more affordable diagnostic methods will improve the monitoring of vaccination effectiveness and allow for the timely detection of immunisation-related problems. Research in the field of bioinformatics and big data analysis can also make a significant contribution to the understanding of immune processes. Modern technologies analyse huge amounts of data and

identify hidden patterns, which can lead to discoveries in the field of immunology and the development of more effective vaccine strategies.

CONCLUSIONS

This study provided important data on the mechanisms of immune response in cows in response to Salmonella vaccination. The results showed that the vaccination caused a significant increase in the number of T lymphocytes, including CD4+, CD8+ and γδ T cells, which confirms their key role in the adaptive immune response. The vaccination also stimulated a significant increase in the levels of specific antibodies, reaching a peak on day 28 and remaining at a high level until day 56. These data indicate the formation of a stable humoral response that provides long-term protection of animals against infection.

The study demonstrated the importance of different phenotypes of T-lymphocytes and effector cells in the formation of immunological memory in cows. The results showed that CD45RA+ effector cells play a key role in the primary immune response, while CD45RA- cells are indicators of persistent immune memory upon repeated exposure to antigens. Comparative analysis of data from Kazakhstan and Latvia showed similar trends, confirming the universality of the observed immune mechanisms. Limitations of the study include the possibility of differences in animal housing conditions, climatic factors and the genetic background of cow populations, which may affect the immune response. In the future, it is necessary to continue researching the duration of immune memory and studying similar processes in other farm animal species to develop universal vaccine strategies.

The results are important for the development of new vaccine strategies and optimisation of existing ones. Addressing regional characteristics and environmental factors will help improve the effectiveness of vaccination in different settings. Further research could focus on the variety of vaccination methods, the influence of genetic factors, and the development of new methods for diagnosing and monitoring the immune response. In the long term, this could help reduce the morbidity and economic losses associated with infections and improve the health and productivity of livestock in different regions.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Спосіб формування імунологічної пам'яті до антигенів сальмонел у корів із застосуванням різних фенотипів популяцій Т-лімфоцитів

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Анотація. Метою даного дослідження було вивчення формування імунологічної пам'яті до антигенів сальмонел у корів з використанням різних фенотипів популяцій Т-лімфоцитів. Дослідження проводилося на базі фермерських господарств у Казахстані та Латвії. У рамках дослідження було зібрано зразки крові у корів, вакцинованих проти сальмонел, для аналізу фенотипів Т-лімфоцитів. Було проведено порівняльне дослідження різних фенотипів популяцій Т-лімфоцитів, зокрема CD4+, CD8+, γδ Т-клітини та ефекторні клітини Т-лімфоцитів (CD45RA+ і CD45RA-), для оцінки їхньої ролі у формуванні імунологічної пам'яті. Методи проточної цитометрії та enzyme-linked immunosorbent assay (ELISA) використовували для кількісного аналізу популяцій Т-лімфоцитів і рівнів специфічних антитіл. Основні результати засвідчили, що вакцинація викликає значне збільшення популяції CD4+ і CD8+ Т-лімфоцитів, що корелює з підвищенням рівня специфічних антитіл до антигенів сальмонел. Популяція γδ Т-клітин також показала значну активацію, що свідчить про їхню потенційну роль у формуванні імунної відповіді на сальмонели. Особлива увага приділялася ефекторним клітинам Т-лімфоцитів: CD45RA+ клітини брали активну участь у первинній імунній відповіді на антигени сальмонел, тоді як CD45RA-клітини демонстрували високу активність під час повторної зустрічі з антигеном, що вказує на їхню ключову роль у підтримці довгострокової імунологічної пам'яті. Порівняльний аналіз даних із Казахстану і Латвії показав схожі тенденції, що вказує на універсальність спостережуваних імунологічних механізмів. Ці результати підкреслюють важливість включення різних фенотипів Т-лімфоцитів у програми вакцинації для забезпечення ефективнішого формування імунологічної пам'яті у корів. Таким чином, дане дослідження надає цінні дані щодо ролі різних популяцій Т-лімфоцитів у формуванні імунологічної пам'яті до антигенів сальмонел у корів, що може сприяти розробці більш ефективних вакцинних програм і покращенню здоров'я та продуктивності худоби в регіонах Казахстану та Латвії

Ключові слова: генетична імунна реакція; фермерські господарств; аналіз Т-клітин; проточна цитометрія; вакцинні стратегії; рівні антитіл

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Quality and safety of products using GM soybeans in the diet of bulls

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Abstract. The production of high-quality and safe food products in areas contaminated by radiation due to the Chornobyl Nuclear Power Plant accident remains a pressing issue. The aim of this study was to determine the concentration and transfer factors of 137Cs, Pb, Cd, Cu, and Zn in bull products when including various high-protein feeds, such as narrow-leaved lupin and genetically modified soybean, in their diets. The study employed zootechnical methods (design and conduct of a scientific-economic experiment on animals), radiological and spectrometric methods (determination of the concentration of 137Cs, Pb, Cd, Cu, and Zn in feeds, longissimus dorsi muscle, liver,

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kidneys, and testes of bulls), and statistical methods. It was established that when using GM soybean in the grain mixture, the concentration of 137Cs in the muscle tissue of animals in Group II (experimental) decreased relative to the control by 2.57 Bq/kg, or by 40.5% with a statistically significant difference between groups (P > 0.99). Furthermore, the transfer factor of the radionuclide into the muscle tissue of animals in Group II compared to Group I also had 2.15% abs. lower. The content of Pb in the muscle tissue of bulls in both experimental groups exceeded the maximum permissible concentration by 2.52-2.78 times, while the concentration of Cd in the longissimus dorsi muscle and Cu in the liver of animals in Group II also exceeded sanitary-hygienic requirements by 10.0% and 2.0%, respectively. The introduction of 40% (by mass) of maize grain and 30% of GM soybean into the grain mixture instead of the same amount of wheat and lupin chop during the fattening of animals in the third zone of radioactive contamination contributed to significantly higher content and transfer of heavy metals into muscle tissue: Pb – by 10.3% and 0.10% abs., Cd – 10.0 and 0.03, Cu – 17.2 and 0.53, and Zn – by 17.2% and 2.40% abs. The results of the research can be used in agricultural enterprises and private households that produce livestock products in areas with a high anthropogenic load

Keywords: feeding; cesium-137; heavy metals; concentration; muscle tissue; kidneys; testes

INTRODUCTION

As a result of the accident at the Chornobyl Nuclear Power Plant, a large area of Ukrainian Polissya was contaminated with radioactive substances such as ^{137}Cs and ^{90}Sr. Their ingestion by animals through feed has necessitated the use of technologies in livestock production that enable the production of safe and high-quality food for the population living in these regions (Bartkowiak, 2021). Reducing the impact of the Chornobyl disaster on agriculture, specifically on crop production, forestry products, and livestock products produced on contaminated land, is a primary societal goal to ensure the supply of safe raw materials and products (Chobotko *et al*., 2023). Therefore, one of the primary objectives of modern radioecological science is the systematic monitoring of the contamination of plant and animal products with ^{137}Cs and ^{90}Sr, and the study of the migration patterns of these radionuclides in agricultural ecosystems (Romanchuk *et al*., 2019).

A significant challenge in the Polissya region is the contamination of soils with heavy metal salts such as Pb, Cd, Cu, and Zn (Savchuk *et al*., 2021). These heavy metals and their derivatives are toxic at high concentrations and can harm human health, animal productivity, and the quality of livestock products (Bakhrillaeva & Razamuradov, 2022). The primary sources of heavy metal pollution in the environment include industry, the thermal and chemical processing of minerals, the combustion of coal, gas, and liquid fuels, municipal waste (landfills, wastewater), and agriculture, particularly the excessive use of mineral fertilisers and pesticides (Nakagawa *et al*., 2022).

Heavy metals are dense metallic elements that accumulate progressively in the food chain, posing a threat to human health. However, some elements such as iron, iodine, cobalt, zinc, copper, manganese, molybdenum, and selenium are essential for various physiological functions and are often added as dietary supplements to animal feed (Chabanenko & Farionik, 2023). In contrast, other metals (Cd, Pb, Hg) do not have established biological functions and are considered pollutants. Heavy metals pose potential hazards due to their toxicity, bioaccumulation, and biomagnification, as they accumulate in living tissues more than they are excreted from the body (Abd Elnabi *et al*., 2023).

Lead is a chemical element belonging to the carbon group of the periodic table, with the symbol Pb and the Latin name *Plumbum*, meaning "liquid silver". It is considered one of the most dangerous heavy metal toxicants (Bernales *et al*., 2022). Lead can damage nearly every system in the body, including the haematopoietic, digestive, urinary, cardiovascular, and endocrine systems. It can also disrupt metabolic processes, the central and peripheral nervous systems, and damage cell membranes and cellular metabolism (Cuomo *et al*., 2020). According to studies by A. Ernyasih *et al*. (2023) and S. Satarug *et al*. (2023), Pb is a tissue toxin that accumulates over time and is found in the bodies of animals, particularly in bones, liver, kidneys, and brain. Research by A. Famurewa *et al*. (2022) has shown that lead exposure causes clinical pathological changes by increasing toxicity in the endocrine system and kidneys.

Cadmium (Cd) is a metal widely distributed in various ecosystems, not only in areas of radioactive contamination but also in soil and ore, where it is associated with zinc (Rahayuningsih *et al*., 2022). This metal is both a mutagen and a carcinogen, posing a significant genetic threat. It enters the environment through volcanic eruptions and is released by plants. However, the primary source of cadmium is anthropogenic (Yuan *et al*., 2019). Chronic cadmium poisoning disrupts calcium metabolism in bone marrow, causes anaemia, and adversely affects the central nervous, cardiovascular, reproductive, and musculoskeletal systems (Dasharathy *et al*., 2022). The high bioaccumulation factor of cadmium is a characteristic of this element's biological action, meaning that even low levels of long-term exposure can have negative health effects on animals.

Minerals such as copper (Cu) and zinc (Zn) are components of numerous enzymes that coordinate many biological processes, making them essential for maintaining animal health and productivity (Oconitrillo *et al.,* 2024). Essential micronutrients perform four critical functions: structural, physiological, catalytic, and regulatory. Zinc is necessary for maintaining and restoring barrier integrity, protecting against pathogens, and modulating the immune system by promoting the production of antibodies against intestinal pathogens (Duffy *et al*., 2023). Additionally, zinc can reduce diarrhoea and increase growth rates in weaned piglets. Copper is another important mineral with deep implications in animal husbandry. Adding to the diets of growing pigs results in faster growth and improved feed conversion ratio (Voloshchuk *et al*., 2020). In poultry, both copper and zinc help prevent certain diseases: copper prevents anaemia, while zinc acts as a catalyst for many enzymatic and hormonal reactions.

Given the broad spectrum of biological and toxic effects of ^{137}Cs and heavy metals and their negative impact on internal organs and animal systems, there is an urgent need to improve livestock management and feeding systems in regions with high levels of anthropogenic pollution in agricultural production. To reduce the accumulation of radionuclides (^{137}Cs) and heavy metal salts (Pb, Cd, Cu, Zn) in livestock products, research into different feeding types and rations for livestock production in the third zone of radioactive contamination following the Chornobyl NPP disaster is crucial. These studies aim to determine the accumulation of ^{137}Cs and heavy metals in the muscle tissue, liver, kidneys, and testes of bulls fed different protein-rich feeds.

MATERIALS AND METHODS

Experimental research was conducted at the physiological farm of the Polissya Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine, located in the Korosten territorial community, which falls within the third zone of radioactive contamination due to the Chornobyl disaster (Hrozyne village, Korosten district, Zhytomyr region), on young cattle (bulls) of Ukrainian Black-and-White dairy breed during 2022-2023. For the experiment, two groups of clinically healthy bulls (7 animal units in each) were formed using the balanced group method according to methodological guidelines (Ibatullin & Zhukorskyi, 2017). When forming the experimental groups, the origin, live weight, age, and growth rate of the animals during the comparative period were considered. The average live weight of the young cattle at the beginning of the experiment was 151.3-151.7 kg, and their age was 6.5-7.0 months. During the experiment, the animals were tethered and fed twice a day. The feeding and watering regimes, as well as the microclimate parameters, were identical in both groups. The duration of the comparative and experimental periods was 66 and 242 days, respectively.

The diets of the experimental animals did not differ significantly in terms of feed composition between the experimental groups, although the diets were balanced in terms of their content of major nutrients. The diets of the experimental animals were adjusted monthly according to the average daily gains and live weight of the animals, following modern detailed feeding standards and taking into account the actual chemical composition and nutritional value of the feed (Ibatullin *et al*., 2016). For feeding the bulls, cereal hay, mixed grass silage, wheat, triticale, and lupin chop were used, which were harvested from agricultural lands with a soil ^{137}Cs contamination level of up to 185 kBq/m^2. Maize grain and GM soy for the study were grown and supplied from a farm in Zhytomyr district (State Enterprise Research Farm "Nova Peremoha").

According to the experimental design, the young cattle in Group I (control) received a standard farm diet consisting of mixed grass silage, cereal hay, common salt, and grain mixture No. 1. Animals in Group II (experimental) received, in addition to the basic diet, grain mixture No. 2 (Table 1). The difference in feeding the experimental bulls during the main experimental period was that animals in Group I (control) received the same diet as in the comparative period of the experiment. Meanwhile, in Group II (experimental), 40% of wheat chop (by weight) in the diet was replaced with 40% corn chop, and 30% of lupin chop was replaced with an equal amount of genetically modified extruded soybeans. In the feed ration structure of the bulls, in terms of energy value, concentrates accounted for 39.4-41.3%, roughage for 23.8-24.6%, and succulent feed for 34.9-36.0%.

Table 1. *Composition of grain mixtures during the research, % by weight*

Concentrated feeds	Grain mixture No. 1	Grain mixture No. 2
Wheat chop	40	-
Corn chop	-	40
Lupine chop	30	-
GM extruded soybeans	-	30
Triticale chop	30	30
Total	**100**	**100**

Source: *compiled by the authors*

Feed samples were collected into polyethene bags, which were labelled with the feed name and the date of collection. The average sample weight for the analyses was 1.5 kg. Collected samples were delivered to the laboratory for further analysis on the day of collection. After the completion of the research, a control slaughter of three animals from each group was conducted at the Ovruch Meat Processing Plant, with live weights corresponding to the group averages, using the technology accepted in meat processing plants. The pre-slaughter live weight of the bulls in Groups I and II was 372.7 kg and 392.7 kg, respectively.

For laboratory analysis, samples of the longissimus dorsi muscle between the 9th and 12th ribs of the right half-carcasses were collected after 48 hours of cooling at 4°C. The weight of the collected samples of muscle tissue and liver was 1 kg, kidneys - 0.8-0.9 kg, and testes – 0.15-0.2 kg from each slaughtered animal. Samples were packaged in tight polyethene bags with zip closures. Labels were attached to the bags indicating the sample (product) code and animal number. The specific activity of ^{137}Cs in feed and products (longissimus dorsi muscle and liver) was determined using a SEG-0.5 gamma-ray spectrometer. Laboratory analyses of muscle tissue, liver, kidneys, and testes of animals, as well as feed for Pb, Cd, Cu, and Zn content, were conducted in the Agrochemical Research, Environmental Safety of Land, and Product Quality Laboratory at the Institute of Agriculture of Polissia NAAS. Plant and animal samples for heavy metal content were analysed using the atomic absorption method according to DSTU 7670:2014 (2015), with analysis performed on an atomic absorption spectrophotometer "Kvant – 2A".

The transfer factors (TF) of ^{137}Cs and heavy metals (Pb, Cd, Cu, Zn) from feed to animal products were calculated using the formula: $TF = C_{HMP}/C_{HMR} \times 100$, where TF is the transfer factor; C_{HMP} is the content of ^{137}Cs and heavy metals in animal products, Bq/kg, mg/kg; C_{HMR} is the content of ^{137}Cs and heavy metals in the daily ration, Bq, mg (Mamenko & Portyanyk, 2019). This factor is a relatively integrated indicator that reflects, in percentage terms, the migration of harmful substances from the diet into the product, allowing for a comparative assessment of the transfer of pollutants when using different feed mixtures for feeding bulls. The research data were processed using variation statistics based on the calculation of the arithmetic mean (M), mean squared error (m), and significance of the difference between comparable indicators (P) (Ruban *et al.*, 2020). All manipulations with animals were carried out by the European Convention for the Protection of Vertebrate Animals used for Experimental and Scientific Purposes, as well as the Law of Ukraine "On the Protection of Scientific Institutions Conducting Experiments and Experiments on Animals" (European Convention for the Protection..., 1986; Law of Ukraine No. 3447-IV..., 2006; Order of the Ministry of Agrarian Policy and Food of Ukraine No. 550 ..., 2017).

RESULTS AND DISCUSSION

Based on the average daily feed consumption by the animals and the ^{137}Cs content in the feed (Fig. 1), the average daily intake of this element into the bodies of growing and fattening bulls was calculated. In Group I, this figure was 123.2 Bq/day, which is 0.9 Bq/day higher than in Group II. In the course of the research, the main pathways of receiving ^{137}Cs entry into the animals' bodies: the lowest level of radioactive caesium was found in grain mixture No. 2 – 4.0 Bq/kg, and the highest – in mixed grass silage (7.5 Bq/kg).

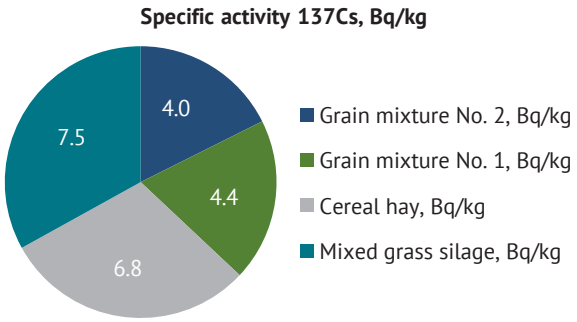

***Figure 1**. The specific activity of ^{137}Cs in feed*
***Source:** compiled by the authors*

Observations of the behaviour of bulls fed radioactively contaminated feed during the comparative and main observation periods did not reveal any abnormal symptoms in any of the animals. The study found a significant intergroup difference in the concentration of ^{137}Cs in the slaughter products of the experimental animals depending on the feed factor (Table 2).

***Table 2**. Specific activity of 137Cs in bulls slaughter products, Bq/kg*

Indicators	Groups	
	I – Control	II – Experimental
^{137}Cs concentration in the feed, Bq/kg	123.2	122.3
^{137}Cs concentration in muscle tissue, Bq/kg	6.34 ± 0.24	3.77 ± 0.25**
137Cs concentration in the liver, Bq/kg	4.50 ± 0.15	4.88 ± 0.41

***Note:** ** P > 0.99*
***Source:** compiled by the authors*

The examination results showed that the specific activity of ^{137}Cs in the longissimus dorsi muscle and liver of bulls in both experimental groups was within the range of 3.77-6.34 Bq/kg and 4.50-4.88 Bq/kg, respectively, which is significantly lower than the permissible levels (PL) for radionuclides in food products established by National Hygienic Regulations of Ukraine of permissible levels (MP) of radionuclides in food products (PL established in 2006 – 200 Bq/kg). At the same time, in animals that consumed diets with grain mixture No. 2, the concentration of ^{137}Cs in muscle tissue was 40.5% lower (P > 0.99), and in the liver 8.4% higher, compared to feeding the young animals with grain mixture No. 1. The transfer factors of ^{137}Cs into the longissimus dorsi muscle and liver of the experimental bulls were 3.08-5.15% and 3.6-3.99%, respectively. The highest transfer of ^{137}Cs into muscle tissue was observed in young cattle of Group I (control) – 5.15%, and into the liver – in animals of Group II (experimental) – 3.99% (Fig. 2).

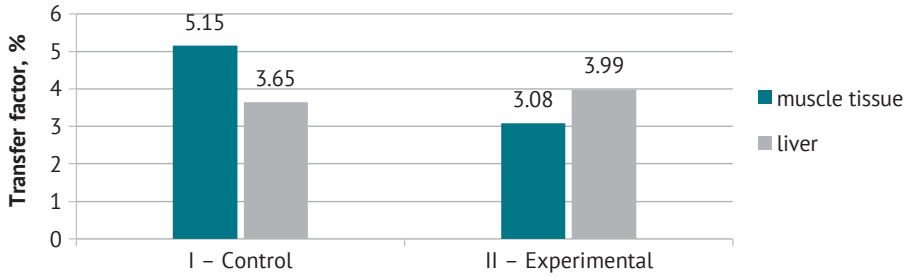

***Figure 2**. Transfer factors of ^{137}Cs to muscle tissue and liver of bulls*
***Source:** compiled by the authors*

The levels of heavy metals (Table 3) in some feeds exceeded the maximum permissible concentration (MPC) established by the Order of the Ministry of Agrarian Policy and Food of Ukraine in the "List of Maximum Permissible Levels of Undesirable Substances in Feed and Feed Raw Materials for Animals" (2017).

***Table 3**. Concentration of heavy metals in feeds, mg/kg of natural feed*

Heavy metals	MPC	Feeds			
		Cereal hay	Mixed grass silage	Grain mixture No. 1	Grain mixture No. 2
Pb	5.0	3.514	1.340	0.897	0.791
Cd	0.3	0.588	0.052	0.386	0.491
Cu	30.0	6.02	0.30	6.55	5.36
Zn	50.0	12.9	11.7	22.5	18.6

***Source:** compiled by the authors*

The research findings indicate that the levels of Pb, Cu, and Zn in roughage, succulent, and concentrated feeds grown on agricultural lands in the III zone of radioactive contamination did not exceed the maximum permissible limits. However, the highest amount of Pb was found in cereal hay, while Cu and Zn were most abundant in grain mixture No. 1. Currently, the amount of Cu and Zn in the analysed feed types is significantly lower than the maximum permissible concentration, which is confirmed by the data of Ukrainian authors on the deficiency of these microelements in feeds of the Polissia region of Ukraine (Ibatullin *et al.*, 2016). In terms of Cd content, most of the feeds exceeded the maximum permissible concentration. For example, this indicator was higher than the MPC for cereal hay by 96.0%, for grain mixture No. 1 by 28.7%, and for grain mixture No. 2 by 63.7%. The lowest amount of Cd was found in mixed grass silage – 0.052 mg/kg.

For feeding the experimental animals, diets with different types of grain mixtures were used with a Pb concentration ranging from 27.570 to 27.809 mg/day (Table 4). According to the Ukrainian State Sanitary Rules and Regulations "Maximum permissible levels of certain pollutants in food products" (Order of the Ministry of Health No. 1238, 2020), the maximum permissible level (MPL) of lead in meat is 0.10 mg/kg, in liver and kidneys – 0.5 mg/kg, and in testes – not regulated. The results of the examinations showed that the accumulation of Pb in the longissimus dorsi muscle exceeded the MPL in animals of both groups by 2.52-2.78 times. However, the concentration of this heavy metal in the muscle tissue of young cattle in Group II, relative to Group I, increased insignificantly by 10.3%. The content of lead in the liver and kidneys of animals in both groups was lower than the MPL by 20.8-26.6% and 35.4-40.4%, respectively. Nevertheless, feeding the bulls diets with GM soybeans compared to the control led to a decrease in Pb content in the liver by 7.3% and an increase in the concentration of the heavy metal in the kidneys and testes of animals by 8.4% and 19.7%, respectively.

***Table 4**. Pb concentration in diets and slaughter products of bulls*

Indicators	Groups	
	I – Control	II – Experimental
Pb content in the diet, mg/kg	27.809	27.570
Pb content in muscle tissue, mg/kg	0.252 ± 0.004	0.278 ± 0.010
Pb content in the liver, mg/kg	0.396 ± 0.019	0.367 ± 0.004
Pb content in the kidneys, mg/kg	0.298 ± 0.008	0.323 ± 0.017
Pb content in the testes, mg/kg	0.193 ± 0.020	0.231 ± 0.041

***Source:** compiled by the authors*

The lowest transfer of this element to the longissimus dorsi muscle, kidneys, and testes was observed in the animals of Group I. However, in the liver of animals from this group, Pb levels were 0.09% higher than in Group II (Fig. 3). Based on the obtained data, it can be concluded that among the studied slaughter products of the bulls, Pb accumulates the most in the liver, followed by the kidneys and muscle tissue, with the least accumulation occurring in the testes. Consumption of hay, silage, and feed mixture No. 2 increased the intake of Cd in the animals of Group II by 0.238 mg/day compared to those in Group I (Table 5).

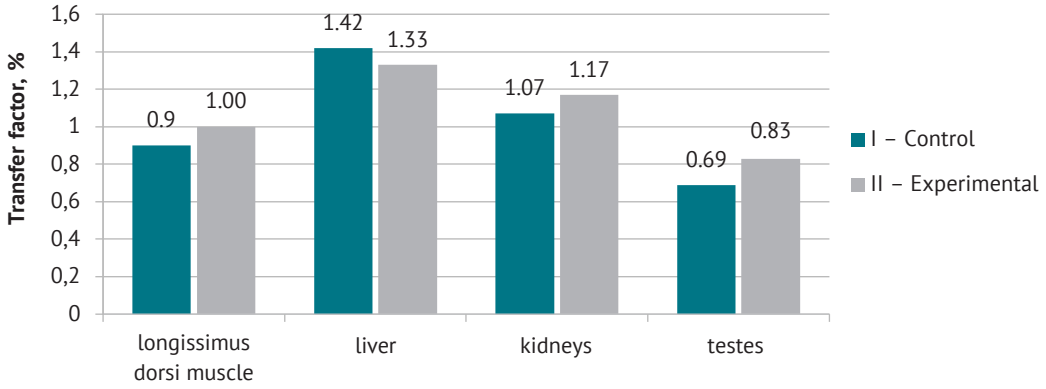

***Figure 3**. Pb transfer factors in slaughter products of bulls*

***Source:** compiled by the authors*

***Table 5**. Cd concentration in diets and slaughter products of bulls*

Indicators	Groups	
	I – Control	II – Experimental
Cd content in the diet, mg/kg	2.961	3.199
Cd content in muscle tissue, mg/kg	0.050 ± 0.003	0.055 ± 0.003
Cd content in the liver, mg/kg	0.093 ± 0.011	0.088 ± 0.005
Cd content in the kidneys, mg/kg	0.169 ± 0.006	0.167 ± 0.004
Cd content in the testes, mg/kg	0.096 ± 0.009	0.110 ± 0.019

***Source:** compiled by the authors*

The conducted research indicated that the concentration of Cd in the longissimus dorsi muscle of young cattle in the fattening Group II (experimental) exceeded the MPC by 10.0%, while the content of this element in the muscle tissue of animals in Group I (control) was at the level of sanitary and hygienic requirements (0.050 mg/kg). At the same time, in bulls that consumed grain mixture No. 2 (Group II) as part of their diet, compared to grain mixture No. 1 (Group I), there was an increase in Cd accumulation in the longissimus dorsi muscle by 0.005 mg/kg, or by 10.0%, with no significant intergroup difference. The highest Cd content in the liver was found in the experimental young animals of the control group – 0.093 mg/kg, which did not exceed the normative values (0.50 mg/kg). In animals fed grain mixture No. 2, the concentration of Cd in the liver decreased by 0.005 mg/kg, or 5.4%, compared to Group I. The inclusion of different feed mixtures in the diet of the bulls during fattening did not significantly affect the Cd content in the kidneys and testes. Thus, when using grain mixture No. 2 compared to grain mixture No. 1, the element concentration decreased in the kidneys by 1.2% and increased in the testes by 14.6% at $P < 0.95$. The transfer factors of Cd into products were low and

amounted to 1.68-1.71% in muscle tissue, 2.75-3.14% in the liver, 5.22-5.70% in the kidneys, and 3.24-3.43% in the testes (Fig. 4). It should be emphasised that the highest amount of this heavy metal accumulates in the kidneys of animals, followed by the testes, then the liver, and finally the longissimus dorsi muscle.

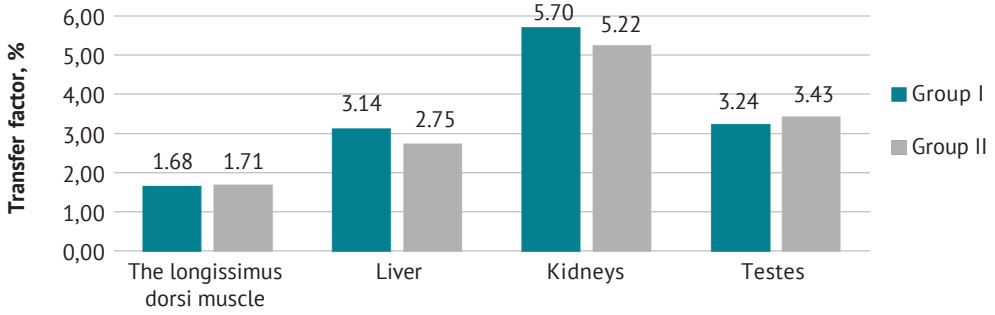

Figure 4. *Cd transfer factors in slaughter products of bulls*
Source: *compiled by the authors*

The concentration of Cu in the longissimus dorsi muscle, kidneys, and testes was low, ranging from 0.64-0.75 mg/kg, 2.92-3.37 mg/kg, and 0.63 mg/kg, respectively, and did not exceed the maximum permissible concentration (Table 6). The highest content of this element was found in the liver of the experimental animals – 16.0-20.4 mg/kg, which was slightly higher than the MPC in the latter case. In the muscle tissue, liver, and kidneys of bulls in the experimental group, whose diets included grain mixture No. 2 with genetically modified soybean, the copper content was higher compared to their counterparts in Group I (control) by 17.2% ($P > 0.95$), 27.5%, and 15.4% ($P > 0.95$), respectively.

Table 6. *Cu concentration in diets and slaughter products of bulls*

Indicators	Groups	
	I – Control	II – Experimental
Cu content in the diet, mg/kg	33.19	30.50
Cu content in muscle tissue, mg/kg	0.64 ± 0.02	0.75 ± 0.03*
Cu content in the liver, mg/kg	16.0 ± 3.56	20.4 ± 2.96
Cu content in the kidneys, mg/kg	2.92 ± 0.12	3.37 ± 0.06*
Cu content in the testes, mg/kg	0.63 ± 0.04	0.63 ± 0.09

Note: *** P > 0.99*
Source: *compiled by the authors*

The transfer factors of Cu from feed rations to the liver of the animals were high – 48.20-66.88% compared to 1.90-2.06% in the testes, 1.93-2.46% in the longissimus dorsi muscle, and 8.80-11.05% in the kidneys (Fig. 5). A positive trend was observed: with the introduction of maize and GM soybeans into the feed grain mixture, the accumulation of Cu in the longissimus dorsi muscle, liver, kidneys, and testes of animals in Group II (experimental) relative to the control increased by 0.53% abs., 18.68%, 2.25%, and 0.16% abs., respectively.

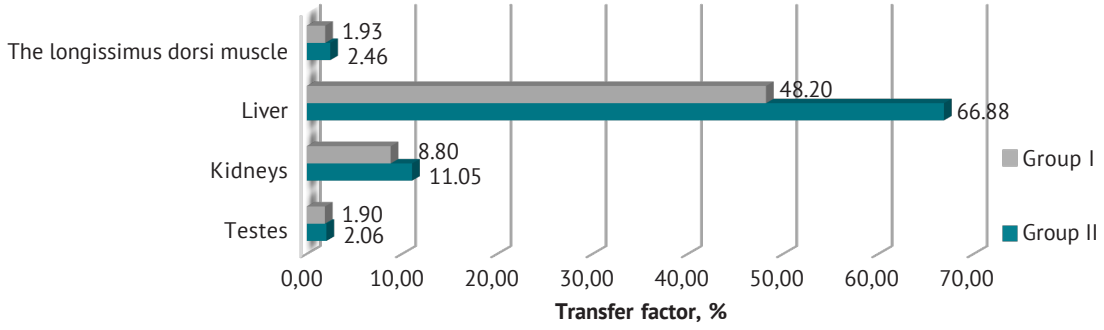

Figure 5. *Cu transfer factors in slaughter products of bulls*
Source: *compiled by the authors*

A significant amount of Zn was supplied to the experimental bulls with the feed rations (233.10-224.29 mg/day), therefore its accumulation in the products was the highest among the studied heavy metals: in the longissimus dorsi muscle – 25.5-29.9 mg/kg, liver – 30.9-31.0, kidneys – 13.98-15.10, and testes – 11.70-16.55 mg/kg without exceeding the MPC (Table 7). Moreover, when feeding young cattle in Group II with a grain mixture containing genetically modified soybean (30% by weight) compared to Group I (30% by weight of lupin), the concentration of Zn in slaughter products increased: in the longissimus dorsi muscle – by 17.2% (P > 0.95), liver – by 0.3%, kidneys – by 8.0%, and testes – by 41.4%.

***Table 7**. Zn concentration in diets and slaughter products of bulls*

Indicators	Groups	
	I – Control	II – Experimental
Zn content in the diet, mg/kg	233.10	224.29
Zn content in muscle tissue, mg/kg	25.5 ± 0.49	29.9 ± 0.71*
Zn content in the liver, mg/kg	30.9 ± 5.17	31.0 ± 0.99
Zn content in the kidneys, mg/kg	13.98 ± 0.67	15.10 ± 0.49
Zn content in the testes, mg/kg	11.70 ± 1.32	16.55 ± 1.99

Note: *** P > 0.99*
Source: *compiled by the authors*

As a result, the transfer factors of Zn to the products of bulls in the experimental group (Group II) relative to the control group also increased: in the longissimus dorsi muscle – by 2.36% abs., in the liver – by 0.57%, in the kidneys – by 0.74%, and in the testes – by 2.36% abs. (Fig. 6).

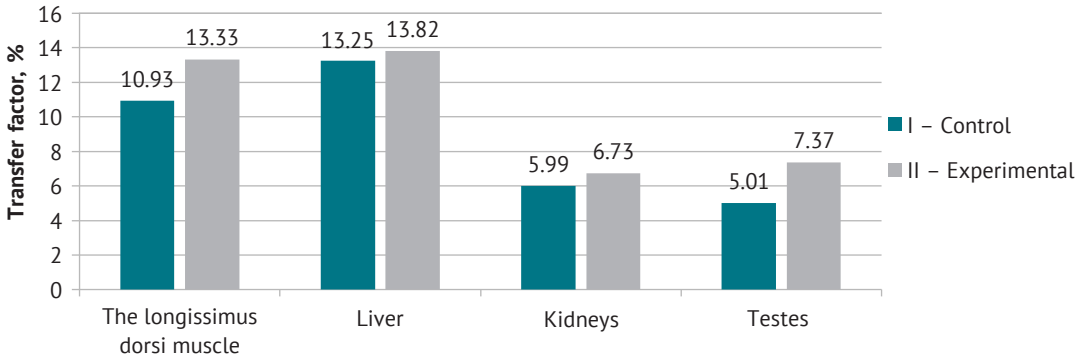

***Figure 6**. Zn transfer factors in slaughter products of bulls*
Source: *compiled by the authors*

Research conducted on young cattle grown in the third zone of radioactive contamination has revealed certain patterns in the transfer of heavy metals into animal products. According to the research results, the transfer factors of heavy metals were (%):

- in the longissimus dorsi muscle: Zn – 10.93-13.33 > Cu – 1.93-2.46 > Cd – 1.68-1.71 > Pb – 0.90-1.00;
- in the liver: Cu – 48.20-66.88 > Zn – 13.25-13.82 > Cd – 2.75-3.14 > Pb – 1.33-1.42;
- in the kidneys: Cu – 8.80-11.05 > Zn – 5.99-6.73 > Cd – 5.22-5.70 > Pb – 1.07-1.17;
- in the testes: Zn – 5.01-7.37 > Cd – 3.24-3.43 > Cu – 1.90-2.06 > Pb – 0.69-0.83.

These laboratory research results demonstrate and confirm that Zn exhibits the highest migratory and depositional activity in the longissimus dorsi muscle and testes, while Cu has the highest activity in the liver and kidneys. Cd also displays significant accumulation properties. The transfer factors of cadmium were 1.7-1.9 times higher than those of lead (Pb) in muscle tissue, 1.9-2.4 times higher in the liver, 4.5-5.3 times higher in the kidneys, and 3.9-5.0 times higher in the testes.

When growing cattle and producing beef in areas with varying levels of radionuclide contamination, the primary goal is to provide animals with "clean" feed and to reduce the transfer factors of ^{137}Cs and heavy metals into livestock products. However, this is not always achievable. Therefore, measures to significantly reduce the specific activity of radionuclides and the concentration of heavy metal salts in feed, as well as changes in the structure of animal diets and the addition of supplements to ensure adequate nutrition, can contribute to reducing the transfer of harmful substances into livestock products. Feeding animals clean and safe feed is not only crucial for their health but is also a significant factor in reducing the impact of toxic substances

on human health. The accumulation of radionuclides and heavy metals in animal organs and tissues is a complex environmental issue that primarily depends on the concentration of toxicants in feed and the duration of feed consumption by animals. Other factors such as the age, weight, and sex of animals are less significant (Cygan-Szszegielniak & Stasiak, 2022).

According to R. Kulibaba *et al.* (2023), contaminated feed is the primary pathway for radionuclides to enter animal organisms after a nuclear disaster, while air and water intake were most significant for animals in the early stages of a nuclear accident. Furthermore, research by V. Kozak and V. Brygadyrenko (2018) revealed that chemical elements such as lead and cadmium and their compounds are highly toxic and do not decompose in soil or water. Instead, they migrate through the food chain, causing adverse effects on both humans and animals. The authors' studies indicate that the main contaminants of meat, liver, kidneys, and testes in animals in the Polissia region are coarse feed produced by natural drying and silage. Young animals have a biological capacity for intensive growth, development, and efficient utilisation of nutrients in muscle tissue when provided with a complete diet. Therefore, the production of high-quality beef should be based on a stable, environmentally friendly, and nutritionally complete diet for young animals from birth to slaughter, depending on age, breed, and live weight.

Following the conducted study, the authors compared the total amount of heavy metals ingested by bulls through feed and their content in muscle tissue, liver, kidneys, and testes. They observed the following accumulation patterns. Firstly, there is an uneven digestion of individual elements within the animal's body. Secondly, a significant portion of these elements is not deposited in the longissimus dorsi muscle or internal organs but is excreted from the body. Similar results were obtained in studies by I. Yashchuk and I. Savchuk (2021) when optimising the protein nutrition of bulls using various high-protein feeds. According to their data, the transfer factors to the young cattle's body were: copper – 3.62-3.97%, zinc – 3.33-3.41%, cadmium – 2.16-2.87%, and lead – 0.3-0.6%, which aligns with the results of the conducted experiment. Therefore, in conditions of high anthropogenic load to reduce the accumulation of harmful substances in animal organisms and obtain high-quality livestock products, scientifically sound feeding systems should be applied, balanced in terms of basic nutritional parameters.

According to both Ukrainian and international research, the transfer factors of radioactive substances and heavy metal salts from feed to livestock products are influenced by production and processing technologies, as well as environmental conditions (Mamenko & Portiannik, 2021; Chalabis-Mazurek *et al.*, 2021). The type and digestibility of feed, along with the age and physiological state of animals, significantly impact the transfer of these toxicants from feed to products. Additionally, the level and quality of animal feeding, a balanced diet in all nutrients with radioprotective properties, also influence transfer factors. Such substances can increase the body's resistance to radiation, accelerate the excretion of toxicants, and reduce their content in livestock products. These substances include sulphur-containing amino acids, minerals, vitamins A, E, B, and C, and fibre (Hashemi, 2018; Alengebawy *et al.*, 2021). Furthermore, selecting the optimal type of animal feeding can significantly reduce the transfer of radionuclides and heavy metals into livestock products, as confirmed by studies conducted on dairy cows, young cattle, and pigs.

It is anticipated that the findings of the authors' research will assist experts in understanding the biological mechanisms of the internal effects of ^{137}Cs, Pb, Cd, Cu, and Zn when feeding young cattle with diets containing various high-protein feeds in a radioactive contamination zone. This understanding is crucial for organising biologically complete feeding regimes and producing safe food products.

CONCLUSIONS

When using various high-protein feeds for optimising the protein nutrition of young cattle, it was found that the specific activity of ^{137}Cs in the longissimus dorsi muscle and liver of the experimental animals varied between groups within the range of 3.77-6.34 Bq/kg and 4.50-4.88 Bq/kg, respectively, and did not exceed the established standards (PL-2006 = 200 Bq/kg). At the same time, the introduction of GM soybean into the grain mixture led to a decrease in the concentration of radiocesium in the muscle tissue of bulls in Group II (experimental) compared to the control by 2.57 Bq/kg, or by 40.5% with a statistically significant difference ($P > 0.99$). Moreover, the transfer factor of the radionuclide into the muscle tissue of animals in the second group compared to the first group was also 2.07% lower (absolute). The concentration of Pb in the longissimus dorsi muscle of young animals in both groups was 2.52-2.78 times higher than the MPC, and the level of contamination of muscle tissue with Cd and liver with Cu in Group II of bulls also exceeded sanitary-hygienic requirements by 10.0% and 2.0%, respectively. The introduction of 40% (by mass) of maize grain and 30% of GM soybean into the grain mixture instead of the same amount of wheat and lupin chop during the fattening of animals in the third zone of radioactive contamination contributed to significantly higher content and transfer of heavy metals into muscle tissue: Pb – by 10.3% and 0.10% abs., Cd – 10.0 and 0.03, Cu – 17.2 and 0.53, and Zn – by 17.2% and 2.40% abs. Moreover, the use of grain mixture No. 2 in the diet of young cattle in Group II compared to Group I led to

a higher concentration and transfer of heavy metals to all internal organs of the bulls, except for the content of Pb and Cd in the liver and Cd in the kidneys.

Further research will be aimed at studying various feedstuffs and feeding types for young mallard ducks to reduce the accumulation of radionuclides and heavy metals in duck products when growing poultry in the third zone of radioactive contamination as a result of the Chornobyl NPP accident.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Якість і безпечність продукції за використанням ГМ- сої в раціоні бугайців

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Анотація. Виробництво якісних і безпечних харчових продуктів в умовах радіоактивного забруднення території внаслідок аварії на Чорнобильській атомній електростанції було і залишається актуальною проблемою. Мета роботи – визначити показники концентрації та переходу 137Cs, Pb, Cd, Cu, Zn у продукцію бугайців за включення у їх раціони різних високобілкових кормів – люпину вузьколистого та генетично модифікованої сої. При проведенні досліджень використані наступні методи: зоотехнічні (постановка і проведення науково-господарського експерименту на тваринах), радіологічні і спектрометричні (визначення концентрації 137Cs, Pb, Cd, Cu, Zn в кормах, найдовшому м'язі спини, печінці, нирках і сім'яниках бугайців), статистичні. Було встановлено, що за використання у складі зерносуміші ГМ-сої, концентрація 137Cs в м'язовій тканині тварин II (дослідної) групи відносно контролю знижувалася на 2,57 Бк/кг, або на 40,5 % за статистично значущої міжгрупової різниці (P>0,99). До того ж коефіцієнт переходу радіонукліду в м'язову тканину тварин II групи порівняно з аналогами I групи також виявився меншим на 2,15 % абс. Уміст Pb у м'язовій тканині бугайців обох піддослідних груп перевищував гранично допустиму концентрацію в 2,52-2,78 раза, а концентрація Cd у найдовшого м'язі спини і Cu в печінці тварин II групи також виявилася більшою за санітарно-гігієнічні вимоги на 10,0 % і 2,0 % відповідно. Уведення до складу зерносуміші 40 % (за масою) дерті кукурудзи і 30 % ГМ-сої замість такої ж кількості дерті пшениці і люпину за відгодівлі тварин у III зоні радіоактивного забруднення сприяє значно більшому вмісту і переходу важких металів у м'язову тканину: Pb – на 10,3 % і 0,10 % абс., Cd – 10,0 і 0,03, Cu – 17 ,2 і 0,53 та Zn – на 17,2 % і 2,40 % абс. Результати досліджень можуть бути використані у сільськогосподарських підприємствах і особистих господарствах населення, які виробляють тваринницьку продукцію у зоні з підвищеним техногенним навантаженням

Ключові слова: годівля; цезій-137; важкі метали; концентрація; м'язова тканина; нирки; сім'яники

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Treatment of functional disorders of gastrointestinal tract of calves with complex phytomineral preparation

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Abstract. Significant economic losses due to diarrhoea morbidity in newborn young animals lead to a decrease in the profitability of the sector in the structure of agricultural production. Therefore, the purpose of this study was to create and investigate the therapeutic effect of application of complex phytomineral preparation using local components: opoka of Taskala deposit and decoction of camelthorn (*Alhagi maurorum*) for treatment of diarrhoea in calves. The therapeutic effect of the preparation was studied in the conditions of dairy farm in Kyzylorda region on 5-7-day-old calves. The effect of the preparation was studied in a comparative aspect with an analogous preparation of imported production and the results obtained from healthy animals. Clinical, haematological, and biochemical methods of investigation were employed. The findings obtained suggest a high therapeutic effect of the created preparation. Its application allowed reducing the duration of the treatment period by 5-7 days compared to the imported preparation and restoring the positive dynamics of average daily gain as early as on the 5th day after the start of treatment. Haematological studies indicate stimulation of the immune system in animals that was manifested by a 14% increase in the count of lymphocytes and a 37% increase in the proteins of the γ-globulin fraction compared to healthy animals. These indices

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suggest an increase in the activity of the humoral part of the immune system in animals after treatment with the preparation. Another positive therapeutic effect of the preparation was observed in the protective effect on the liver of diseased animals. Despite the present effect of both preparations, the decrease in the activity of markers characterising hepatocyte destruction was higher with the Kazakh preparation. Thus, the created preparation is characterised by a higher therapeutic effect in comparison with the imported preparation and allow recommending it for treatment and prevention of diarrhoea in young animals

Keywords: diarrhoea; camelthorn; opoka of Taskala deposit; therapeutic effect; Diastatin

INTRODUCTION

One of the key manifestations of morbidity of young cattle, in the first days of life, both in Kazakhstan and worldwide, are disorders of functional activity of the gastrointestinal tract (GIT) with the manifestation of diarrhoeal syndrome. Such symptomatology is inherent in many infectious and non-infectious diseases in newborn calves and young animals in the first months of life. Therefore, this pathology is especially common in industrial cattle breeding, when many animals are concentrated in a limited area, which contributes to the spread of morbidity. In this regard, the level of calf morbidity depends largely on the quality of veterinary care, the immune status of the animals, and the sanitary and hygienic rules established on the farm for the care and feeding of calves (Saribayeva *et al.*, 2015).

D. Wilson *et al.* (2023) indicate that diarrhoea occurs in 5-23% of calves in farms that raise dairy and beef cattle. The effects of diarrhoea on young animals are extremely diverse, depending on the intensity and duration of the process and can lead to both a reduction in growth and development rate and, consequently, a decrease in the genetic potential of the animals, as well as lead to the death of calves. Thus, the disease of young animals with the manifestation of diarrhoeal syndrome leads to a decrease in the profitability of the livestock industry and underproduction of economic profit by the farm. Due to such circumstances, the problem of disease incidence in young cattle in Kazakhstan and the economic consequences of this problem are significant for the economy of the country and need constant research and search for effective treatment methods to reduce the consequences of this problem (Kirimbayeva *et al.*, 2023; Turmagambetova *et al.*, 2017).

Modern methods of treatment of diarrhoeal syndrome in calves in Kazakhstan, according to K. Norboyev and S. Fayziyeva (2024), are based on the aetiopathogenetic principle, and are aimed at normalising digestion, eliminating dysbacteriosis, dehydration, and intoxication. But despite the complexity of the recommended treatment protocols, in general, most of the procedures to eliminate diarrhoea, Kazakh veterinarians are reduced only to the use of antimicrobial preparations to suppress the negative impact of pathogenic and opportunistic microflora in the body of calves. This is indicated by A. Zhylgeldieva *et al.* (2024), who note that broad-spectrum antibiotics, in most cases, can reduce the manifestation of clinical signs of disease in calves, but at the same time their use is accompanied by negative socio-economic consequences, which are manifested by an increase in the count of antibiotic-resistant strains of microorganisms, which reduces the effectiveness of treatment procedures in medical and veterinary practice and is a threat to national security for any country, including Kazakhstan.

Therefore, the relevant area of scientific developments for the livestock industry of the country is the search for alternative preparations, including those of plant origin, for the treatment of animal diseases of bacterial aetiology. This explains the considerable increase in the number of articles in specialised and scientific journals aimed at the use of substances with a pronounced antimicrobial effect for the treatment of various animal diseases. For this purpose, probiotics are used – S. Fayzieva *et al.* (2024); medicinal plants – Zh. Abirbekkyzy *et al.* (2024) (opuntia fruits, birch leaves, chamomile flowers), Kh. Azizov *et al.* (2023) (St. John's wort, sage, elecampane, althea); and others – S. Smulski *et al.* (2020) (lactoferrin and bacteriophages). But a one-sided approach, considering only the antimicrobial effect, does not allow to obtain prominent treatment results, as indicated by C. Eibl *et al.* (2021), and therefore the prospect belongs to complex preparations. This approach guarantees a systemic effect on the whole calf organism and will ensure action not only on the causes of the disease but will also have a stimulating effect on all systems and internal organs.

Taking as a basis this approach to the treatment of diseases of young cattle with signs of diarrhoeal syndrome, the purpose of this study was to create a complex preparation for the treatment and prevention of dyspepsia of calves, using natural mineral and plant substances characteristic of the territory of Kazakhstan. For this, the study of investigated the therapeutic effect of the developed preparation in diarrhoea of calves, as well as its influence on qualitative and quantitative indicators of the blood system in animals after its application.

LITERATURE REVIEW

Diarrhoeal syndrome in calves develops in many diseases in newborn animals. This, according to A. Nikkhah and M. Alimirzaei (2022), is due to the failure of the immune system in newborn animals. Therefore,

diarrhoea is most often a consequence of infectious diseases of bacterial aetiology – salmonellosis, escherichiosis, clostridiosis, campylobacteriosis (Kasa *et al*., 2020); of viral nature – consequences of rota and corona viruses, bovine viral diarrhoea virus, etc. (Castells & Colina, 2021); or of parasitic agents – cryptosporidiosis and giardiasis of calves (Kim *et al*., 2021). However, vaccination of breeding stock against these diseases, according to G. Maier *et al*. (2022), have a low impact on the subsequent incidence of diarrhoea in young animals. Apart from microbiological nature, disorders in housing and feeding of calves were also frequent causes of diarrhoea (Kara, 2020; Maliuk *et al*., 2024). Considering this polygenic nature of the disease, according to C. Eibl *et al*. (2021), the majority of veterinarians and livestock breeders, more than 52% of the total number of respondents, use the latest generation of antibiotics to treat this pathology. This approach, according to W. Du *et al*. (2023) has a series of disadvantages and leads to an increase in the number of resistant microorganisms before the action of antimicrobials, as well as to the accumulation of antibiotics in the muscle tissue of animals. Therefore, through the use of antibiotics, the studies of X. Zhang *et al*. (2022) indicate that the number of resistant microorganisms causing diarrhoea is much higher than among microorganisms – causative agents of pneumonia in calves. Furthermore, according to C. Bernal-Córdoba *et al*. (2022), there are no methods in the scientific literature that allow an objective assessment of the effectiveness of antibiotics for the treatment of diarrhoea in calves.

With most antibiotics becoming less effective, S. Wang *et al*. (2022) recommend that attention should be paid to alternative treatments for animals. Authors recommend adding herbal extracts from medicinal plants used to treat gastrointestinal diseases to such solutions. This approach cured 82% of sick calves, compared with only 62% of recovered animals when antibiotics were used. In this case, the use of an innovative approach in the treatment of calves, reduced the recovery period to 3.9 days against 6.62 days ($p = 0.001$) with antibiotic therapy. Such results encouraged further research to find effective treatment approaches for calves using topical substances with therapeutic effects. Thus, a series of studies have examined the use of different medicinal plants and their derivatives for the treatment of animals with diarrhoeal syndrome. Italian scientists S. Madeddu *et al*. (2021) examined the effect of essential oils obtained from plants grown on the island of Sardinia to treat the effects of bovine diarrhoea virus on the organism. Algerian researchers S. Torche *et al*. (2024) conducted a series of experiments on the effect of desert wormwood, common pomegranate, common oregano, red-fruited juniper and carob tree on treatment lines and its effectiveness. Analogous studies were conducted by L. Shen *et al*. (2023), using polysaccharides of Pueraria loblata as a raw material for calf treatment, which has a pronounced anti-inflammatory effect and helps to eliminate dysbiosis. M. Ansari *et al*. (2022) used ether-containing plant material for the treatment of calves in their study. Fennel seed powders and oregano leaves substantially reduced the duration of the disease period in animals. B. Stefańska *et al*. (2021) indicated that the applied phytobiotics, apart from the therapeutic effect, showed a positive effect on the growth characteristics of calves in terms of average daily weight gain.

Furthermore, reports on the high efficacy of other substances of non-plant origin for the treatment of diarrhoea in animals have been found, specifically the alkaloids isoquinoline – F. Mendonça *et al*. (2021) and racecadotril – B. Tras *et al*. (2023). But most attention has been given to the use of sorbents to partially or completely bind the toxins produced in the body by dispersion. For this, both mineral rocks with high adsorbing effect, zeolites, and commercially produced sorbents were used (Davis, 2022). These preparations are used both independently to treat animals and in combination with other preparations. In addition, some researchers recommend the use of other preparations with proven therapeutic effects. Most studies point to the use of probiotics, prebiotics, synbiotics, and other biological preparations (Bondarenko *et al*., 2023). M. Alomari *et al*. (2021) indicate that the use of such biologics and bacteriophages can also be an effective substitute for antibiotic therapy in diarrhoeal syndrome.

Thus, the conducted literature search indicates the prevalence of studies focused on the search for preparations to treat dyspepsia in calves with the use of local minerals and plant materials with prominent antibacterial and immunomodulatory effect.

MATERIALS AND METHODS

Studies investigating the therapeutic effect of complex phytomineral preparation, created from mineral and plant components obtained in Kazakhstan, were conducted in 2022–2023 at the dairy farm "Kazyna" in the Kyzylorda region and the Institute of Veterinary Medicine and Animal Husbandry West Kazakhstan Agrarian and Technical University named after Zhangir Khan.

The preparation was prepared in the laboratory of the Institute of Veterinary Medicine and Animal Husbandry of West Kazakhstan Agrarian and Technical University named after Zhangir Khan. To make the complex preparation, 10 g of pharmacy preparation of camelthorn (*Alhagi maurorum*) produced by pharmaceutical company "Zerde" were poured with 200 ml of hot (80°C) boiled water in an enamelled dish. Subsequent extraction was carried out on a boiling water bath for 15 minutes. After cooling and filtering the decoction, its volume was brought to 200 ml with boiled water. When preparing the mineral basis of the preparation, siliceous rock – opoka of Taskala deposit of West Kazakhstan region was preliminarily subjected to drying at temperature 90-100°C to constant weight and subsequent

grinding using laboratory jaw breaker 6 to particle size of 20-30 mm. Subsequently, the milled substrate was transferred to a muffle furnace at 350-400°C and incubated for 1 hour, and then milled in a porcelain ball mill MSL-1 to the consistency of fine powder of pink colour. In the last step of preparation, 200 ml of camelthorn decoction and 50 g of fine opoka powder were mixed and left to settle for 2 hours. After settling, the liquid portion was poured into glassware and brought to the level of isotonic solution by adding sodium and potassium chlorides. The obtained preparation was stored at +4°C in the refrigerator. Shelf life of the ready preparation is not more than 3 days.

Clinical trials of the prepared preparation were conducted in conditions of dairy farm "Kazyna". For this, two groups of 10 calves of 4-5-days-old weighing 35-40 kg were formed, with signs of gastrointestinal tract dysfunction in the form of diarrhoeal syndrome, as well as a group of healthy calves, which were not amenable to therapeutic procedures. Sick calves of the experimental group were administered a complex phytomineral preparation at a dose of 10 ml/kg body weight twice a day for 5 days, calves of the control group were administered a pharmacological preparation of analogous action of industrial production Diastatin in the same dosage. During the study, all experimental animals were kept under the same housing and feeding conditions adopted by the farm. During this period, daily clinical examination of sick calves was performed, as well as monitoring of changes in their weight and blood system parameters. Haematological and biochemical studies were conducted at the end of the treatment period in the biochemistry laboratory of the Institute of Veterinary Medicine and Animal Husbandry of West Kazakhstan Agrarian and Technical University named after Zhangir Khan. Blood was collected from the jugular vein into Vacusera vacuum tubes with anticoagulant as ethylenediaminetetetraacetic acid. Indices were determined using a BC-2800 Vet Mindray and Chem Well 2910 (C) haematological and biochemical veterinary analyser. The obtained haematological and biochemical indices were mathematically processed in TIBCO Statistica® 14.1.0 software, for further statistical analysis to form conclusions and suggestions for production.

RESULTS

Manifestations of diarrhoeal syndrome in calves and lambs in the southern regions of Kazakhstan are quite common, and in some farms the incidence can reach 20-40% of all newborn animals. Considering the significant percentage of lethal outcomes in the development of such pathological process in calves, this disease makes provision for the search for effective approaches in the treatment and prevention of diarrhoea of young animals in farms of different forms of ownership. The use of local natural fossils and herbal raw materials from plants growing in Kazakhstan for treatment will reduce the costs of animal husbandry and increase its profitability. In this area, the research conducted within the framework of this study is relevant and has practical value for livestock farming in Kazakhstan.

The preparation developed and created at the Institute of Veterinary Medicine and Animal Husbandry of West Kazakhstan Agrarian and Technical University named after Zhangir Khan, in the conditions of field trials, showed a higher therapeutic effect in comparison with industrial pharmacological preparation and at the same time helped to reduce the period of treatment. The findings of the experiments suggest that the created phytomineral preparation in comparison with the analogous preparation of industrial production Diastatin had more pronounced therapeutic effect on the organism of diseased calves. Daily clinical examination of sick animals helped to reveal that in calves of the experimental group, which were treated with the synthesised phytomineral preparation, the manifestation of diarrhoea symptoms began to decrease as early as on Day 3 after the beginning of treatment. At the same time, the positive effect of Diastatin application was observed only after Day 5, when the signs of diarrhoea in calves had already stopped with the use of phytomineral preparation. When using the preparation synthesised at the Institute of Veterinary Medicine and Animal Husbandry of West Kazakhstan Agrarian and Technical University named after Zhangir Khan, the signs of dyspepsia stopped on Day 3-5, and complete recovery in more than 90% of animals was observed after Day 7. In the group of animals, where treatment procedures were performed with Diastatin, improvement of general condition was observed only on Days 5-7, and cessation of diarrhoea was observed on Days 8-9, while the effectiveness of treatment was 80%. Apart from symptoms of diarrhoeal syndrome in sick animals, changes in the dynamics of live weight gain were also observed compared to healthy calves. Indicators of changes in live weight of calves of different groups are presented in Figure 1.

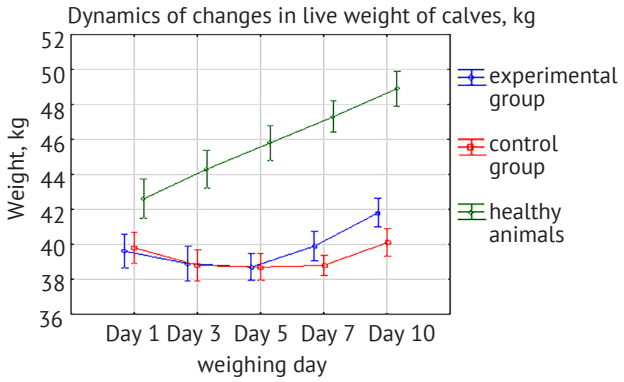

Figure 1. *Change in live weight of calves of experimental and control groups during the therapeutic period and comparison with the indicators of healthy animals*
Source: *compiled by the authors of this study*

One of the key differences between sick and healthy animals was the significant difference ($p < 0.05$) between the live weight of calves at the stage of treatment initiation. This indicates that even in the absence of symptoms of diarrhoea in sick animals, a decrease in body weight is observed in the first few days, which may be a consequence of impaired absorption of nutrients in the gastrointestinal tract. The difference between groups of diseased and healthy animals of the same age was greater than 2 kg. Newborn calves were not weighed on the farm, and therefore it is not possible to track the effect of disease incidence on diarrhoea in calves of different weights, so this will be a key area for future research to identify priority factors for preventive interventions to reduce the incidence of diarrhoea in young calves.

The live weight of sick calves of both groups, at the stage of manifestation of the first symptoms of the disease, practically did not differ – 39.6 kg and 39.8 kg, respectively, in the experimental and control groups. Therewith, live weight indices in the groups of sick calves corresponded to normal distribution, as the average indices did not exceed the deviation of more than 3 sigma, indicating the similarity of the disease manifestation in sick animals. During the treatment, the average daily weight gain in the groups that were subjected to the therapeutic procedure significantly lagged behind that of healthy animals (Table 1).

Table 1. *Average daily weight gain in groups of healthy and sick calves, M ± m*

Groups	No.	Duration of the period of illness			
		1-3 days	3-5 days	5-7 days	7-10 days
Experimental	10	-350 ± 150	-100 ± 124.7	600 ± 66.7	633 ± 59.8
Control	10	-500 ± 129.1	-50 ± 116.7	50 ± 116.7	433 ± 51
Healthy	10	850 ± 76.4	750 ± 83.3	750 ± 83.3	533 ± 54.4

Source: *compiled by the authors of this study*

In sick animals in the first days of the disease manifestation instead of positive weight gain there was observed a decrease in live weight as a result of active excretion of fluid from the body. At treatment of calves with phytomineral preparation created in West Kazakhstan Agrarian and Technical University named after Zhangir Khan increase in weight was observed from Day 5 after the beginning of treatment, while when using Diastatin positive indicators of growth occurred only from Days 7-10, and the level of weight gain was lower than when using phytopreparation. There were no failures in weight gain in healthy animals during this period, and therefore the weight gain during the entire experimental period was at the same level.

Thus, one of the key factors of the negative economic effect of the disease of young animals for diarrhoea is the reduction of animal weight gain during this period. Therefore, reducing the period of animal disease even by 1-2 days will improve livestock production indicators in the farm. The use of Diastatin for five days had only a temporary therapeutic effect, it was due to the fact that in 70% of calves of the control group in 3-4 days after discontinuation of the preparation administration signs of dyspepsia and dehydration of the organism (pronounced distress, diarrhoea, liquid and watery faeces, with an admixture of mucus, putrid odour) returned. Therefore, the average duration of the disease in calves of the control group was 11-15 days. This indicates that the created phytomineral preparation helped to reduce the period of calf disease by 5-7 days.

No less principal factor in the treatment of animals are the indicators of internal homeostasis of the animal's organism and the state of its immune system. These are most easily tracked by haematological and biochemical changes in the blood system as an integral tissue in the whole body. Therefore, to determine the therapeutic effect of preparations on the calf organism, quantitative and qualitative blood parameters were determined in the groups of treated animals, while referential parameters characteristic for the given age and species of animals, as well as analogous parameters from the group of healthy animals were used as indicators for comparison. The results of haematological studies are presented in Table 2.

Table 2. *Haematological parameters of blood cell fraction of healthy animals and calves treated with antidiarrhoeal therapy (n = 10), M ± m*

Indicators	Reference values characteristic for calves 1-3 months of age	Groups		
		Experimental	Control	Healthy animals
Erythrocytes, 10^{12}/l	5.9 - 6.2	7.7 ± 0.11	7.3 ± 0.12	7.5 ± 0.16
Leukocytes, 10^{9}/l	8 - 8.4	8 ± 0.13**	7.9 ± 0.15***	10.4 ± 0.55
Haemoglobin, g/l	100 - 105	108.6 ± 1.92**	104.3 ± 1.11*	99.5 ± 1.63

Table 2. Continued

Indicators	Reference values characteristic for calves 1-3 months of age	Groups		
		Experimental	Control	Healthy animals
		Leucocyte counts, %		
Eosinophils	1 - 2	1.5 ± 0.45	2.1 ± 0.58	1.7 ± 0.51
Juvenile neutrophils	1 - 2	0.7 ± 0.24	0.3 ± 0.24	0.9 ± 0.45
Band neutrophils	< 3 - 5	3.2 ± 0.49**	3.6 ± 0.35**	5.3 ± 0.58
Segmented neutrophils	40 - 45	36.4 ± 1.25*	37 ± 1.21	39.3 ± 1.16
Lymphocytes	45 - 50	51.5 ± 0.68***	50.1 ± 2.27*	45 ± 1.03
Monocytes	< 3 - 5	4.1 ± 0.37	4 ± 0.58	5 ± 0.58

Note: **** – $p \leq 0.001$; ** – $p \leq 0.01$; * – $p \leq 0.05$*
Source: *compiled by the authors of this study*

Quantitative indices of form elements in the blood of healthy and sick animals of experimental groups from the "Kazyna" farm practically did not differ from each other. At the same time, in terms of erythrocyte content in blood, animals from the farm exceeded the reference values typical for 1-3-month-old calves. If these differences were characteristic only of groups of animals after treatment, it could be explained by blood clotting due to dehydration of the organism during diarrhoea, but as it is, except for hereditary characteristics, no other explanation could be found. In calves of the experimental group the number of erythrocytes in the blood exceeded the analogous index of animals of the control group by 4.9%. Furthermore, in animals of the experimental and control groups there was also an increase in the count of haemoglobin above the reference values, while in animals that did not receive treatment, the level of haemoglobin was normal. The only logical explanation for this is the stimulating effect of the preparations due to the iron content. In contrast to the animals from the control groups, in healthy calves the level of leucocytes exceeded not only the count of leucocytes in sick animals, but also the norm indicators inherent in this kind of animals. The resilience of the animals before the disease may have been related to this. Therefore, future studies will genetically analyse animal resistance to diarrhoea in a population of dairy cattle.

Analysis of the leukocytic formula indicates that almost all white blood counts are within the physiological norm, except for a slight decrease in the count of segmented neutrophils and a slight lymphocytosis. Both phenomena are interrelated and indicate a change in priority in the organism from cellular to humoral form of defence. Even though the indices of young forms of neutrophils were within the physiological norm, in calves of the experimental group they were significantly decreased compared to animals from other groups. This may suggest a decrease in the activity of the cellular part of the immune system, as there is a decrease in the production of macrophage precursors in the body. This fact can also be explained by the increase in the count of lymphocytes in the peripheral blood, which are more active in case of infectious aetiology of the disease. Not an insignificant fact associated with the growth of leukocytes in calves of the experimental group may be a considerable stimulating effect of the plant component included in the phytomineral preparation, since the decoction of camelthorn contains a significant amount of physiologically active substances – saponins, flavonoids, essential oils, steroids, alkaloids, and vitamins C, K, and B group. Statistically significant increase of separate elements of white blood in animals of the experimental group may be connected with it.

The next stage of testing the effect of phytopreparation in field conditions for the treatment of animals with diarrhoeal syndrome was the study of a series of biochemical indicators of blood in the organism of treated animals. For this, the most common indicators were used, such as the content of protein fractions in serum, a series of enzymes involved in protein metabolism, as well as the content of certain macro- and microelements. The results of such studies are presented in Table 3.

Table 3. *Biochemical parameters of blood serum of healthy animals and calves after dyspepsia treatment (n = 10), M ± m*

Indicators	Reference values characteristic for calves 1 - 3 months of age	Groups		
		Experimental	Control	Healthy animals
Total protein, g/l	50 - 55	58.5 ± 1.09**	54.9 ± 1.05*	47.4 ± 0.82

Table 3. Continued

Indicators	Reference values characteristic for calves 1 - 3 months of age	Groups		
		Experimental	Control	Healthy animals
Protein fractions (%)				
Albumins	30 - 50	31.9 ± 0.91*	31.9 ± 0.71	34.3 ± 0.78
α - globulins	20 - 25	19.7 ± 0.49**	20.9 ± 0.99**	24.7 ± 0.41
β - globulins	15 - 25	16.9 ± 0.77	17.9 ± 0.84	18.3 ± 0.75
γ - globulins	20 - 30	28.1 ± 0.79**	25.3 ± 0.98*	20.4 ± 0.86
Enzyme systems				
AST, IU/l	95 - 105	70.9 ± 4.8	83.9 ± 5.08**	113.8 ± 9.51
ALT, IU/l	40 - 45	32.9 ± 2.97	36.9 ± 3.52	49.9 ± 4.96
Macro - and micronutrients				
Total calcium, mmol/l	2.5 - 3.1	2.81 ± 0.06	2.83 ± 0.03	2.59 ± 0.05
Inorganic phosphorus, mmol/l	1.45 - 2.5	2.36 ± 0.05	2.39 ± 0.06	2.79 ± 0.08
Copper, μg %	115 - 125	149.6 ± 11.9	134.9 ± 10.9	122.3 ± 11.8
Iron, μmol/l	25 - 30	27.8 ± 4.34	23.8 ± 4.69	20.5 ± 2.74

Note: **** – $p \leq 0.001$; ** – $p \leq 0.01$; * – $p \leq 0.05$; AST – aspartate aminotransferase; ALT – alanine aminotransferase*
Source: *compiled by the authors of this study*

The conducted studies of protein components content in blood serum of controlled calves at the end of the treatment period indicate that the compounds included in the developed therapeutic preparation had a significant activation of protein synthesising function in the organism, thereby increasing the level of total protein in the blood of calves of the experimental group to the maximum level, which significantly exceeded ($p \leq 0.01$) analogous indicators of calves of the control group by 6.1% and healthy animals by 22.5%. This increase was mainly due to an increase in the γ-globulin fraction. This fact confirms the growth of activity of the humoral part of the immune system in the organism of calves treated with complex preparations. In healthy calves, the level of γ-globulins stayed at the lower level of physiological norm, indicating the absence of bacterial load on the organism of animals. Other fractions of protein components in animals of experimental and control groups were practically at the same level and inferior to the values obtained in healthy animals. This decrease is a consequence of diarrhoea, because during the period of illness, nutrient absorption was reduced through increased gastrointestinal peristalsis.

No less significant property of the preparation for the treatment of diarrhoeal syndrome is the presence of hepatoprotective action and the ability to bind and remove from the body toxic products formed during the development of pathological microflora. Both preparations, which were used for the treatment of calves, have this effect due to the content of mineral compounds with adsorbing effect. The efficacy of these components in the composition of therapeutic preparations is confirmed by the activity of liver enzymes as markers of toxic damage to liver cells. In the studies conducted in healthy animals, an increase in the activity of alanine aminotransferase and aspartate aminotransferase enzymes was observed as indicators of liver damage syndrome, while in animals after treatment of diarrhoea, the activity of these enzymes was even below the physiological level, indicating a decrease in the toxic load on the liver. Notably, siliceous rock – opoka of Taskala deposit included in the developed phytomineral preparation helped to reduce the activity of enzymes ALT – by 22.4% and AST – by 28.7%, which in comparison with an analogous preparation, which was used for treatment of calves of the control group, was almost 2 times more effective (12.4% and 15.2%, respectively).

During the biochemical study of blood serum, a positive effect of complex preparations on the level of macro- and microelements assimilation in the body of calves was also established. In calves of the experimental and control groups, the level of these elements was higher than in animals that did not receive such treatment. The efficiency of the developed preparation in terms of mineral metabolism was 8-20% higher than that of the industrial pharmacological preparation Diastatin. Thus, the conducted studies indicate a positive therapeutic effect of the developed complex phytomineral preparation with the use of local fossils: opoka of Taskala deposit and decoction obtained from the vegetative part of camelthorn for the treatment of calves with diarrhoea. This preparation is not only not inferior to the pharmacological product Diastatin, but also exceeds it in therapeutic effect. Furthermore, due to the improvement of most of the body functions in animals, which have been treated with this preparation, it can be recommended to use it for prevention of diseases of young cattle in conditions of their industrial keeping.

DISCUSSION

Due to the high level of dyspepsia morbidity in young ruminants in the first days after birth, as well as a

significant percentage of mortality due to this disease, the most common methods of treatment of sick animals in farms of Kazakhstan, as well as scientific sources, were analysed to determine the most efficacious approaches in the treatment of dyspepsia in young animals. Considering that the duration of treatment can be from several days to several weeks and the cost of drugs, especially imported, is quite high, it was decided to develop a Kazakh analogue of the most effective preparation for the treatment of diarrhoea using as components local fossils and medicinal plants to obtain a therapeutic effect at the level of the imported preparation Diastatin, which was used by cattle breeders of Kyzylorda region most often in the treatment of diarrhoeal syndrome in young animals of large and small ruminants. The manufacturer of Diastatin does not report the full composition of the ingredients, and the instructions for the preparation only stated that Diastatin contains an inorganic enterosorbent based on highly dispersed silica and plant tannins, which help to improve digestion. Thus, the preparatory work for the development of the preparation centred on finding the necessary components. As a mineral component it was decided to use siliceous rocks – opoka of Taskala deposit of West Kazakhstan region.

When choosing a plant component, the key condition was its efficacious impact on digestive processes in the gastrointestinal tract, and high content of tannins for rapid antidiarrhoeal therapy. After comparing medicinal plants that are used by local people to treat diseases related to gastrointestinal disorders, it was decided to use the vegetative parts of camelthorn (*Alhagi maurorum*) as a plant base. B. Khasanova *et al*. (2023) and M. Urabee *et al*. (2021) also reported prominent therapeutic results of camelthorn in the treatment of digestive disorders in animals and humans. Furthermore, the fact that the pharmacological company "Zerde" (Kazakhstan) produces a pharmacy preparation containing raw material of camelthorn (*Alhagi maurorum*), which can be used for preparation of a medicinal preparation, was not an insignificant factor in the choice of a medicinal plant for creation of a phytomineral preparation. Considering that dyspepsia in calves is observed throughout the year, and the duration of storage of the preparation, while limited to a few days, this approach will avoid seasonality in the treatment and will ensure maximum therapeutic effect due to the control of plant raw materials at the pharmaceutical company.

As a result of this study, a Kazakh phytomineral preparation was obtained for the treatment of diarrhoea symptoms in calves, regardless of the aetiological factor. The preparation has high sorptive characteristics and contains macro- and microelements necessary for growth and development of calves, as well as flavonoids, saponins, sugars, tannins, vitamins C, K, and B group, carotene, and other biologically active substances due to their presence in the raw material of camelthorn (Mahde & Hammod, 2024). Therewith, the created preparation is absolutely harmless and has no side effects due to the use of environmentally friendly natural mineral sorbent opoka and medicinal herb camelthorn. At the same time, the imported preparation Diastatin consists mainly of chemical components, making it more expensive economically and less natural.

The next and most responsible stage of the study was to obtain a comparative therapeutic effect from the use of both preparations in the field and to investigate their effect on metabolic processes in the organism of sick calves. For this, to eliminate the majority of subjective and economic factors, groups of animals were formed in the conditions of one herd to study the effect of both preparations. For a more objective judgement on the therapeutic effect of preparations, apart from direct comparison of experimental and control groups, the study searched for physiological changes in the organism of animals subjected to treatment with the results obtained from healthy animals in this herd and reference values typical for animals of this species and age.

The results of the experiments suggest that the preparation developed at the Institute of Veterinary Medicine and Animal Husbandry of West Kazakhstan Agrarian and Technical University named after Zhangir Khan was found to be more effective in comparison with imported preparation. This was expressed in earlier cessation of diarrhoea symptoms and restoration of positive dynamics of average daily weight gain in calves. It is not yet possible to draw an analogy with other findings, as these are the first studies of the phytomineral preparation created. But the positive effect of this preparation can be traced in the studies of M. Mahde and A. Hammod (2024), who obtained better feed conversion rates in young poultry when camelthorn root decoction was introduced into the diet than in comparison with pharmacological preparations Immuno-Care and Immunity-Stim. Thus, due to the improvement of digestive processes, the preparation containing decoction of camelthorn plant material could shorten the period of diarrhoea treatment by 5–7 days in comparison with the group treated with Diastatin.

Studies of the blood system of calves, which were treated with two preparations with analogous action, revealed that practically all indices of quantitative characteristics of blood forming elements were on the side of the animals to which the phytomineral preparation was applied. And even though these differences ultimately were not statistically significant, a more pronounced stimulating effect in the restoration of the body's defence mechanisms was characteristic of the Kazakh preparation. Notably, due to the use of biologically active substances of camelthorn in the organism of diseased calves, the acceleration of the development of mechanisms of humoral response of the immune system of the organism was observed. This was expressed in an increase in the count of lymphocytes by 3% and

γ-globulin fraction by 11% compared to animals receiving Diastatin. These processes occurred in parallel in both groups of diseased animals, as they were significantly higher compared to healthy animals. Z. Manafu *et al*. (2024) noted this effect of stimulating immune system function in lambs. No less important therapeutic effect in the treatment of animals was revealed by a significant hepatoprotective effect of the created preparation, which was manifested in a substantial decrease in markers of liver damage – activity in the blood of intracellular liver enzymes – alanine aminotransferase and aspartate aminotransferase. Initially, this effect was attributed to the adsorbing effect of the mineral component of the preparation, as in the case of Diastatin, but a more in-depth investigation of this effect helped to identify an analogous effect of the plant component – biologically active substances of camelthorn.

Considering the conducted theoretical and experimental study of therapeutic action of the created Kazakh preparation from diarrhoea of calves, the findings allow recommending this preparation for treatment and prophylaxis of morbidity of young stock of large and small cattle with digestive disorders.

CONCLUSIONS

Based on the findings obtained during the comparative analysis of the effectiveness of the therapeutic action of the created Kazakh complex preparation for the treatment of diarrhoea in newborn calves, as well as laboratory studies of haematological and biochemical blood parameters conducted after the use of this preparation, the following conclusions and suggestions for future studies can be made. The created complex phytomineral preparation helps, after detection of symptoms of digestive disorders in calves, in a brief time to reduce the manifestation of diarrhoeal syndrome and restore the physiological process in the intestines of young animals, thereby returning live weight gain of calves to their level before the disease.

In contrast to imported preparation with analogous action (Diastatin) application of phytomineral preparation allows in 90% of cases to cure animals on 6-7 days after the first symptoms of diarrhoea, whereas the treatment with Diastatin lasted 11-15 days. Thus, the use of phytomineral preparation allows reducing the treatment period by 5-7 days in comparison with imported preparation, and at the same time to restore positive dynamics of weight gain already on Day 5. Stimulating effect of the preparations included in the created preparation helps to improve haematological indices of the blood of the treated calves and to improve the immunological status of their organism due to the increase in the count of lymphocytes and proteins of γ-globulin fraction. This was not observed with the imported preparation.

An equally significant therapeutic effect observed in both preparations was a considerable hepatoprotective effect, which was manifested by a decrease, even below the physiological norm, in the activity of enzymes-markers of liver cell destruction. But in contrast to the imported preparation, in the Kazakh phytopreparation both components have such an effect, which was the reason for the lower values of alanine aminotransferase and aspartate aminotransferase activity in the blood of animals of the experimental group. The conducted studies did not consider the aetiological cause of diarrhoeal syndrome in calves, and therefore, these studies should be expanded with testing of the preparation in calf diseases of bacterial, viral, parasitic, and other aetiologies to understand such therapeutic effect of the preparation and to detect limitations in its use.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Лікування функціональних розладів шлунково-кишкового тракту телят комплексним фітомінеральним препаратом

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Анотація. Значні економічні втрати, внаслідок захворюваності новонародженого молодняка на діарею, ведуть до зниження рентабельності галузі в структурі сільськогосподарського виробництва. Тому метою роботи стало створення та вивчення терапевтичного ефекту від застосування комплексного фітомінерального препарату з використанням місцевих компонентів: опоки Таскалінського родовища та відвару рослинної сировини верблюжої колючки (*Alhagi maurorum*) для лікування діареї у телят. Вивчення лікувальної дії від препарату проводили в умовах молочнотоварної ферми в Кизилординській області на поголів'ї телят 5-7-денного віку. Дію препарату вивчали в порівняльному аспекті з аналогічним препаратом імпортного виробництва та результатами, отриманими від здорових тварин. При цьому використовували клінічний, гематологічний та біохімічний методи дослідження. Отримані результати вказують на високий терапевтичний ефект створеного препарату. Його застосування дало змогу скоротити тривалість лікувального періоду на 5-7 днів порівняно з імпортним препаратом і вже на 5 день після початку лікування відновити позитивну динаміку середньодобових приростів. Гематологічні дослідження вказують на стимулювання імунної системи у тварин, що проявлялося збільшенням на 14 % кількості лімфоцитів і на 37 % білків γ-глобулінової фракції порівняно зі здоровими тваринами. Ці показники вказують на підвищення активності гуморальної частини імунної системи у тварин після застосування препарату. Також позитивний терапевтичний ефект від препарату спостерігався і в захисній дії на печінку хворих тварин. Незважаючи на присутній ефект в обох лікарських препаратів, зниження активності маркерів, що характеризують руйнування гепатоцитів, було вищим у казахського препарату. Таким чином, створений препарат характеризується вищою терапевтичною дією, порівняно з імпортним препаратом, що дає змогу його рекомендувати для лікування та профілактики діареї у молодняка тварин

Ключові слова: діарея; верблюжа колючка; опока Таскалінського родовища; терапевтичний ефект; Діастатин

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Sowing properties of sunflower seeds of *Talento* hybrid under the influence of a modified plant growth regulator

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Abstract. The improvement of agricultural crop cultivation technologies enables the production of high sunflower yields with high-quality indicators. One such element is pre-sowing seed treatment. This study aimed to investigate the effect of a plant growth regulator supplemented with calcium on the sowing properties of sunflower seeds. The experiment was conducted under laboratory conditions. For pre-sowing seed treatment, a semi-synthetic film-forming agent with an anti-stress effect was

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used, which was modified with Ca^{2+} ions in the form of calcium chloride. It was established that the encrustation of sunflower seed with a growth regulator stimulates germination processes and activates the initial stages of sunflower organogenesis. This increases the indicators of germinative vigour and germination capacity. Adding calcium to the plant growth regulator contributes to a further increase in the indicators of germinative vigour and seed germination capacity of sunflowers by 5.4% and 7.7%, respectively, compared to the control. At the same time, the hypocotyl length increased by 1.51 times compared to the control, while the root length increased by 1.37 times. The accumulation of organic substances in sunflower seedlings is characterised by an increase in dry matter. When calcium was added to the plant growth regulator, a more intensive accumulation of dry matter in the hypocotyl and root was observed compared to the control and the variant using only the growth regulator. The establishment of a ranking range indicated that, based on the parameters studied, the optimal treatment option for the pre-sowing treatment of sunflower seeds is the application of a plant growth regulator containing calcium ions at a concentration of 1.0 g/L. The use of this preparation is relevant and promising for studying the formation of sunflower plant productivity with increased quality indicators under field conditions

Keywords: germinative vigour; germination capacity; calcium; seedling length; dry matter; ranking range

INTRODUCTION

The production of oilseed crops holds a significant place within the structure of Ukraine's agro-industrial complex, with sunflower being the leading crop. The high adaptability of this crop to arid soil and climatic conditions has contributed to increasing production volumes. However, in light of global warming and climate change, there is a growing need to enhance sunflower's adaptability and resilience to adverse environmental conditions. This has prompted researchers to refine and improve the cultivation techniques for this crop to achieve a stable, high-quality yield.

In their analyses of the weather and climate conditions in southern Ukraine, V. Karamushka *et al.* (2022) and V. Pichura *et al.* (2022) noted significant changes over the past decades: there has been a decrease in precipitation, winters have become milder, and summers hotter with persistent dry hot winds. Under these conditions, plants experience hydrothermal stress. One method to enhance the adaptability of crops to adverse conditions is the pre-sowing seed treatment with plant growth regulators. Studies by S. Guo *et al.* (2021), H. Mostafa and M. Afify (2022) confirm that seed germination is a critical stage in plant life. In their studies, G. Kulyk *et al.* (2022) state that seed encrustation with plant growth regulators activates self-regulation processes, improves germination capacity and enhances resistance to unfavourable abiotic factors. Moreover, this enhances root system development (Vasylenko *et al.,* 2020), improves mineral nutrition (Polyakov & Shcherbak, 2022), and fosters the development of floral primordia and sunflower head growth (Tsylyurik & Ostapchuk, 2023).

To enhance the adaptive capacity of plants, nutrients such as calcium are also used in pre-sowing seed treatments. Calcium ions play a role in forming adaptive responses to stress during plant growth and development, improving osmotic tolerance, heat resistance, cold resistance, and more (Vancostenoble *et al.,* 2022). According to U. Aqeel *et al.* (2022), the action of calcium is due to its ability to induce defensive responses in plants (under certain conditions, it enhances the generation of ROS), superoxide radicals and peroxides, and the subsequent activation of other antioxidant signalling systems. A. Haj Sghaier *et al.* (2023) found that pre-sowing seed treatment with calcium chloride improves plant adaptation to adverse conditions. M. Bourioug *et al.* (2020) observed similar results, noting improvements in seed germination improve germination capacity, biomass production, crop structure, and, consequently, crop yields.

Calcium influences various cellular processes in plants by activating antioxidant enzymes, protein synthesis, and the accumulation of low-molecular-weight protectants. In a study examining the role of calcium under salt stress in tomato plants, K. Tanveer *et al.* (2020) found that calcium application mitigated the negative effects of salinity on germination and growth. This was accompanied by an increase in the maturity index, seedling vigour, dry matter accumulation in roots and seedlings, and an increase in plant height and leaf area. R. Catiempo *et al.* (2021) noted that in the presence of calcium ions under salt stress, seed germination and root growth improved, and the epidermis and xylem layers were better protected from damage.

Calcium compounds have been shown to enhance the productivity of rice plants by increasing seed germination capacity, seedling biomass, and reducing lipid peroxidation products. The accumulation of bioactive compounds (polyphenols, flavonoids, and γ-aminobutyric acid) is improved, cell viability is increased, and the antioxidant capacity of germinated rice is enhanced due to the activation of enzymes. Similar enhancements in endogenous antioxidant activity and enzyme activity during seed germination in lettuce were observed by E. Ademola *et al.* (2020), who also noted a reduction in lipid peroxidation. Improvements in growth processes under calcium ion treatment have been observed not only under salt stress but also under drought conditions when plants experience

hydrothermal stress (Silveira *et al.,* 2020). Such drought conditions are typical of the growing season in the Southern Steppe of Ukraine.

A review of the literature on the selected topic revealed that the aspect of increasing the adaptive capacity of sunflower plants has been insufficiently studied. Therefore, the aim of this research was to investigate the effect of a plant growth regulator, modified with calcium ions, on the sowing properties of sunflower seeds of the *Talento* hybrid and to determine the optimal calcium concentration for pre-sowing seed treatment.

MATERIALS AND METHODS

The research was conducted in the Soil and Plant Product Quality Monitoring Laboratory at the Agrotechnology and Ecology Research Institute of the Dmytro Motornyi Tavria State Agrotechnological University. In investigating the effectiveness of calcium and its positive impact on plants, the authors relied on existing literature concerning calcium's efficacy and beneficial effects. This led to the consideration of improving the AKM plant growth regulator by incorporating calcium ions and testing its effectiveness on the sowing quality of sunflower seeds under laboratory conditions.

The plant growth regulator AKM is included in the list of pesticides and agrochemicals approved for use in Ukraine (2023). It is a semi-synthetic film-forming agent with an anti-stress effect. The formulation contains distinol 0.015 g/L (dimethyl sulfoxide + ionol), polyethylene glycol (PEG) – 1500 (440 g/L) and PEG – 400 (190 g/L), the remainder being water. AKM was modified by adding Ca^{2+} ions in the form of calcium chloride. The seed material was encrusted with the resulting preparation one day before the start of the experiment at the recommended concentration of 200 ml/ton. The working solution was applied at a rate of 10 L/ton of seed. The treated sunflower seeds were germinated in rolls on filter paper in a TS-80 thermostat of Ukrainian manufacture at a temperature of +20°C (DSTU 4138-2002). Between two layers of moistened paper, one hundred seeds were placed with the embryo facing downwards in three replications. The experimental design is presented in Table 1. The experiment was replicated four times, according to the methodology for conducting plant science experiments by V. Lypovy *et al.* (2020).

Table 1. *Experimental design of the laboratory study*

Variant	Seed treatment preparation
1	Water (control)
2	AKM
3	AKM + Ca (0.25 g/L)
4	AKM + Ca (0.50 g/L)
5	AKM + Ca (0.75 g/L)
6	AKM + Ca (1.00 g/L)
7	AKM + Ca (1.25 g/L)
8	AKM + Ca (1.50 g/L)
9	AKM + Ca (1.75 g/L)
10	AKM + Ca (2.00 g/L)

Source: *developed by the authors*

The research was conducted on sunflower seeds of the *Talento* hybrid (originator – *Syngenta*), using standard methodologies. This is a high-oleic hybrid for the Clearfield system, with an oleic acid content in the oil of up to 90%, belonging to the mid-early maturity group. It is recommended for cultivation in the Steppe and Forest-Steppe zones. The hybrid was registered in 2016. Sample selection and preparation for analysis, as well as the determination of seed germinative vigour and laboratory germination, were carried out according to the standard methodology (DSTU 4138-2002, 2004). Seed germinative vigour was counted on the fourth day of germination, and germination capacity – on the eighth day. Biometric indicators of sunflower seedlings (hypocotyl and root length) were measured using a standard methodology (Palamarchuk *et al.,* 2022). Dry matter content was determined gravimetrically (DSTU 4138-2002, 2004). Statistical evaluation of the data was performed using the Student's t-test and the "Agrostat" program.

A multi-criteria optimisation method was employed to determine the most effective pre-sowing seed treatment for sunflowers. This method is based on the application of a decision-making mechanism that considers multiple criteria, allowing for the exclusion of the influence of measurement units of seed quality indicators, as well as the magnitudes of acceptable value ranges for each indicator when selecting the pre-sowing treatment method for sunflower seeds (the objective function). The data for selecting the best pre-sowing treatment for sunflower seeds have a two-sided alternative-criteria classification with criterion values f_j and characterise the sowing quality indicators A_j – in quantitative scales and dimensionless form.

Experimental research on plants (both cultivated and wild), including the collection of plant material,

adhered to institutional, national, or international guidelines. The authors complied with the standards set forth by the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

The use of the encrustation method with modern preparations for pre-sowing seed treatment activates self-regulation processes and enhances the sowing quality of seeds as well as their resilience to adverse external factors. In this study, it was found that encrustation of sunflower seeds with the growth regulator AKM stimulated germination processes, as evidenced by a 2.2% increase in germinative vigour compared to the control (Fig. 1). A similar effect with increased seed germinative vigour under the influence of AKM was also observed in the studies of O. Yeremenko and O. Onyshchenko (2020). The addition of calcium to AKM further enhanced this indicator, especially in the variant with a calcium ion concentration of 1.0 g/L, where germinative vigour was 5.4% higher than the control and 3.2% higher compared to the variant where only AKM was used. High calcium concentrations of 1.75 g/L and 2.0 g/L led to a decrease in germinative vigour by 2.2-7.7% compared to all other variants in the study. When determining the laboratory germination capacity of sunflower seeds, it was established that pre-sowing seed treatment contributed to an increase in this indicator by 5.4% compared to the control (Fig. 2). Moreover, the best effect was observed in the variant combining the plant growth regulator AKM with calcium ions at a concentration of 1.0 g/L.

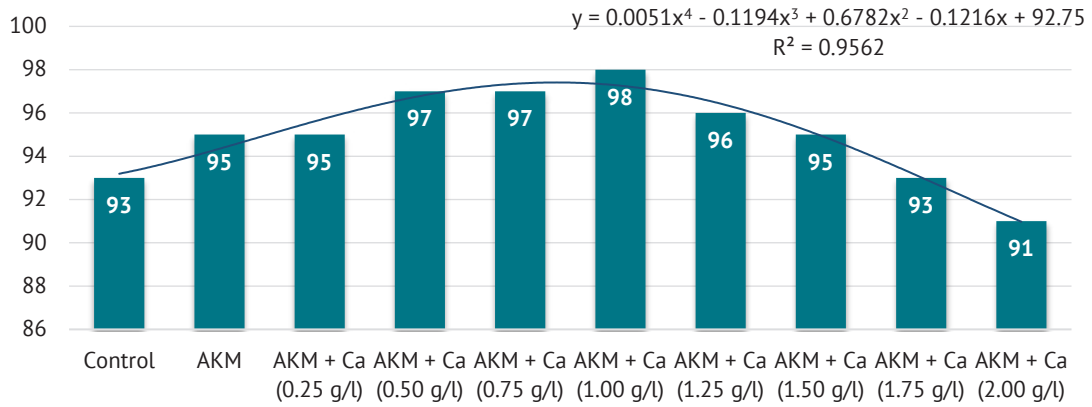

Figure 1. *Effect of the plant growth regulator AKM + Ca on the germinative vigour of Talento hybrid sunflower seeds (approximated polynomial curve of the 4th degree)*
Source: *developed by the authors*

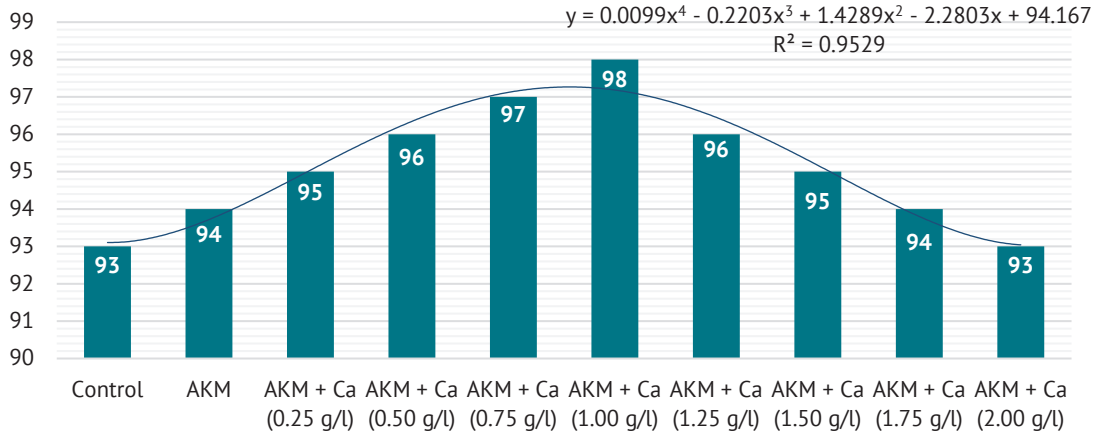

Figure 2. *Effect of the plant growth regulator AKM + Ca on the laboratory germination capacity of Talento hybrid sunflower seeds (approximated polynomial curve of the 4th degree).*
Source: *developed by the authors*

A significant advantage of this seed treatment is the absence of a difference between the germinative vigour and germination capacity percentage of the seeds. This lack of difference in field conditions contributes to a 1-2-day reduction in the sowing-to-emergence period and results in more uniform emergence.

For field trials, it is recommended to treat sunflower seeds with the plant growth regulator AKM saturated with calcium ions at a concentration of 1.0 g/L. When constructing an approximated polynomial curve of the 4th degree of the influence of pre-sowing seed treatment on germinative vigour and laboratory germination capacity, a strong functional dependence was established, where R^2 = 0.95-0.96. Similar results for pre-sowing seed treatment with calcium chloride were obtained by scientists K. Reddy *et al.* (2023), who confirmed the positive impact of calcium ions on seed germination capacity, especially under stress conditions. Subsequently, such treatment contributes to the improvement of both morphological and productive traits of crops. E. Ademola *et al.* (2020) explain the positive effect of calcium ions on improving seed germination processes by enhancing the activity of antioxidant enzymes and reducing lipid peroxidation.

H. Choe *et al.* (2021), in addition to improved germination processes, also reported a better accumulation of antioxidant components (polyphenols, flavonoids, γ-aminobutyric acid) in seedlings in the presence of calcium ions, which activate enzymes, reduce oxidative stress, and improve cell viability. During germination, the embryo utilises the stored nutrients of the achene. In this process, division zones appear on the radicle, cells stretch and differentiate, nutrients and physiologically active substances of the seed are assimilated, and the seedling grows. The activity of growth processes at the initial stages of organogenesis is characterised by the length of the seedlings, especially in variants with pre-sowing treatment of the studied components (Table 2).

Table 2. *Biometric parameters of sunflower seedlings of Talento hybrid*

Variant	Length, cm	
Control	Hypocotyl	4.11 ± 0.16
	Root	7.93 ± 0.31
AKM	Hypocotyl	4.80 ± 0.20
	Root	9.85 ± 0.39
AKM + Ca (0.25 g/L)	Hypocotyl	4.92 ± 0.24
	Root	9.92 ± 0.36
AKM + Ca (0.50 g/L)	Hypocotyl	5.27 ± 0.24
	Root	10.10 ± 0.47
AKM + Ca (0.75 g/L)	Hypocotyl	5.52 ± 0.23
	Root	10.36 ± 0.43
AKM + Ca (1.00 g/L)	Hypocotyl	6.20 ± 0.30
	Root	10.83 ± 0.51
AKM + Ca (1.25 g/L)	Hypocotyl	5.83 ± 0.27
	Root	10.42 ± 0.43
AKM + Ca (1.50 g/L)	Hypocotyl	5.23 ± 0.21
	Root	9.75 ± 0.40
AKM + Ca (1.75 g/L)	Hypocotyl	4.70 ± 0.17
	Root	9.02 ± 0.38
AKM + Ca (2.00 g/L)	Hypocotyl	4.18 ± 0.14
	Root	8.49 ± 0.39

Source: *developed by the authors*

The shortest hypocotyl and root lengths were observed in the control group of sunflower seedlings. The application of AKM resulted in a 16.8% increase in hypocotyl length and a 24.2% increase in root length. A significant impact on seedling growth was observed in variants where calcium was added to AKM. This was particularly evident at concentrations of 0.75, 1.0, and 1.25 g/L, where the hypocotyl length was 1.34-1.51 times higher than the control, and root length was 1.31-1.37 times higher compared to the control. A higher concentration of calcium (2.0 g/L) inhibited growth processes. For instance, the hypocotyl and root lengths in this variant were 14.8% and 16.0% lower, respectively, compared to the variant treated with the regulator alone.

The research revealed that a well-formed, biologically complete reserve of nutrients in seeds significantly influences the initial growth and development of a plant. This reserve determines the direction and intensity of physiological and biochemical processes not only in the initial period of plant growth and development but also throughout the entire growing season (Matskevych *et al.,* 2022). Sunflower seedlings consist of water and dry matter, which is represented by mineral and organic compounds. The increase in dry matter in plants characterises the efficiency of the assimilatory apparatus, the accumulation of macronutrients, the formation of reproductive organs, and, consequently, the formation of yield (Kalenska *et al.,* 2023). The dry matter content in the seedlings of the studied crop is shown in Figure 3.

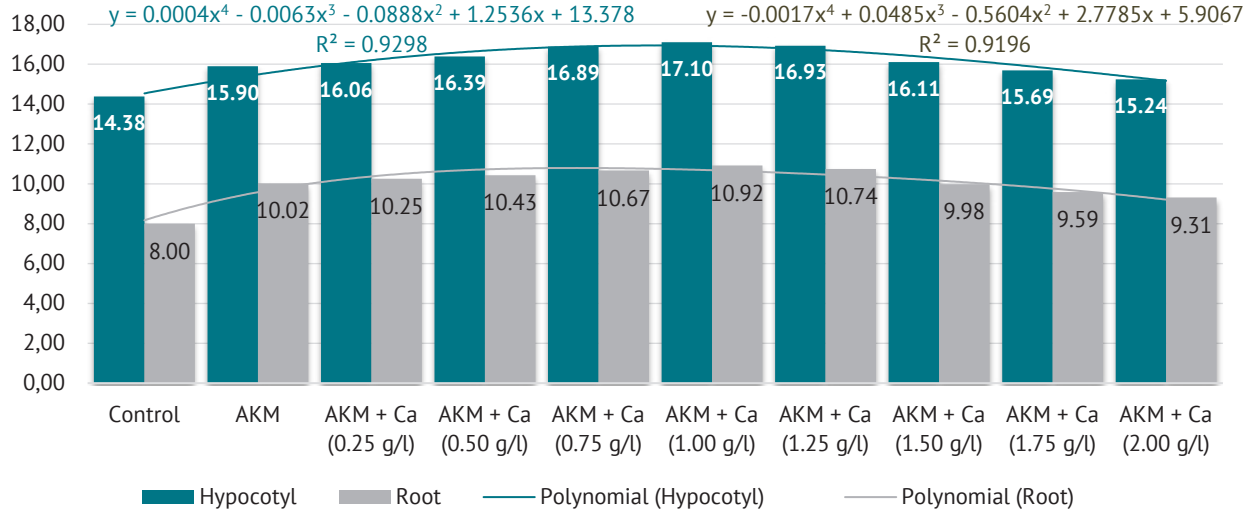

Figure 3. *Dry matter content (%) in sunflower seedlings of the Talento hybrid (approximated polynomial curve of the 4th degree)*

Source: *developed by the authors*

Laboratory experiments revealed that the dry matter content in the hypocotyls of sunflower seedlings was higher than in the roots. The use of a plant growth regulator for pre-sowing seed treatment did not have a significant impact on the dry matter content in the hypocotyl. However, the modification of AKM with calcium ions contributed to a better accumulation of dry matter in the hypocotyl. Specifically, in treatment variants with calcium ion concentrations of 0.5-1.25%, a significant increase of 1.14-1.19 times in this indicator was observed compared to the control.

The accumulation of dry matter in the root was significantly higher than the control, ranging from 1.25 to 1.37 times across all treatment variants. Moreover, the maximum accumulation of dry matter was observed in the hypocotyl and root of sunflower seedlings treated with a calcium ion concentration of 1.0 g/L. Increasing the calcium ion concentration to 2.0 g/L tended to decrease the rate of dry matter accumulation in sunflower seedlings. The construction of an approximated polynomial curve of the 4th degree revealed a strong functional relationship between dry matter accumulation in the hypocotyl and root and the effect of pre-sowing seed treatment with the plant growth regulator AKM in combination with calcium ions, where $R^2 = 0.92 – 0.93$. The corresponding equations are presented in Figure 3.

Similar effects of calcium ions on biometric indicators in tomato plants were observed by A. Singh *et al.* (2020), who noted an increase in fresh and dry mass of roots and shoots in seedlings, as well as an increase in membrane stability index. M. Ashraf *et al.* (2022) in their research also reported an increase in biomass of agricultural crop seedlings, root and shoot length in the presence of calcium compounds, along with increased seed germination, better preservation of carotenoids and phenolic compounds, reduced chlorophyll degradation, and decreased oxidative stress intensity. Scientists T. Mulaudzi *et al.* (2020) found that the presence of calcium ions mitigated the effects of salt stress during the germination of *Sorghum bicolour*. The authors noted improvements in seed germination, root growth, and seedling growth, and highlighted the effectiveness of Ca^{2+} in protecting the xylem from damage. A comparative assessment of the research results established a ranking range for the experimental variants (Table 3).

Table 3. *The results of the values of objective functions ϕ(x1)...ϕ(x10) when choosing the optimal variant of pre-sowing treatment of sunflower seeds*

Alternatives		Criteria, A_j												Values of the objective functions, $\phi(x_i)$	Rank
Experiment variant		Germinative vigor (%), A_2		Seed germination capacity (%), A_2		Hypocotyl length (cm), A_3		Root length (cm), A_4		Dry matter content of hypocotyls (%), A_5		Dry matter content of the root (%), A_6			
f_1		$\hat{f}_1$	f_2	$\hat{f}_2$	f_3	$\hat{f}_3$	f_4	$\hat{f}_4$	f_5	$\hat{f}_5$	f_6	$\hat{f}_6$			
x_1	Control	93.00	0.30	93.00	0.30	4.11	0.05	7.93	0.07	14.38	0.12	8.00	0.07	5.09	10

Table 3. Continued

Alternatives		Criteria, A_j												Values of the objective functions, $\Phi(x_i)$	Rank
Experiment variant	f_1	Germinative vigor (%), A_2		Seed germination capacity (%), A_2		Hypocotyl length (cm), A_3		Root length (cm), A_4		Dry matter content of hypocotyls (%), A_5		Dry matter content of the root (%), A_6			
		$\hat{f}_1$	f_2	$\hat{f}_2$	f_3	$\hat{f}_3$	f_4	$\hat{f}_4$	f_5	$\hat{f}_5$	f_6	$\hat{f}_6$			
x_2	AKM	95.00	0.50	94.00	0.40	4.80	0.34	9.85	0.62	15.90	0.53	10.02	0.65	2.96	7
x_3	AKM+Ca 0.25 g/L	95.00	0.50	95.00	0.50	4.92	0.39	9.92	0.64	16.06	0.58	10.25	0.71	2.68	6
x_4	AKM+Ca 0.50 g/L	97.00	0.70	96.00	0.60	5.27	0.53	10.10	0.7	16.39	0.67	10.43	0.77	2.03	4
x_5	AKM+Ca 0.75 g/L	97.00	0.70	97.00	0.70	5.52	0.64	10.36	0.77	16.89	0.80	10.67	0.83	1.56	2
x_6	AKM+Ca 1.00 g/L	98.00	0.80	98.00	0.80	6.20	0.92	10.83	0.91	17.10	0.86	10.92	0.91	0.80	1
x_7	AKM+Ca 1.25 g/L	96.00	0.60	96.00	0.60	5.83	0.77	10.42	0.79	16.93	0.81	10.74	0.85	1.58	3
x_8	AKM+Ca 1.50 g/L	95.00	0.50	95.00	0.50	5.23	0.52	9.75	0.60	16.11	0.59	9.98	0.64	2.65	5
x_9	AKM+Ca 1.75 g/L	93.00	0.30	94.00	0.40	4.70	0.30	9.02	0.38	15.69	0.48	9.59	0.52	3.62	8
x_{10}	AKM+Ca 2.00 g/L	91.00	0.10	93.00	0.30	4.18	0.08	8.49	0.23	15.24	0.35	9.31	0.44	4.50	9
	f_j^-	90.00		90.00		3.99		7.69		13.95		7.76			
	f_j^+	100		100		6.39		11.15		17.61		11.25			
	$f_j(\delta^e)$	1		1		1		1		1		1			
	f_j^{max}	100 (max)		100 (max)		6.39 (max)		11.15 (max)		17.61 (max)		11.25 (max)			

Source: *developed by the authors*

The optimal treatment for pre-sowing sunflower seed treatment in this experiment was found to be the combination of the plant growth regulator AKM and calcium at a concentration of 1.0 g/L, achieving the first rank (φ (x_1) = 0.80). The second and third ranks were assigned to the treatments of AKM+Ca with active substance concentrations of 0.75 and 1.25 g/L, respectively, as confirmed by the objective function values φ (x_2) = 1.56 and φ (x_3) = 1.58. The control sunflower seeds, based on a comprehensive assessment of sowing quality indicators, were found to be the least suitable for sowing, receiving the tenth rank.

Therefore, the pre-sowing treatment of *Talento* hybrid sunflower seeds with the modified plant growth regulator AKM and a calcium ion concentration of 1.0 g/L exhibited superior seed quality compared to other treatment variants. The impact of calcium ions on seed germination processes is indisputable. However, under various stress conditions, researchers have noted different optimal calcium concentrations. T. Mulaudzi *et al.* (2020) observed that the exogenous application of 5 mM Ca^{2+} was most effective in increasing the salt stress tolerance of *Sorghum bicolour*. To mitigate the negative effects of salt stress on sorghum plants, a concentration of 50 mM $CaCl_2$ was noted. X. Chen *et al.* (2021) also highlighted the positive impact of calcium chloride application on the germination and growth of tomato plants under saline conditions. However, the optimal calcium concentration in this case was found to be 10 mM.

Therefore, the research findings confirm the data of other scientists regarding the influence of growth regulators and calcium ions on the seed quality of sunflowers. The obtained data suggest the promising potential for further research into the effects of the modified plant growth regulator AKM+Ca under field conditions, where the productivity of sunflowers and the quality of the harvested product will be studied. This will allow for the provision of a high-quality food supply to the population.

CONCLUSIONS

Encrusting sunflower seeds with a growth regulator stimulates germination processes, increasing germinative vigour by 2.2% and germination capacity by 3.3% compared to the control. Saturating the regulator with calcium ions (1.0 g/L) further increases these indicators by 5.4% and 7.7%, respectively. Pre-sowing seed treatment activates the initial stages of organogenesis in sunflowers. The application of the preparation increases hypocotyl length by 16.8% and root length by 24.2% compared to the control. The addition of calcium ions (0.75, 1.0, and 1.25 g/L) to AKM increases hypocotyl length relative to the control by 1.34 to 1.51 times and root length by 1.31 to 1.37 times. High concentrations of calcium (2.0 g/L) inhibited growth processes and caused a decrease in germinative vigour by 4.4%, a reduction in hypocotyl length (by 14.8%), and a reduction in root length (by 16.0%), compared to pre-sowing seed treatment of sunflower with a plant growth regulator. The use of a plant growth regulator modified with calcium ions (0.5-1.25 g/L) promoted the intensive accumulation of dry matter in the hypocotyl by 1.14-1.19 times and in the root by 1.30-1.37 times relative to the control. When constructing the ranking range, it was determined that the optimal treatment for pre-sowing sunflower seed processing, based on the investigated indicators, was the application of the growth regulator with a calcium ion concentration of 1.0 g/L. Therefore, further study of the effects of the plant growth regulator in combination with calcium ions under field conditions is both appropriate and promising for obtaining high sunflower seed yields with improved quality.

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None.

CONFLICT OF INTEREST

None.

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Посівні властивості насіння соняшнику гібриду *Talento* за дії модифікованого регулятору росту рослин

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Анотація. Удосконалення технологій вирощування сільськогосподарських культур дає змогу отримувати високі врожаї соняшнику з високими показниками якості. Одним з таких елементів є передпосівна обробка насіння. Метою досліджень було вивчення впливу регулятора росту рослин з додаванням кальцію на посівні властивості насіння соняшнику. Дослід проведений у лабораторних умовах. Для передпосівної обробки насіння використовували напівсинтетичний плівкоутворюючий препарат антистресової дії, який модифікували іонами Ca^{2+} у вигляді хлориду кальцію. Було встановлено, що інкрустація насіння соняшнику регулятором росту стимулює процеси проростання і активізує початкові етапи органогенезу соняшнику. При цьому збільшуються показники енергії проростання і схожості насіння, спостерігається збільшення довжини гіпокотилю і довжини кореня. Додавання кальцію до регулятору росту рослин сприяє додатковому збільшенню показників енергії проростання і схожості насіння соняшнику на 5,4 % і 7,7 %, порівняно з контролем. При цьому довжина гіпокотилю збільшується відносно контролю у 1,51 рази, а довжина коренів у 1,37 рази. Накопичення пластичних речовин у проростках соняшнику характеризує приріст сухої речовини. При додаванні кальцію до регулятора росту рослин спостерігається більш інтенсивне накопичення сухої речовини гіпокотилю і сухої речовини кореня, порівняно з контролем і варіантом досліду з використанням тільки регулятору росту. При побудуванні ранжируваного ряду встановлено, що за досліджуваними показниками для передпосівної обробки насіння соняшнику оптимальним варіантом досліду є варіант обробки регулятором росту рослин з вмістом іонів кальцію 1,0 г/л. Використання даного препарату є актуальним і перспективним для вивчення формування продуктивності рослин соняшнику з підвищеними показниками якості у польових умовах

Ключові слова: енергія проростання; схожість; кальцій; довжина проростків; суха речовина; ранжируваний ряд

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Selection of productive early maturing cotton genotypes with improved fibre quality parameters

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Abstract. The purpose of this article was to study productivity and fibre quality of different cotton genotypes under conditions of Turkestan region of Kazakhstan to determine the most promising genotypes for commercial cultivation. Four genotypes were selected: Tashkent-6, Maktaral-5027, Namangan-1 and Bukhara-8. The study included analysis of such parameters as germination and sprouting time, plant height, flowering and maturity time, yield, number of bolls and fibre quality characteristics.

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The results showed that Tashkent-6 and Maktaral-5027 had the best parameters: yield 3.8 t/ha and 3.5 t/ha, flowering time 55 days and maturity 120 days, plant height 120 cm and 115 cm, number of bolls 45 and 42. The fibre quality of these genotypes was also high: length 32 mm and 31 mm, tensile strength 30 g/tex and 29 g/tex, fineness 2.5 dtex and 2.6 dtex. Namangan-1 and Bukhara-8 genotypes showed moderate results: yield 3.2 t/ha and 3.0 t/ha, flowering time 60 days and ripening time 130 days, plant height 110 cm and 105 cm, number of bolls 40 and 38, fibre length 30 mm and 29 mm, tensile strength 28 g/tex and 27 g/tex, fineness 2.8 dtex and 2.9 dtex. Statistical analysis confirmed the significance of differences between genotypes. The results of the study confirmed high productivity and fibre quality of genotypes Tashkent-6 and Maktaral-5027, which makes them promising for commercial cultivation in Kazakhstan, while genotypes Namangan-1 and Bukhara-8 also have potential for certain agronomic conditions

Keywords: yield; fibre quality; flowering time; plant height; number of bolls

INTRODUCTION

Cotton research is an important aspect of agricultural science in Kazakhstan, as this crop plays a key role in the textile industry. Under conditions of changing climate and growing demand for high quality fibre, there is a need to develop and evaluate new cotton genotypes that can ensure high productivity and fibre quality under different agronomic conditions. In the Turkestan region of Kazakhstan, there is a need to study genotypes adapted to local climatic conditions to improve the efficiency of agricultural production.

Existing research on cotton breeding in Kazakhstan shows considerable success in developing genotypes with improved characteristics (Penkova & Kharenko, 2023). For example, a study by S.P. Makhmadjanov *et al*. (2024) found that thicker stems and more bolls contribute to higher plant productivity under Kazakh conditions. They concluded that genotypes with thicker stems have better resistance to external influences such as wind and rain, which allows them to achieve high productivity even under difficult climatic conditions. In a study by G. Rahimova *et al*. (2024), the authors observed that plant height and stem thickness correlate with drought tolerance, which contributes to their ability to produce high yields. They found that tall plants with thick stems retained moisture better and were more tolerant to drought periods. N.E. Chorshanbiev *et al*. (2021) found that an increase in boll number was directly related to an increase in total cotton yield in different regions of Kazakhstan. They noted that plants with more bolls provide higher fibre yields, which is particularly relevant in resource-limited regions.

Despite significant successes, these studies have their limitations. For example, G. Rahimova *et al*. (2024) did not analyse the resistance of genotypes to diseases and pests, which is an essential factor for practical application of the results. In the study of N.E. Chorshanbiev *et al*. (2021), the authors also did not consider aspects such as the effect of different irrigation and fertilization methods on plant productivity. These limitations indicate the need for more comprehensive studies that consider all possible factors affecting cotton productivity.

Fibre quality is also an important aspect of the research. I.C. Zeynalova *et al*. (2022) found that high fibre length and strength make fibres more suitable for the textile industry in Kazakhstan. They noted that fibres with high strength and length provide better textile products, which increases the competitiveness of Kazakh cotton in the world market. S. Babakholov *et al*. (2022) highlighted that improved fibre quality characteristics contribute to its market value and competitiveness in local and global markets. They showed that fibres with high-quality characteristics attract more buyers and provide better income to producers. In a study by D.K. Akhmedov *et al*. (2022), the authors noted that fibre quality attributes are key to the production of high-end textile products. They found that fibres with high homogeneity and flexibility enable the production of higher quality fabrics and garments, which contributes to the export potential of Kazakhstan.

The study by S. Babakholov *et al*. (2022) was limited only to laboratory conditions without considering field trials, which also reduces the practical relevance of the findings. In the work of D.K. Akhmedov *et al*. (2022), the authors did not consider such critical factors as fibre resistance to mechanical damage and wear, which also affects its quality and suitability for textile production. Several studies have shown the importance of agronomic practices in improving cotton productivity (Shahini *et al.*, 2023). For example, E. Khusanboy *et al*. (2022) confirmed that improved agronomic conditions, such as the use of organic fertilizers and regular irrigation, increase cotton productivity in Kazakhstan. They noted that organic fertilizers improve soil structure and soil fertility, which in turn increases plant yields. D. Kazakova *et al*. (2023) observed that regular irrigation not only increases yield but also improves fibre quality. Sufficient water supply allows plants to develop better and form better quality fibre, which is important for the textile industry. Nevertheless, there are limitations here as well. E. Khusanboy *et al*. (2022) did not consider the long-term effects of organic fertilizer application, which may affect soil sustainability and fertility in the future, and D. Kazakova *et al*. (2023) did not conduct

comparative studies with other irrigation methods, which limits the ability to choose the best irrigation method for specific growing conditions.

Thus, the purpose of this study was to assess the productivity and fibre quality of different cotton genotypes under the conditions of Turkestan region of Kazakhstan. This research is aimed at filling the existing gaps in knowledge and developing recommendations to improve the efficiency of agricultural production in the region. The problematic issue of the study is the need to identify the most productive and sustainable cotton genotypes that can adapt to local climatic conditions and provide high quality fibre.

MATERIALS AND METHODS

The study was conducted in the Turkestan region of Kazakhstan in 2023. Various cotton genotypes were used for selection, including Namangan-1, Tashkent-6, Bukhara-8 and Maktaral-5027 known for their early maturing and high yielding characteristics. The source material was collected from different regions of Kazakhstan, which provided the necessary genetic diversity for the study. The experimental plots were prepared in accordance with agrotechnical norms. The soils of the plots were chernozems with high fertility, which favoured good plant development. The average annual temperature in the region is about 10°C, with summer temperatures reaching 25-30°C, and precipitation is about 300 mm per year, which is typical climatic conditions for the area.

Sowing was carried out in early May, when the soil had warmed to the optimum temperature of 15°C for cotton seed germination. Plant care included regular watering, weeding, fertilization and pest control. All agronomic measures were carried out under the same conditions for all genotypes, which ensured equal opportunities for their development. A drip irrigation system was used for irrigation to ensure uniform water distribution and prevent drought. Watering was done twice a week, depending on weather conditions and soil moisture level. Weeding was done manually every fortnight to prevent weeds from competing for resources and to ensure optimal conditions for plant growth. Fertilization was carried out in three stages. At sowing, a complex fertilizer of nitrogen, phosphorus, potassium (NPK) was applied in the proportion of 15:15:15, 50 kg/ha, to ensure initial plant growth. In the phase of active growth, an additional nitrogen fertilizer in the form of urea (carbamide) with a concentration of 46%, 30 kg/ha, was applied to stimulate vegetative growth. Before flowering, potassium fertilizer (potassium sulphate) was applied at 20 kg/ha to improve fibre quality and plant stability. Insecticides and fungicides were used for pest protection. Insecticide "Aktara" (thiamethoxam) was used for protection against aphids and whitefly, applied at a concentration of 0.2 g/litre of water, spraying was carried out once a month. Topaz fungicide (pencicuron) was used to prevent fungal diseases, applied at a concentration of 1 ml/litre of water, sprayed twice a season. Spraying with Bordeaux liquid (1% solution) at the beginning of the season and before flowering was also carried out to prevent diseases, which helped to prevent fungal infections.

During the growing season, regular monitoring and data collection was carried out on the following parameters: germination and sprouting time, plant height, flowering and ripening time, yield, and biometric parameters (stem length and thickness, number of bolls). The germination and sprouting time were recorded by the number of days from sowing to first sprouts. Plant height was measured at different growth stages using a ruler. Flowering and ripening times were recorded by the dates of onset of flowering and ripening of fruits. Yield was measured by weighing the harvested fibre from each experimental plot. Biometric parameters such as the length and thickness of stems were measured using caliper and the number of bolls was recorded by counting.

After maturation, fibre was collected for further analysis. The fibres were evaluated for the following qualitative parameters: length, tensile strength, fineness, uniformity, and flexibility. Fibre length was measured using a microscope and special equipment, and each fibre sample was measured in length at least 10 times to ensure accuracy. Tensile strength was determined using a tensile testing machine, with at least 10 tests for each sample to obtain average values. Thinness was measured with a micrometre, followed by calculation of the average value from 10 measurements for each specimen. Homogeneity was assessed visually and with a microscope, recording uniformity and the absence of significant deviations in the fibre structure. Flexibility was measured by mechanical tests involving bending and stretching of the fibre.

Various methods were used to assess fibre quality. Microscopic examination determined the length and uniformity of the fibre. Mechanical tests were performed to determine the strength and flexibility of the fibre, including tensile and bending tests. Chemical analysis was used to determine the composition and purity of the fibre, including analysis of cellulose content and impurities. Chemical analysis was carried out using standard methods such as acid and alkaline hydrolysis to determine fibre composition. The data obtained were subjected to statistical analysis to identify significant differences between genotypes. The method of analysis of variance (ANOVA) and multiple comparative analysis made it possible to identify the best samples for each indicator, which ensured the objectivity and reliability of the conclusions. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

The germination and sprouting time for different cotton genotypes varied but averaged 7-10 days. Genotypes Tashkent-6 and Maktaral-5027 showed the fastest sprouting, reaching 7 days, which indicates their good adaptation to the climatic conditions of the region and their ability to quickly start vegetation. This is especially important in conditions of limited vegetation period characteristic of Turkestan region. While genotypes, Namangan-1 and Bukhara-8 required up to 10 days for full germination. Rapid germination and sprouting allow plants to start photosynthesis earlier, which ensures better development and productivity. Also, a faster start of vegetation gives plants more time to form a full crop, which reduces the risks associated with unfavourable weather conditions at the end of the season. For example, fast-growing genotypes will have an advantage in the face of unexpected cold weather or prolonged rains that may occur in late summer or early autumn. Plant height was measured at different growth stages, and the maximum height was recorded in genotype Tashkent-6 (120 cm). This indicates its vigorous growth and potential ability to form a significant amount of vegetative mass, which is crucial for high yield formation (Table 1). The genotype Maktaral-5027 followed with a height of 115 cm, showing similar growth characteristics. Namangan-1 and Bukhara-8 attained heights of 110 cm and 105 cm, respectively. Taller plants can capture more light, which contributes to a more efficient photosynthesis process and higher yields. In addition, high plant mass provides more leaf area, which also has a positive effect on photosynthetic activity and hence the overall biomass of the plant. However, plants that are too tall may be more prone to lodging due to wind or rainfall, which should be considered when selecting genotypes for cultivation.

Table 1. *Height of cotton genotypes at different growth stages, cm*

Genotype	Plant height on day 30	Plant height at day 60	Plant height at day 90	Maximum height
Tashkent-6	30	70	110	120
Maktaral-5027	28	68	105	115
Namangan-1	25	65	100	110
Bukhara-8	23	60	95	105

Source: *developed by the authors*

The time of flowering and maturation is an important indicator determining the possibility of obtaining an early harvest. Genotypes Tashkent-6 and Maktaral-5027 started flowering 55 days after sowing, which is an advantage in conditions of a short growing season. Early flowering allows plants to use available resources more efficiently and avoid the impact of possible unfavourable weather conditions at the end of the season. While Namangan-1 and Bukhara-8 genotypes started flowering 5 days later, which is also an acceptable result, but may reduce their competitiveness in conditions of tough competition for light and nutrients. Fruits ripened in 120 days in Tashkent-6 and Maktaral-5027 and in 130 days in Namangan-1 and Bukhara-8. Early ripening allows for faster production and reduces the risks associated with unfavourable weather conditions at the end of the season. For example, early ripening can be particularly significant in environments where autumn rains or first frosts can damage unharvested crops. It also allows optimization of the schedule of farm machinery and labour, which is important for efficient farm management.

Early flowering and ripening have a significant impact on the overall production cycle of an agricultural enterprise. The Tashkent-6 and Maktaral-5027 genotypes allow farmers to plan and allocate labour resources more efficiently. For example, the ability to start harvesting 10 days earlier compared to Namangan-1 and Bukhara-8 avoids the peak period of loading agricultural equipment and labour, which reduces costs and reduces the likelihood of errors and losses associated with overloading. Early flowering is also critical for the integration of crop management systems. It allows for more flexible fertilizer and protection schedules. For example, genotypes that flower earlier can take advantage of early nitrogen fertilization to improve plant development and disease and pest resistance.

Yield was measured by weighing the harvested fibre from each experimental plot. The highest yield was recorded for genotype Tashkent-6 (3.8 t/ha), indicating its high productivity and ability to form a significant amount of marketable fibre. Maktaral-5027 showed slightly lower yield (3.5 t/ha), but also demonstrated a high level of productivity. Genotypes Namangan-1 (3.2 t/ha) and Bukhara-8 (3 t/ha) showed slightly lower results, but still high enough for the conditions of the region. Differences in yield were statistically significant ($p<0.05$), which confirms the objectivity and reliability of the obtained data. For more detailed analysis, yields were compared in different phases of the growing season. At the beginning of the growing season, when plants were just beginning to form fruits, it was observed that genotypes Tashkent-6 and Maktaral-5027 showed more active growth and development compared to Namangan-1 and Bukhara-8. This was expressed in a greater number of ovaries and intensive formation of bolls.

In the middle phase of vegetation, Tashkent-6 and Maktaral-5027 plants continued to outperform other

genotypes in the number of formed capsules and total biomass. Observations showed that during this period, Tashkent-6 had an average of 10-12% more bolls formed than Namangan-1 and Bukhara-8. Maktaral-5027 showed similar results, which confirms its high potential. At the final stage of the growing season, when ripening and harvesting took place, Tashkent-6 and Maktaral-5027 again showed their advantages. Data analysis showed that Tashkent-6 genotype provided 15% higher yield of marketable fibre compared to Namangan-1, and Mactaral-5027 – 12% more. These results are significant and indicate the high potential of these genotypes for industrial cultivation.

Based on the analysis, it can be concluded that genotypes Tashkent-6 and Maktaral-5027 have high productivity and yield stability under different growing conditions. Their ability to form numerous bolls, responsiveness to improved agronomic conditions and resistance to climatic stresses make them promising for commercial use. The Namangan-1 and Bukhara-8 genotypes, despite their lower performance, also showed stable results and can be used in environments where resource conservation or specific constraints are required. These genotypes can be recommended for use in combination with improved agronomic practices to achieve optimal results. An important aspect of the study was the biometrics, which were studied in detail for each cotton genotype. Biometric data include stem length and thickness, as well as the number of bolls per plant, which are directly related to yield potential.

Stem length was measured at different growth stages, and the maximum stem length was recorded in genotype Tashkent-6 (120 cm). This indicates the vigorous growth of this genotype and its potential to form a significant amount of vegetative mass. Genotype Maktaral-5027 reached a height of 115 cm, showing similar growth characteristics. Namangan-1 and Bukhara-8 showed lower stem heights of 110 cm and 105 cm, respectively. Taller plants can capture more light, which contributes to a more efficient photosynthesis process and increased yield. However, it should be noted that too high plant mass may be more prone to lodging due to wind or rainfall, which should be considered when selecting genotypes for cultivation. On the other hand, plant height can also have an impact on the ease of carrying out agricultural operations such as processing and harvesting. For example, plants that are too tall may make mechanized harvesting difficult, requiring additional costs for manual labour or special machines. It is therefore important to consider the balance between plant height and lodging resistance when selecting genotypes for commercial cultivation.

Stem thickness also played a pivotal role in the evaluation of biometric indices. Stem thickness was highest in Tashkent-6 (1.8 cm), followed by Maktaral-5027 (1.7 cm), Namangan-1 (1.6 cm) and Bukhara-8 (1.5 cm). Thicker stems may indicate greater plant resistance to lodging and damage, which is also crucial for high yields. Thicker stems promote better transport of nutrients and water within the plant, which contributes to overall plant health and productivity. In addition, lodging resistance is relevant for maintaining fibre quality, as damaged or lodged plants can lead to contamination and poor harvest quality. Stem thickness can also affect the mechanical properties of plants, such as flexibility and strength. Thicker stems may be more resistant to mechanical damage, which is particularly essential in high wind conditions or when cultivating plants. Importantly, genotypes with thicker stems, such as Tashkent-6 and Maktaral-5027, may provide more stable and consistent plant development, which contributes to overall plant productivity and longevity.

Box number is another key indicator that was studied in detail. Genotypes Tashkent-6 and Maktaral-5027 had a higher number of bolls (45 and 42, respectively) compared to Namangan-1 (40) and Bukhara-8 (38) (Table 2). This indicates the ability of the first two genotypes to form more fruits, which directly affects the total yield. The increased number of bolls per plant indicates the high potency of these genotypes to produce more cotton, making them more economically viable for commercial cultivation. A high number of bolls may also indicate good pollination and fruiting, which is a critical factor for consistently high yields.

Table 2. *Number of bolls of early maturing cotton genotypes with improved fibre quality in the Republic of Kazakhstan*

Genotype	Number of boxes on day 30	Number of boxes on day 60	Number of boxes on day 90	Maximum number of boxes
Tashkent-6	10	30	45	45
Maktaral-5027	9	28	42	42
Namangan-1	8	25	40	40
Bukhara-8	7	23	38	38

Source: *developed by the authors*

It should also be noted that the number of bolls may be related to the genetic predisposition of plants to fruiting and their adaptive capacity in the conditions of a particular region. In the genotypes Tashkent-6 and Maktaral-5027, the high level of fecundity may be due to their genetic features, as well as good adaptation

to soil and climatic conditions of Turkestan region. This is confirmed by the stability of their indicators during the whole period of cultivation. The fibre quality was assessed according to the following parameters: length, tensile strength, fineness, uniformity, and flexibility. These parameters are of key importance for determining the suitability of fibre for the textile industry and its market value. The fibre length was maximum in genotype Tashkent-6 (33 mm), indicating its high value for textile industry (Table 3). Long fibres provide strong and quality yarn, which is especially important to produce high-quality textile products. Maktaral-5027 showed a fibre length of 32 mm, Namangan-1 showed a fibre length of 30 mm and Bukhara-8 showed a fibre length of 29 mm. Fibre length is an essential indicator, as long fibres are easier to process and produce stronger and higher quality yarns. For example, long fibres can be used to produce fabrics with a high level of strength and durability, which is especially crucial for garments and other products subjected to intensive use.

Table 3. *Fibre quality of early maturing cotton genotypes with improved fibre quality in the Republic of Kazakhstan*

Genotype	Fibre length (mm)	Tensile strength (g/tex)	Fibre fineness (microns)	Fibre homogeneity (1-10)	Fibre flexibility (1-10)
Tashkent-6	33	35	4.5	9	9
Maktaral-5027	32	34	4.6	9	9
Namangan-1	30	32	4.7	8	8
Bukhara-8	29	30	4.8	8	8

Source: *developed by the authors*

Tensile strength was also highest in Tashkent-6 (35 g/tex), followed by Maktaral-5027 (34 g/tex), Namangan-1 (32 g/tex) and Bukhara-8 (30 g/tex). Tensile strength is an important indicator as it determines the durability and wear resistance of the final textile products. High tensile strength allows the fibre to withstand significant loads, which is particularly crucial in the production of fabrics and other textile products. For example, a strong fibre can be used to produce fabrics that will withstand intense mechanical stresses, such as workwear, sports equipment and other products subjected to high stresses during use. The fibre fineness was measured with a micrometre and was 4.5 micron for Tashkent-6, 4.6 micron for Maktaral-5027, 4.7 micron for Namangan-1 and 4.8 micron for Bukhara-8. Fibre fineness is an essential indicator, as finer fibres provide a softer and more pleasant to the touch fabric. In addition, fine fibres are easier to process, which reduces the cost of textile production (Sakkaraeva & Kumashev, 2024). For example, fine fibres can be used to produce fabrics that are soft and comfortable to wear, which is particularly important to produce clothing and bed linen.

Fibre homogeneity was assessed visually and using a microscope. Tashkent-6 and Maktaral-5027 showed the best homogeneity, which indicates the stability of their genetic characteristics and ability to form high quality fibre. Namangan-1 and Bukhara-8 showed slight deviations, which may be due to less stable genetic characteristics or the influence of external factors on plant development. Fibre homogeneity is critical for obtaining quality yarns and fabrics without defects. For example, homogeneous fibre allows the production of fabrics with uniform texture and no weaknesses, which increases their overall strength and quality. Fibre flexibility was maximum in Tashkent-6 and Maktaral-5027, which was confirmed by mechanical bending and tensile tests. Fibre flexibility is a critical indicator, as it determines the usability and durability of textile products. High flexibility allows the fibre to easily adjust to different shapes and loads, which is especially relevant in the production of clothing and other textile products (Boyko & Prokopchuk, 2024). For example, flexible fibres can be used to produce fabrics that are comfortable to wear and do not restrict movement, which is particularly important for sports and workwear.

The data obtained were subjected to detailed statistical analyses to determine the significance of differences between the cotton genotypes under study for various indicators. ANOVA was used to assess the differences between the mean values of the indicators of each genotype. This method determines whether the observed differences between genotypes are significant or can be explained by random variation. Tashkent-6 and Maktaral-5027 showed the best results for most parameters (Table 4). In particular, the analysis showed that in terms of germination and sprouting time, plant height, flowering and ripening time, yield, stem length and thickness, number of bolls, and fibre quality (length, tensile strength, fineness, uniformity, and flexibility), the differences between these genotypes and others were statistically significant ($p < 0.05$). This confirms their high productivity and improved fibre quality parameters.

Table 4. *Results of ANOVA analysis of early maturing cotton genotypes with improved fibre quality in the Republic of Kazakhstan*

Parameter	p-value (ANOVA)	Statistical significance ($p < 0.05$)
Germination time (days)	0.0012	Significant

Table 4. Continued

Parameter	p-value (ANOVA)	Statistical significance (p < 0.05)
Plant height (cm)	0.0025	Significant
Flowering time (days)	0.0018	Significant
Maturation time (days)	0.0015	Significant
Yield (tonnes/ha)	0.0009	Significant
Number of boxes	0.0031	Significant
Fibre length (mm)	0.0004	Significant
Tensile strength (g/tex)	0.0003	Significant
Fibre fineness (microns)	0.0045	Significant
Fibre homogeneity	0.0056	Significant
Fibre flexibility	0.0061	Significant

Source: *developed by the authors*

Based on research and data analysis, the genotypes Tashkent-6 and Maktaral-5027 were selected as the most promising for further breeding and industrial introduction. These genotypes showed high yield, good biometric parameters and excellent quality characteristics of fibre, which makes them ideal candidates for improving the efficiency of cotton production in Kazakhstan. The conclusion summarized the results of the work, described the main results, and made conclusions about the prospects of using the selected cotton genotypes in agricultural production. The obtained data confirmed that selection of productive early maturing genotypes with improved fibre quality indicators is effective and promising for further development of the industry.

DISCUSSION

The study showed that genotypes Tashkent-6 and Maktaral-5027 have high productivity and fibre quality, which makes them promising for commercial cultivation in the conditions of Turkestan region of Kazakhstan. High yields of genotypes Tashkent-6 and Maktaral-5027 (3.8 t/ha and 3.5 t/ha, respectively) indicate their potential for forming a significant volume of commercial fibre. It is important to note that in the study of J. Dirbas *et al.* (2023), the authors also found high productivity of cotton genotypes adapted to Central Asian conditions, which confirms the importance of selecting high yielding genotypes for regions with similar climatic conditions. Similar results were also obtained by D. Queiroz *et al.* (2021) and I. Gomes *et al.* (2022), who noted that high yielding genotypes provide stability and production efficiency even under climatic stresses.

Early flowering and maturity of genotypes Tashkent-6 and Maktaral-5027 is an important advantage. These genotypes started flowering 55 days after sowing and matured in 120 days, which avoids unfavourable weather conditions such as autumn rains and frosts. In the studies of P. Wang *et al.* (2021), it was observed that early flowering and maturation promotes better utilization of available resources and reduces the risk of yield losses due to adverse weather conditions. The results of the above study support these findings, highlighting the importance of selecting genotypes with early flowering to enhance tolerance to climatic stresses. Similar conclusions were drawn in the studies of Z. Ma *et al.* (2021) and O. Alishah (2021), who emphasized that early flowering and maturation significantly increase the chances of successful production in a changing climate.

Stem thickness and number of bolls also play a pivotal role in high productivity (Dymytrov *et al.*, 2023). In the study, genotypes Tashkent-6 and Maktaral-5027 showed thicker stems and higher number of bolls compared to Namangan-1 and Bukhara-8. This agrees with the findings of A. Younas *et al.* (2021) and L. Li *et al.* (2022), who revealed that thicker stems promote better nutrient and water transport, which has a positive effect on overall plant productivity. Similar results were also reported by X. Song *et al.* (2021) and G. Billings *et al.* (2022), who showed that increased stem thickness correlates with overall plant resilience and ability to produce high yields. The study also revealed a significant correlation between boll number and total fibre yield. The genotypes Tashkent-6 and Maktaral-5027 formed more bolls, which directly influenced the total fibre yield. This is supported by the studies of E. Seidy *et al.* (2023), who found that an increase in boll number was associated with an increase in total cotton yield. These results agree with those presented in the work by X. Liu *et al.* (2022), where it was also shown that the number of bolls is an important indicator of the potential yield of cotton genotypes.

A crucial aspect of research on early maturing cotton genotypes in the Republic of Kazakhstan was the study of fibre quality, as it directly affects its suitability for the textile industry. Genotypes Tashkent-6 and Maktaral-5027 showed high performance in key fibre characteristics: length, tensile strength, fineness, uniformity, and flexibility. In particular, the fibre length of Tashkent-6 was 32 mm and that of Maktaral-5027 was 31 mm, which is higher than that of other tested genotypes. The tensile strength for these genotypes was 30 g/tex for Tashkent-6 and 29 g/tex for Maktaral-5027, indicating their high strength and durability. Fibre

fineness was 2.5 dtex for Tashkent-6 and 2.6 dtex for Maktaral-5027, indicating their good textile properties. Fibre uniformity was evaluated by coefficient of variation, which was 8% in Tashkent-6 and 9% in Maktaral-5027, indicating a low level of variation in fibre characteristics. The flexibility of the fibre was also found to be high, making it more convenient for processing and use in the textile industry.

These results agree with the studies of A. Razzaq *et al*. (2022), who also noted that high fibre length and tensile strength contribute to the improvement of fibre textile qualities and its market value. In their study analysing different cotton genotypes, it was shown that fibres with a length greater than 30 mm and a tensile strength greater than 28 g/tex provided higher textile strength and durability. This makes the fibre more suitable for making high quality textile products such as fabrics and garments, which is consistent with the findings on the quality of Tashkent-6 and Maktaral-5027 fibres. An exploratory study by M. Peixoto *et al*. (2022) also supports the results of the above study, stressing that improved quality characteristics of fibre contribute to its market value and competitiveness in the global market. Their work points out that fibres with high length, strength, and uniformity characteristics are becoming more marketable as they are used to producing fabrics that require high quality standards. They emphasize that improving these characteristics allows producers to earn higher profits and gain a competitive position in the international market. The research data in Kazakhstan supports these conclusions, showing that Tashkent-6 and Maktaral-5027 have high fibre characteristics that can significantly improve their competitiveness and attractiveness to the textile industry.

Correlation analysis between biometric parameters and yield showed that such parameters as plant height, stem thickness and number of bolls have strong positive correlation with total yield. In the study, genotypes Tashkent-6 and Maktaral-5027 showed high values for these parameters, which explains their high yield. The plant height of Tashkent-6 reached 120 cm and that of Maktaral-5027 reached 115 cm, which allowed these genotypes to capture sunlight and conduct photosynthesis efficiently. Stem thickness was also significant: Tashkent-6 had 1.8 cm and Maktaral-5027 had 1.7 cm, which ensured the strength and stability of the plants, as well as their ability to support numerous bolls. In a study by M. Mari *et al*. (2022), it is also noted that these biometric indices are reliable indicators of overall plant productivity. They pointed out that plant height and stem thickness are directly related to their ability for efficient photosynthesis and biomass accumulation, which ultimately leads to higher yields. In the study, it was shown that plants with a height of more than 110 cm and a stem thickness of more than 1.5 cm exhibited 20 per cent higher yields compared to plants that had lower biometric parameters.

Similar conclusions were reached in the work of D. Cardoso *et al*. (2021), who emphasized the importance of an integrated approach to assess biometric characteristics to predict potential yield. They noted that the number of bolls is a key indicator, as each boll represents a potential source of fibre. In the study, the number of bolls in Tashkent-6 was 45 and 42 in Maktaral-5027, which is significantly higher than Namangan-1 (40) and Bukhara-8 (38). These data confirm that an increase in the number of bolls leads to a significant increase in the total volume of fibre produced. The results also emphasize the need for further research into the adaptation of genotypes to different climatic conditions. A study by R. Gibely (2021) showed that studying the adaptive capacity of genotypes under changing climate conditions can help to develop strategies to improve crop resilience. The results of the above study are consistent with their findings and emphasize the importance of selecting genotypes with high adaptability to increase resilience to climate stresses.

In addition, the results confirm the importance of genetic analysis and breeding programmes to improve existing genotypes. In a study by M. Divya *et al*. (2023), the authors showed that the use of modern genetic methods and technologies can significantly accelerate the breeding process and improve the productivity and sustainability of new varieties. The study also points out the importance of such approaches for further development of cotton production in Kazakhstan. Thus, the results of the above study confirm high productivity and fibre quality of genotypes Tashkent-6 and Maktaral-5027, which makes them promising for commercial cultivation in Kazakhstan. Comparison of the data with the results of other researchers shows that the findings are consistent with global trends and emphasize the importance of selecting appropriate genotypes to improve the efficiency of agricultural production. In particular, the results of studies by J. Patel *et al*. (2022), E. Amer and S. Hassan (2023), confirmed the importance of early flowering and maturity, as well as high biometric traits for improving overall productivity and tolerance to climatic stresses.

CONCLUSIONS

As a result of the research, the productivity, and fibre quality of four cotton genotypes: Tashkent-6, Maktaral-5027, Namangan-1 and Bukhara-8 were determined under the conditions of Turkestan region of Kazakhstan. The main results showed that the genotypes Tashkent-6 and Maktaral-5027 have the highest indicators for most of the studied parameters, which makes them promising for commercial cultivation in the region. These genotypes showed high yields of 3.8 t/ha and 3.5 t/ha, respectively, which is significantly higher than Namangan-1 (3.2 t/ha) and Bukhara-8 (3 t/ha). Both genotypes were also distinguished by early flowering (55 days) and ripening (120 days), which is a significant

advantage in conditions of short growing season. The height of Tashkent-6 plants reached 120 cm, and Maktaral-5027 – 115 cm, which contributed to their high productivity. The number of bolls in Tashkent-6 was 45 and in Mactaral-5027 – 42, which also exceeds the results of Namangan-1 (40) and Bukhara-8 (38).

The fibre quality of Tashkent-6 and Maktaral-5027 genotypes was at a high level. Fibre length was 32 mm and 31 mm, respectively, tensile strength was 30 g/tex and 29 g/tex, fineness was 2.5 dtex and 2.6 dtex. These values exceed the results obtained for Namangan-1 and Bukhara-8, which makes Tashkent-6 and Maktaral-5027 fibres more attractive for the textile industry. The results of the study underline the significance of selection of genotypes with high productivity and fibre quality for increasing the efficiency of agricultural production. Genotypes Tashkent-6 and Maktaral-5027 are recommended for use in Kazakhstan to increase yield and improve the quality of fibre produced. Genotypes Namangan-1 and Bukhara-8 also have potential for certain agronomic conditions, but they showed more moderate results.

Limitations of the study include the specificity of climatic conditions in Turkestan Oblast, which may limit the applicability of the results in other regions. Possible variations in agronomic practices and their impact on fibre productivity and quality also need to be considered. In the future, it is recommended to conduct comparative studies in different climatic zones and using different agronomic practices to obtain more generalized data. To further increase productivity and fibre quality, it is recommended to continue research in several directions. Study the adaptive capacity of genotypes to changing climatic conditions. Optimize agronomic practices to improve productivity and conduct genetic research to improve breeding programmes. Long-term studies are also needed to assess the stability of productivity and fibre quality under different conditions.

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CONFLICT OF INTEREST

None.

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Селекція продуктивних ранньостиглих генотипів бавовнику з поліпшеними якісними показниками волокна

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Анотація. Метою даної статті було вивчення продуктивності та якості волокна різних генотипів бавовнику в умовах Туркестанської області Казахстану для визначення найбільш перспективних генотипів для комерційного вирощування. Було обрано чотири генотипи: Ташкент-6, Мактарал-5027, Наманган-1 і Бухара-8. Дослідження включало аналіз таких параметрів, як час проростання і сходів, висота рослин, час цвітіння і дозрівання, врожайність, кількість коробочок і якісні характеристики волокна. Результати засвідчили, що Ташкент-6 та Мактарал-5027 мали найкращі показники: врожайність 3,8 т/га та 3,5 т/га, час цвітіння 55 днів та достигання 120 днів, висота рослин 120 см та 115 см, кількість коробочок 45 та 42. Якість волокна цих генотипів також була високою: довжина 32 мм і 31 мм, міцність на розрив 30 г/текс і 29 г/текс, тонкість 2,5 дтекс і 2,6 дтекс. Генотипи Наманган-1 і Бухара-8 показали помірні результати: врожайність 3,2 т/га та 3 т/га, час цвітіння 60 днів та дозрівання 130 днів, висота рослин 110 см та 105 см, кількість коробочок 40 та 38, довжина волокна 30 мм та 29 мм, міцність на розрив 28 г/текс та 27 г/текс, тонкість 2,8 дтекс та 2,9 дтекс. Статистичний аналіз підтвердив значущість відмінностей між генотипами. Результати дослідження підтвердили високу продуктивність та якість волокна генотипів Ташкент-6 та Мактарал-5027, що робить їх перспективними для комерційного вирощування в Казахстані, в той час як генотипи Наманган-1 та Бухара-8 також мають потенціал для певних агротехнічних умов

Ключові слова: урожайність; якість волокна; час цвітіння; висота рослин; кількість коробочок

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Influence of sowing dates and fertilisation on yield and quality of winter wheat grain

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Abstract. New wheat varieties exhibit a high adaptive potential for productivity. The question of improving cultivation technologies, specifically sowing dates, optimised fertilisation systems, and micronutrient application, remains relevant to fully realise the genetic potential of these varieties under specific soil and climatic conditions. The aim of this study was to determine the influence of sowing dates, fertilisation, and foliar application of micronutrients on the yield and quality parameters of winter wheat grown in the Western Forest-Steppe zone. A field experiment was conducted on grey forest surface-gleyed soils during 2021-2023. The study evaluated the yield formation parameters and quality indicators of the winter wheat varieties Estafeta myronivska, Dovira odeska, and Akhim under sowing dates of 20 September, 5 October, and 20 October. It was determined that the yield and grain quality of the studied wheat varieties varied under the influence of sowing dates, fertilisation, and foliar micronutrient application. Sowing winter wheat on 5 October resulted in the highest yields over the years of the study: on average, 5.29 t/ha for the Estafeta myronivska, 4.78 t/ha for Dovira odeska, and 5.05 t/ha for Akhim. The highest productivity (5.83 t/ha) was achieved by sowing Estafeta myronivska with $N_{120}P_{90}K_{90}$ fertilisation and foliar application of the Aidamin complex. Across all wheat varieties, protein content, gluten content, and vitreousness increased from the earliest to the latest sowing dates. The findings of this study can be applied to enhance the productivity of winter wheat agroecosystems and produce high-quality grain under production conditions

Keywords: winter wheat; yield; 1,000-grain weight; protein content

INTRODUCTION

The introduction of new winter wheat varieties into production is directly linked to the improvement of existing cultivation technologies. Under conditions of changing weather and climate, the development of measures to mitigate the negative impact of changing temperature regimes and soil moisture deficits on the productivity of grain crops is becoming increasingly important. Researchers L. Wilson *et al*. (2021) note an increase in temperature of 2.0°C since the beginning of the 20th century and 1.2 degrees since the 1990s. According to scientists' forecasts, this trend will affect the growing conditions of all crops. O. Tarariko *et al*. (2022) also indicate that the shift of soil-climatic zones northward in the next 20-50 years may cause significant changes in agricultural production in general. Already, there is an observed lengthening of the growing season of winter crops by 10-20 days due to an increase in the frost-free period in winter and a shortening of the spring vegetation period, which necessitates changes in some elements of the cultivation technology, in particular, a review of the sowing dates of winter crops.

Researchers B. Bliznyuk *et al*. (2019) highlight that optimal sowing dates vary in different soil and climatic conditions and depend on preceding crops, soil moisture reserves, and other factors. Only by adhering to optimal sowing dates can high grain yields with corresponding quality indicators be achieved. According to observations by S. Poltoretskyi *et al*. (2020), the increase in average daily air temperatures during the autumn growing season causes a shift of optimal sowing dates towards later terms. According to V. Petrychenko and O. Korniychuk (2018), the warming in the first half of November is 1.8°C, which significantly reduces the impact of late sowing on overwintering conditions and allows them to be shifted to later dates.

O.L. Ulich (2018) indicates a shift towards later sowing dates for winter wheat: by 30 days compared to the 1950s, and by 10 days compared to the 1990s. V. Polovyi *et al*. (2018) in their research also highlight that, compared to the late 20th century, at the beginning of the 21st century, optimal sowing dates shifted from 15-25 September to 25-5 September-October. The increase in seed productivity of plants when sowing dates are shifted from the second decade of September to the first decade of October is confirmed by the research of R.A. Vozhegova and V.M. Bily (2019). When sowing at later dates, the 1,000-grain weight increased by 31.0%, 24.6%, and 15.7% compared to the first sowing date.

Currently, applying macronutrients alone is insufficient to achieve high yields of quality grain. Micronutrients are also essential for normal plant growth as they enhance enzyme efficiency and influence plant growth and development processes. Researchers O. Markovska and T. Grechishkina (2020), and V. Hanhur *et al*. (2021) note the high effectiveness of applying nitrogen fertilisers and foliar applications of micronutrients. V. Yamkoviy *et al*. (2021) also confirm the positive impact of micronutrients on the quality indicators of winter wheat grain. For instance, the application of micronutrients contributed to an increase in grain protein content by 3.4-8.8%, and the 1,000-grain weight increased by 4.4-8.1% compared to the control.

The question of determining the optimal technological components to ensure the realisation of the genetic potential of new varieties under the influence of various weather conditions remains relevant today. Therefore, this study aimed to determine the specific features of the formation of yield components and overall yield of winter wheat varieties depending on mineral fertilisation and foliar application of micronutrients under different sowing dates.

MATERIALS AND METHODS

The research was conducted from 2021 to 2023 at the experimental fields of the Institute of Agriculture of the Carpathian Region, National Academy of Agrarian Sciences of Ukraine, on grey forest surface-gleyed, coarse-silty, light loamy soil. The agrochemical parameters (before the experiment was set up) were as follows: pH (in salt extract) – 4.8-5.2, humus content 1.97-2.2% (determined by Tyurin's method, DSTU 7855:2015), easily hydrolysable nitrogen 99.0-114.2 mg/kg soil (by Kjeldahl's method, DSTU 7863:2015), mobile phosphorus 95.2-101.1 and exchangeable potassium 107.1-112.0 mg/kg soil (by Kirsanov's method, DSTU 4405:2005).

Factor A (varieties): 1. Estafeta myronivska; 2. Dovira odeska; 3. Achim;

Factor B (sowing dates): first sowing date (20.09), second sowing date (5.10), third sowing date (20.10). Years of the study: 2021–2023.

Factor C (fertilisation):

1. $N_{60}P_{60}K_{60}$;
2. $N_{120}P_{90}K_{90}$;
3. $N_{120}P_{90}K_{90}$ + foliar application of Aydamin complex (1.0 L/ha).

Plot size: sown area – 40.8 m^2, accounting area – 25 m^2, replicates – 4 times. The protection system included seed treatment with Vitavaks 200 FF at 34% active substance (3.0 L/t) and the application of the herbicide Grodyl Maxi at 37.5% active substance (0.09–0.11 L/ha). Field experiments were established according to the methodology of V. Ushkarenko *et al.* (2019). Harvesting of the plots was performed using a Sampo-130 combine harvester. Yield calculations were carried out based on standard grain moisture content. Statistical analysis of the results was conducted using the software "Statistica 6.0" and "Excel 2003".

Grain quality assessment for 1,000-grain weight, test weight, and vitreousness was conducted according to DSTU 3768:2019 (2019). The content of crude protein and gluten was determined using an IR analyser, Spectran-119 M. Weather conditions during the study years were characterised by elevated temperatures during the winter wheat growing season, except for April 2021 and 2022, when the average daily air temperature was below normal (7.4°C) by 1.2 and 0.9°C, respectively. Precipitation in individual months differed significantly from long-term averages: either excess or insufficient precipitation was observed. The distribution by decades was extremely uneven, with no precipitation in some decades. The highest amount of precipitation fell in September 2020 (173% of the norm) and 2022 (236% of the norm), while the lowest amount was recorded in October 2021 (14% of the norm).

All experimental research involving plants, both cultivated and wild, including plant material collection, adhered to institutional, national, or international guidelines. The authors complied with the standards set by the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS AND DISCUSSION

In the cultivation of cereal crops, agronomic practices play a crucial role in significantly improving seed yield and quality. Climate change necessitates a reevaluation of certain aspects of winter wheat cultivation, particularly the timing of sowing. As is well-known, sowing dates and fertilisation systems throughout the winter wheat growing season are pivotal components of the overall cultivation system.

The results of the study indicate that among all the varieties, the agrocenosis of winter wheat of the Estafeta myronivska variety achieved the highest average yield (5.29 t/ha) when sown on 5 October (Table 1). The yield under the $N_{60}P_{60}K_{60}$ fertilisation treatment was 4.37 t/ha. Increasing the mineral fertiliser rate to $N_{120}P_{90}K_{90}$ resulted in a significant yield increase of 1.29 t/ha compared to the control, while the application of the Aidamin complex contributed an additional 0.17 t/ha. Sowing Estafeta myronivska on 20 October led to a decrease in average yield by 0.69 t/ha (to 4.6 t/ha) compared to the second sowing date (5 October), and sowing on 20 September resulted in a decrease of 0.45 t/ha (to 4.84 t/ha). In all experimental variants and years, the variety Estafeta myronivska consistently produced the highest yields when sown on 5 October. For the varieties Dovira odeska and Achim, the highest yields were observed in 2021 and 2022 when sown on 5 October, but in 2023, the highest yield was achieved with a sowing date of 20 September.

Table 1. *Winter wheat yield depending on technology elements, 2021-2023, t/ha*

Variants	Yield, t/ha											
	First sowing date (20 September)				Second sowing date (5 October)				Third sowing date (20 October)			
	2021	2022	2023	Avg.	2021	2022	2023	Avg.	2021	2022	2023	Avg.
1	2	3		4	5	6		7	8	9	10	11
Estafeta myronivska variety												

Table 1. Continued

Variants	Yield, t/ha											
	First sowing date (20 September)				Second sowing date (5 October)				Third sowing date (20 October)			
	2021	2022	2023	Avg.	2021	2022	2023	Avg.	2021	2022	2023	Avg.
1	2	3		4	5	6		7	8	9	10	11
$N_{60}P_{60}K_{60}$	4.09	4.00	4.01	4.0	4.45	4.32	4.35	4.37	3.75	4.15	3.31	3.73
$N_{120}P_{90}K_{90}$	5.04	5.03	5.38	5.15	5.75	5.54	5.69	5.66	4.76	5.18	4.99	4.97
$N_{120}P_{90}K_{90}$ + Aidamin	5.26	5.27	5.49	5.34	6.0	5.65	5.84	5.83	4.93	5.30	5.10	5.11
Average	4.8	4.77	4.96	4.84	5.42	5.17	5.26	5.29	4.48	4.88	4.46	4.6
Dovira odeska variety												
$N_{60}P_{60}K_{60}$	3.56	3.23	4.26	3.68	4.36	3.79	3.93	4.02	3.47	3.26	3.5	3.41
$N_{120}P_{90}K_{90}$	4.51	4.07	5.59	4.72	5.35	4.81	5.2	5.12	4.66	4.35	5.04	4.68
$N_{120}P_{90}K_{90}$ + Aidamin	4.68	4.24	5.62	4.84	5.47	4.92	5.27	5.22	4.78	4.45	5.14	4.79
Average	4.25	3.85	5.15	4.41	5.06	4.51	4.8	4.78	4.30	4.02	4.56	4.29
Achim variety												
$N_{60}P_{60}K_{60}$	4.08	3.54	4.52	4.04	4.26	4.13	4.31	4.23	3.54	3.68	4.16	3.79
$N_{120}P_{90}K_{90}$	5.13	4.57	6.34	5.35	5.29	5.07	5.89	5.41	4.68	4.81	5.32	4.93
$N_{120}P_{90}K_{90}$ + Aidamin	5.28	4.70	6.41	5.46	5.47	5.18	5.95	5.53	4.89	4.96	5.46	5.1
Average	4.83	4.27	5.75	4.95	5.0	4.79	5.38	5.05	4.37	4.48	4.94	4.59
$HIP_{0.5}$, t/ha A (sowing dates)	0.058	0.061	0.061									
B (fertilisation)	0.058	0.064	0.062									
C (varieties)	0.058	0.061	0.063									
ABC (interaction)	0.173	0.190	0.188									

Source: *developed by the authors*

On average, during the years of the study (2021-2023), the winter wheat varieties Dovira odeska and Achim also achieved their highest yields with the second sowing date (5th October), producing 4.78 and 5.05 t/ha, respectively. The yield increase due to fertilisers was 1.1 and 1.18 t/ha, and from foliar application, it was 0.1 and 0.12 t/ha. The Dovira odeska variety showed a lower average yield when sown on 20 September, with a decrease of 0.37 t/ha compared to the 5 October sowing, and the yield decreased by 0.49 t/ha when sown on 20 October. A significant yield reduction compared to the second sowing date was also observed in the Achim variety, with an average decrease of 0.1 t/ha when sown on 20 September and 0.46 t/ha when sown on 20 October. When $N_{120}P_{90}K_{90}$ fertilisation was applied, the yield increase for the wheat varieties compared to the control was 1.04-1.31 t/ha for the 20 September sowing, 1.1-1.29 t/ha for the second sowing date, and 1.14-1.27 t/ha for the third sowing date. Foliar application with micronutrients provided a significant yield increase within the range of 0.1-0.17 t/ha.

The highest yield (5.83 t/ha) was achieved by sowing the winter wheat variety Estafeta myronivska on 5 October, combined with the application of $N_{120}P_{90}K_{90}$ mineral fertiliser and foliar application with the Aidamin complex. In contrast, the control treatment ($N_{60}P_{60}K_{60}$) yielded 4.37 t/ha. Increasing the rate of mineral fertiliser resulted in a significant yield increase of 1.29 t/ha, while the application of the Aidamin complex contributed an additional 0.17 t/ha. High grain yields do not always correspond to high quality. Often, the grain quality is poor and does not meet the requirements of the food industry. The results of the conducted research have established that sowing dates have a direct impact on the quality indicators of the grain, including 1000-grain weight, test weight, and vitreousness.

In 2021, the winter wheat variety Estafeta myronivska achieved the highest 1,000-grain weight when sown on 20 September. Sowing on 5 October and 20 October resulted in a decrease in 1,000-grain weight by 0.77 g and 1.99 g, respectively (Table 2). For the winter wheat varieties Dovira odeska and Achim, the highest 1,000-grain weight was recorded with the second sowing date (5 October). Deviations from this sowing date, either earlier or later, resulted in a decrease in 1,000-grain weight by 0.51 and 1.11 g for early sowing and 0.89 and 2.91 g for late sowing, respectively.

Table 2. *The 1000-grain weight and quality indicators of winter wheat grain depending on sowing dates and nutrition backgrounds, 2021-2023*

No. Var.	1000-grains weight, g				Test weight, g/L				Vitreousness, %			
	2021	2022	2023	Avg.	2021	2022	2023	Avg.	2021	2022	2023	Avg.
Estafeta myronivska variety – first sowing date												
1	41.16	42.64	39.4	41.07	790.2	800.2	781.5	790.63	47	69.25	49.75	55.3
2	42.15	43.91	40.58	42.21	804	809.7	784	799.23	56	73	72.5	67.2
3	43.22	44.04	41.64	42.97	804.7	810.6	784.5	799.93	63	76.5	72.75	70.8
Avg.	42.2	43.5	40.5	42.1	799.6	806.8	783.3	796.6	55.3	72.9	65.0	64.4
Estafeta myronivska variety – second sowing date												
1	41.11	44.26	40.69	42.0	789.5	798	783.2	790.2	51	73.5	53.25	59.3
2	41.5	44.51	40.89	42.3	802.5	811.5	792	802.0	59.5	79.5	76	71.7
3	41.62	45.17	41.27	42.7	806.2	813.8	793.2	804.4	65.5	81.25	79.5	75.4
Avg.	41.4	44.6	41.0	42.3	799.4	807.8	789.5	798.9	58.7	78.1	69.6	68.8
Estafeta myronivska variety – third sowing date												
1	39.95	42.58	39.42	40.7	790	801.5	776.2	789.2	58.75	70.25	57.75	62.3
2	40.26	42.85	40.76	41.3	805.8	807.9	792.5	802.1	60.5	80.75	75	72.1
3	40.37	43.56	41.37	41.8	806.3	810.8	793.3	803.5	63	81.5	77.5	74.0
Avg.	40.2	43.0	40.5	41.2	800.7	806.7	787.3	798.3	60.8	77.5	70.1	69.4
Dovira odeska variety – first sowing date												
1	37.69	38.25	38.5	38.1	740.7	798	736.2	758.3	22.75	42	16	26.9
2	39.68	40.76	40.34	40.3	754.7	804.3	769	776.0	24.5	53.75	37.75	38.7
3	40.2	41.41	41.18	40.9	757.3	805.8	772.3	778.5	27.25	57.5	39	41.3
Avg.	39.2	40.1	40.0	39.8	750.9	802.7	759.2	770.9	24.8	51.1	30.9	35.6
Dovira odeska variety – second sowing date												
1	39.28	40.01	40.96	40.1	745.3	795.2	761	767.2	23.5	38.5	26.75	29.6
2	39.23	41.61	41.24	40.7	745.7	804.4	776.7	775.6	28	62.25	33	41.1
3	40.59	41.91	41.27	41.3	749.5	804.5	777.3	777.1	29	63.5	36.25	42.9
Avg.	39.7	41.2	41.2	40.7	746.8	801.4	771.7	773.3	26.8	54.8	32.0	37.9
Dovira odeska variety – third sowing date												
1	37.82	38.65	36.55	37.7	730.2	795	749.2	758.1	28.25	48.25	21.25	32.6
2	39.13	40.29	39.62	39.7	739	803.8	765.7	769.5	31	64.75	31	42.3
3	39.47	41.43	39.74	40.2	741.8	804	767.2	771.0	31.25	76.25	31.75	46.4
Avg.	38.8	40.1	38.6	39.2	737.0	800.9	760.7	766.2	30.2	63.1	28.0	40.4
Achim variety – first sowing date												
1	37.11	38.63	43.73	39.8	765	769.3	759.8	764.7	41.25	11	49.75	34.0
2	41.59	42.11	44.38	42.7	768.7	777.9	776	774.2	50.75	43	58	50.6
3	42.42	42.39	44.78	43.2	772	787.2	776.7	778.6	53	53.5	59	55.2
Avg.	40.4	41.0	44.3	41.9	768.6	778.1	770.8	772.5	48.3	35.8	55.6	46.6
Achim variety – second sowing date												
1	39.94	42.8	41.35	41.4	768	769.6	762.7	766.8	46.25	17.5	45.25	36.3
2	41.71	42.94	42.39	42.3	744.7	772.4	777.7	764.9	58.25	38.25	68	54.8
3	42.79	43.07	42.9	42.9	756.7	787.4	780.5	774.9	58.75	47.75	72.75	59.8
Avg.	41.5	42.9	42.2	42.2	756.5	776.5	773.6	768.9	54.4	34.5	62.0	50.3
Achim variety – third sowing date												
1	37.46	33.64	38.52	36.5	752.2	767.9	762.7	760.9	56	26	46.5	42.8
2	38.53	37.44	39.96	38.6	745.2	770.8	775.5	763.8	59.75	49.75	78.5	62.7
3	39.71	37.7	39.92	39.1	755.3	787.3	775.7	772.8	61	51.75	79	63.9
Avg.	38.6	36.3	39.5	38.1	750.9	775.3	771.3	765.8	58.9	42.5	68.0	56.5

Source: *developed by the authors*

The test weight of the winter wheat variety Estafeta myronivska ranged from 799.6 to 800.7 g/L, Dovira odeska from 737.0 to 750.9 g/L, and Achim from 750.9 to 768.57 g/L. The 1,000-grain weight of Estafeta myronivska was not significantly affected by sowing dates, while for Dovira odeska and Achim, this parameter decreased from the earliest to the latest sowing dates. Vitreousness increased from the earliest to the latest sowing dates for all wheat varieties. Estafeta myronivska had the highest vitreousness,

ranging from 55.3% to 60.75%. Dovira odeska had a vitreousness of 24.83% to 30.17%, and Achim had a vitreousness of 48.33% to 58.92%. In 2022, the highest 1,000-grain weight (42.58-45.17 g), test weight (800.2-813.8 g/L), and vitreousness (58.1-73.4%) were observed in the Estafeta myronivska wheat variety. For the Dovira odeska variety, the 1,000-grain weight was 38.25-41.91 g, test weight 795.0-805.8 g/L, and vitreousness 38.5-76.25%; for Achim, the corresponding values were 38.63-43.07 g, 767.9-787.3 g/L, and 26.13-56.38%. The protein and gluten content in winter wheat varied depending on the sowing date. These indicators increased from early to optimal and late sowing dates (Table 3).

Table 3. *Selected quality indicators of winter wheat grain, 2021-2023*

No. Var.	Protein, %				Crude gluten, %				Ash content, %			
	2021	2022	2023	Avg.	2021	2022	2023	Avg.	2021	2022	2023	Avg.
Estafeta myronivska variety – first sowing date												
1	11.7	12.8	11.4	12.0	17.1	26.1	20.5	21.2	1.2	1.3	1.3	1.3
2	14.3	13.9	14.5	14.2	25.3	27.8	28.3	27.1	1.3	1.3	1.3	1.3
3	14.7	14.5	15.1	14.8	25.5	29.9	30.3	28.6	1.3	1.3	1.3	1.3
Estafeta myronivska variety – second sowing date												
1	11.7	12.8	11.4	12.0	17.4	24.7	20.5	20.8	1.3	1.3	1.3	1.3
2	14.4	13.9	14.8	14.4	25.8	28.2	31.7	28.5	1.3	1.3	1.3	1.3
3	14.8	14.4	15.1	14.8	26.4	29.9	31.9	29.4	1.3	1.3	1.3	1.3
Estafeta myronivska variety – third sowing date												
1	12.0	12.5	13.7	12.7	17.9	23.4	27.6	23.0	1.3	1.3	1.3	1.3
2	14.6	14.3	14.8	14.6	26.2	29.5	31.9	29.2	1.3	1.3	1.3	1.3
3	15.0	14.4	15.4	14.9	26.7	29.4	33.3	29.8	1.3	1.3	1.3	1.3
Dovira odeska variety – first sowing date												
1	11.3	11.4	10.2	11.0	15.9	20.8	17.3	18.0	1.3	1.3	1.3	1.3
2	12.5	11.6	11.8	12.0	20.2	21.5	22.6	21.4	1.3	1.3	1.3	1.3
3	13.0	12.8	12.6	12.8	21.1	24.7	24.5	23.4	1.3	1.3	1.3	1.3
Dovira odeska variety – second sowing date												
1	11.6	11.2	12.5	11.8	16.1	20.5	23.9	20.2	1.3	1.3	1.3	1.3
2	12.8	13.0	13.0	12.9	21.4	25.5	25.7	24.2	1.3	1.3	1.3	1.3
3	13.5	13.5	13.6	13.5	22.1	27.3	27.2	25.5	1.3	1.3	1.3	1.3
Dovira odeska variety – third sowing date												
1	12.7	11.8	12.0	12.2	19.6	21.9	22.7	21.4	1.3	1.3	1.3	1.3
2	13.4	13.5	13.3	13.4	21.6	26.4	26.3	24.7	1.3	1.3	1.3	1.3
3	13.9	13.6	13.5	13.7	22.3	27.2	26.7	25.4	1.3	1.3	1.3	1.3
Achim variety – first sowing date												
1	12.1	10.3	10.9	11.1	17.8	17.4	19.4	18.2	1.3	1.3	1.3	1.3
2	12.9	11.9	12.0	12.3	19.9	21.8	22.0	21.2	1.3	1.3	1.3	1.3
3	13.5	13.0	13.5	13.3	20.7	25.1	26.7	24.2	1.3	1.3	1.3	1.3
Achim variety – second sowing date												
1	12.3	10.5	11.0	11.3	18.2	18.8	20.1	19.0	1.3	1.3	1.3	1.3
2	13.1	12.4	13.8	13.1	20.6	22.7	27.9	23.7	1.3	1.3	1.3	1.3
3	13.7	13.1	14.0	13.6	21.2	24.9	28.7	24.9	1.3	1.3	1.3	1.3
Achim variety – third sowing date												
1	12.6	10.5	12.3	11.8	18.6	18.8	22.7	20.0	1.3	1.3	1.3	1.3
2	13.4	12.4	13.3	13.0	20.8	23.1	25.9	23.3	1.3	1.3	1.3	1.3
3	13.9	13.1	14.0	13.7	21.5	25.0	28.6	25.0	1.3	1.3	1.3	1.3

Source: *developed by the authors*

In 2021, regardless of sowing dates (except for the control plots), the winter wheat variety Estafeta myronivska, based on its protein content, crude gluten, vitreousness, and test weight, belonged to the 2nd quality class, while the control plots were classified as the 4th class (DSTU 3768:2019). The variety Dovira odeska, when sown on 20 September 2021 and 05 October 2021, produced grain of the 4th quality class on the control plots. However, with fertilisation at the $N_{120}P_{90}K_{90}$ rate and foliar application of micronutrients (Aidamin complex foliar application), the grain was classified as the 3rd quality class. The grain sown on 20 October 2021 also belonged to the 3rd class. The winter wheat variety Achim, when sown on 20 October 2021, had 4th

class quality on the control variant, while on other variants, the grain belonged to the 3rd class.

In 2022, under all sowing dates, the Estafeta myronivska variety, when fertilised with $N_{120}P_{90}K_{90}$ and supplemented with a micronutrient feed, produced 1st class-quality grain. The same quality was achieved for the third sowing date when only $N_{120}P_{90}K_{90}$ fertiliser was applied. Other treatments resulted in 2nd class grain. The Dovira odeska variety produced 3rd class grain on control plots for all sowing dates and the $N_{120}P_{90}K_{90}$ fertilised plot for the first sowing date. Other treatments resulted in 2nd class grain. The Achim variety had the lowest grain quality, 4th class, on all control plots regardless of sowing date. Fertilisation with $N_{120}P_{90}K_{90}$ improved the quality to the 3rd class, while other treatments resulted in 2nd class grain.

In 2023, the Estafeta myronivska variety produced 1st class-quality grain when fertilised with $N_{120}P_{90}K_{90}$, and third-class quality grain on control plots for all sowing dates. The Akhim wheat variety produced first-class quality grain when sown in the second and third periods and treated with $N_{120}P_{90}K_{90}$ fertiliser and foliar application of the Aidamin complex. On other treatments, the grain quality ranged from 2nd to 3rd class. The Dovira odeska variety produced 2_{nd} and 3_{rd} class quality grain.

The yield and quality of grain are directly influenced by a range of factors including soil and climatic conditions, the genetic characteristics of the variety, and agricultural practices such as sowing dates and fertilisation (Oliinyk *et al.,* 2018; Jaisi *et al.,* 2021). Maximum yields are achieved when there is an optimal balance of all these factors (Kovalenko & Kiriyak, 2018). The question of optimal sowing dates and fertilisation systems for winter wheat is not new and has been studied extensively. Researchers such as U. Madhu *et al.* (2018) and A. Siroshtan *et al.* (2021) have investigated the impact of these factors on the yield and quality of winter wheat. However, the emergence of new varieties and changing climatic conditions necessitate continuous adjustments.

According to O.A. Zaima *et al.* (2024), adhering to optimal sowing dates (the third decade of September and the first decade of October) ensures maximum yields for the studied varieties. L. Gandjaeva (2019) highlights the reduction in crop productivity when sowing dates deviate from the optimal ones. In the Polissia region, sowing on 10 October resulted in a yield of winter wheat 1.02 t/ha lower compared to sowing on 10 September (3.56 t/ha). However, the question of optimal sowing dates remains controversial. Specifically, G. Gutsol and I. Ovcharuk (2023) recommend sowing 11 days later in the Right-bank Forest-Steppe, and in some years, these dates can be further adjusted. H. Chuhrii (2019) also found increased yields when sowing was delayed to 10 October compared to 10 September.

According to A. Kryvenko *et al.* (2019), sowing on 5 October resulted in a 25.5% higher yield compared to sowing on 25 September. However, further delaying sowing to 15 October decreased the grain yield by 37.6%, and to 25 October by 53.2%. Sowing on 5 and 15 October resulted in the highest quality grain in terms of weight and the weight of 1,000 grains. R. Vozhegova and V. Bily (2019) found that the highest number of productive stems and grains per ear were obtained with later sowing dates. Many researchers have noted an improvement in grain quality with later sowing dates. S. Shakaliy *et al.* (2020) observed an increase in the protein content of winter wheat grain when sowing on 10 October, reaching 12.8-12.6%, compared to earlier sowing on 10 September (11.3-12.0%).

The most effective factor in increasing the yield and quality of winter wheat is the application of mineral fertilisers. Research has confirmed that the use of mineral fertilisers increases the yield of grain crops. According to V. Ivanina and I. Korotenko (2022), the use of fertilisers increased crop yields regardless of sowing date. The application of $N_{80}P_{60}K_{60}$ to winter wheat in a crop rotation with peas increased grain yield by 1.02 t/ha compared to the control without fertilizers, reaching 5.42 t/ha. Scientists believe that a significant reserve for increasing crop productivity lies in the application of micronutrients (Vozhegova & Kryvenko, 2019). Their application effectively influences growth processes, as well as yield and grain quality. The use of micronutrients for seed treatment or foliar application is an effective agronomic measure to provide plants with micronutrients during the growing season. V. Petrychenko and V. Lykhochvor (2020) observed a 14.5% increase in grain yield compared to the control when using seed treatment with the growth stimulator Vimpel-K and foliar application of Vimpel-2 in combination with Oracle micronutrients. V. Hanhur *et al.* (2021) noted a trend toward increased 1,000-grain weight and gluten content in treatments where seeds were pre-sown treated with the micronutrient Vuksal and followed by foliar application of micronutrients.

In conclusion, based on the findings presented above, it is clear that established crop production practices, particularly sowing dates, are influenced by weather conditions and require adjustments. To achieve high yields and grain quality, it is essential to use not only mineral fertilisers but also micronutrients for foliar application.

CONCLUSIONS

Research findings indicate that, under the soil and climatic conditions of the Western Forest-Steppe, the highest yields of winter wheat crops were achieved with the first sowing date (5 October). For this sowing date, the studied varieties – Dovira odeska, Achim, and Estafeta myronivska – produced average yields of 4.78 t/ha, 5.05 t/ha, and 5.29 t/ha, respectively. Shifting the sowing dates either earlier (20 September) or later (20 October) resulted in lower yields. For Estafeta myronivska,

the deviations from the optimal yield were 0.45 t/ha and 0.69 t/ha, respectively, for Dovira odeska – 0.37 t/ha and 0.49 t/ha, and for Achim – 0.1 t/ha and 0.46 t/ha.

Although, on average, the second sowing date (5 October) was the most effective during the years of the study, the varieties exhibited varying yields in different years of observation. Of all the varieties studied, only Estafeta myronivska consistently produced the highest yields when sown on 5 October. Dovira odeska and Achim achieved their highest yields in 2021 and 2022 when sowed on 5 October, but in 2023, their highest yields were obtained with a sowing date of 20 September. The lowest yields for all wheat varieties were observed when sown on 20 October.

Increasing the application rate of mineral fertilisers to $N_{120}P_{90}K_{90}$ led to an increase in grain yield for all sowing dates. Depending on the variety and experimental variant, the increase was 1.04–1.31 t/ha. Foliar application of the micronutrient Aidamin complex provided an additional yield increase of 0.11–0.19 t/ha. Among the varieties, the highest yield (5.83 t/ha) was obtained from winter wheat cultivar Estafeta myronivska sown on 5 October, with the application of mineral fertilisers at the rate of $N_{120}P_{90}K_{90}$ and foliar application of the micronutrient Aidamin complex. The increase from mineral fertilisers was 1.29 t/ha and from the application of micronutrients – 0.17 t/ha. The application of mineral fertilisers and foliar application with micronutrients improved grain quality in all experimental variants. On average, over the years of the study, the 1,000-grain weight was highest for all varieties with the second sowing date (5 October), while the test weight was highest for Estafeta myronivska and Dovira odeska with the second sowing date, and for Achim with the first sowing date. The vitreousness increased from the first to the third sowing dates.

Future research could focus on the evaluation of new winter wheat varieties and the identification of effective micronutrients and growth stimulators that can mitigate the impact of negative biotic and abiotic factors during the growing season and ensure stable high-quality grain yields.

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CONFLICT OF INTEREST

None.

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Вплив строків сівби і удобрення на врожайність і якість зерна пшениці озимої

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Анотація. Нові сорти пшениці відзначаються високим адаптивним потенціалом продуктивності. Актуальним залишається питання удосконалення елементів технології їх вирощування в конкретних ґрунтово-кліматичних умовах, зокрема строків сівби, оптимізації системи удобрення, застосування мікроелементів, за рахунок яких можна суттєво вплинути на реалізацію генетичного потенціалу сортів. Метою роботи було встановити вплив строків сівби, удобрення і фоліарного підживлення мікроелементами на врожайність і якісні показники зерна пшениці озимої за вирощування в зоні Лісостепу західного. У процесі виконання роботи були застосовані польовий метод, лабораторний (визначення якісних показників зерна) та статистичний (оцінка достовірності даних). Польові дослідження проводили на сірих лісових поверхнево оглеєних ґрунтах впродовж 2021-2023 рр. Було встановлено параметри формування продуктивності і якісні показники пшениці озимої сорту Естафета миронівська, Довіра одеська і Ахім за сівби 20.09; 05.10; 20.10. Визначено, що показники врожайності і якість зерна досліджуваних сортів змінювалися під впливом строків сівби, удобрення та листкового підживлення мікродобривом. Сівба пшениці озимої 05.10 забезпечила найвищу врожайність за роки дослідження: в середньому у сорту Естафета миронівська – 5,29 т/га, Довіра одеська – 4,78, Ахім – 5,05 т/га. Максимальну продуктивність (5,83 т/га) сформував посів сорту Естафета миронівська за внесення $N_{120}P_{90}K_{90}$ і листкового підживлення мікродобривом Айдамін-комплексний листкове підживлення. У всіх сортів пшениці озимої зафіксовано зростання вмісту білку, клейковини і скловидності зерна від першого до третього строку сівби. Отримані результати можуть бути застосовані для підвищення продуктивності агроценозів пшениці озимої і отримання продукції високої якості у виробничих умовах

Ключові слова: пшениця озима; врожайність; маса 1000 зерен; вміст білку

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Development and implementation of energy-saving technologies for growing sunflower hybrids in the south of Ukraine

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Abstract. The development and implementation of energy-saving technologies for growing sunflower hybrids is a relevant area of research to ensure sustainable development of the agricultural sector and environmental protection. The study aimed to analyse the impact of different tillage methods on sunflower yields in southern Ukraine. To achieve this goal, a field study was conducted in the fields of the Educational and Research Centre of Mykolaiv National Agrarian University in 2021-2023. The study determined that the method of soil cultivation has a significant impact on its density, moisture reserves and structural stability. Reducing the intensity of cultivation, especially when using no-till, preserves moisture in the soil more effectively, but increases its density. With no-till, before sowing sunflower, it was 1.11 g/cm^3 at a depth of 0-10 cm and 1.21 g/cm^3 before harvesting, while with conventional tillage, the soil density was 1.02 g/cm^3 and 1.1 g/cm^3, respectively. In addition, no-till tillage provided

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the best sunflower productivity indicators, including 1000-seed weight (47.3 g), basket diameter (20.2 cm) and yield (2.6 t/ha). No-till cultivation also improves the quality of the sunflower crop, increasing the content of oleic acid (86.5%) and crude fat in the seeds (48.3%). The obtained results contribute to the development of integrated approaches to the introduction of energy-saving technologies in the cultivation of sunflower hybrids in southern Ukraine, which will increase production efficiency and reduce production costs

Keywords: soil cultivation; yield; seed quality; field and laboratory experiments; agrophysical soil parameters

INTRODUCTION

Energy-saving technologies play a key role in modern agriculture, as they help to reduce production costs and reduce the negative impact on the environment. With rising energy prices and increasing pressure on natural resources, efficient use of energy is becoming a necessity. The cultivation of sunflower hybrids, one of the leading oilseeds, is a significant segment of the agricultural sector, where the introduction of energy-saving technologies can bring significant economic and environmental benefits (Casali *et al*., 2022). Global trends in agricultural development are increasingly focused on the integration of innovative solutions that reduce energy use and increase crop yields. Countries such as the United States, Canada, Brazil, China, and the European Union are actively implementing modern agricultural practices and technologies that optimise all stages of the production process (Melnyk *et al*., 2019; Basile *et al*., 2021).

Y. Majeed *et al.* (2023) argue that the introduction of energy-saving technologies in agriculture is extremely important for ensuring the sustainable development of the agricultural sector. They emphasise that the efficient use of energy resources not only reduces production costs but also helps to reduce environmental impact. T. Vician *et al.* (2022) emphasises that modern agrotechnical methods, such as precision farming, minimal and no-till tillage, and the use of renewable energy sources, have significant potential to reduce energy consumption and increase crop productivity. At the same time, to achieve sustainability in the agricultural sector, it is necessary to implement integrated approaches that consider the specific climate and soil conditions of the regions. J. Akuaku *et al.* (2020) also emphasise the importance of adapting these technologies to specific conditions, which allows for the most efficient use of natural resources and high yields with minimal energy consumption.

Sunflower is a crop widely grown in Ukraine and holds a leading position in the global production and export of sunflower oil. However, according to S. Kalenska *et al.* (2020), traditional methods of growing this crop are often accompanied by significant energy consumption, which necessitates the modernisation of production processes. The use of energy-saving technologies in growing sunflower hybrids includes the introduction of modern agrotechnical techniques, the selection of energy-efficient varieties and hybrids, and the optimisation of all stages of the production process. Effective implementation of such technologies can involve several aspects. This includes the use of precision farming systems that optimise the use of fertilisers, plant protection products and water resources, the transition to no-till and minimum tillage systems that reduce energy consumption for mechanical operations, and the use of renewable energy sources such as solar and wind power to meet the needs of farms (Ryzhenko *et al*., 2020; Duca *et al*., 2022)).

It is worth noting that several scholars, including O. Kovalenko *et al.* (2024), agree that the development and implementation of energy-saving technologies in the cultivation of sunflower hybrids not only increases the economic efficiency of production but also contributes to the conservation of natural resources and reduces greenhouse gas emissions. This is in line with global trends towards sustainable development and environmental safety. Thus, energy-saving technologies are becoming an important component of modern agricultural production, striking a balance between economic benefits and environmental responsibility.

Despite a considerable amount of research on the implementation of energy-saving technologies in agriculture, there are some gaps in the literature, especially when it comes to specific regional conditions such as southern Ukraine. This region is characterised by hot summers with high temperatures and low humidity, which affects sunflower cultivation and necessitates integrated solutions for efficient energy use. Thus, the purpose of this study was to investigate the impact of different tillage technologies on the yield of sunflower hybrids in the south of Ukraine. To achieve this goal, the following tasks were performed: to analyse the impact of different tillage methods on soil agrophysical properties, as well as to assess the impact of each method on sunflower yield and productivity indicators.

MATERIALS AND METHODS

To study the energy-saving technologies for growing sunflower hybrids, a field experiment was conducted using laboratory and field observations of the growth and development of plants grown under different methods of soil cultivation in southern Ukraine. The study was conducted in the fields of the Educational and Research Centre of Mykolaiv National Agrarian University in 2021-2023.

The soil of the experimental plots is represented by southern chernozem, low-power, low-sunny, heavy loamy on loess. The reaction of the soil solution was neutral (pH 6.8-7.2). The humus content in the 0-30 cm layer was 123-125 g kg^{-1}. On average, the topsoil contained the following: nitrates (by the method of interaction of nitrates with disulfophenolic acid, from which trinitrophenol is formed). In an alkaline environment, it gives a yellow colour due to the formation of potassium trinitrophenolate (or sodium, depending on the alkali used) in an amount equivalent to the nitrate content) – 15-25 mg/kg^{-1}, mobile phosphorus (by extraction of mobile phosphorus and potassium compounds from the soil with a 1% solution of ammonium carbonate, pH 9, at a temperature of 25 ± 20°C) – 41-46 mg/kg^{-1}, exchangeable potassium (flame photometer) – 389-425 mg/kg^{-1} of soil (Panfilova, 2021).

The subject of the study was the sunflower hybrid P64HE133. The sunflower was sown at a soil temperature of 8-10°C with a seeding rate of 50,000 germinating seeds per hectare. The experiment was replicated three times. The total area of the experimental plot was 320 m^2, while the area of the accounting plot was 90 m^2. The sunflower's predecessor was winter wheat. The experimental design included three variants of tillage methods:

1. Traditional soil cultivation includes ploughing to a depth of 25 cm, harrowing and cultivation to a depth of 5-10 cm.

2. Minimum tillage, which included reducing the number of mechanical tillage operations by using disc harrows to a depth of 10-15 cm.

3. No-till tillage – when the soil is not subjected to traditional tillage using ploughs or harrows. Crop residues remain on the surface, which helps to protect the soil from erosion and retain moisture.

The study determined the following agrophysical parameters of the soil: density of the topsoil – by the method of M.A. Kachinsky, whereby the density in different layers was assessed every 10 cm to a depth of 30 cm, the content of water-resistant soil aggregates – by the Savvinov method, soil moisture – by the thermostat-weight method, whereby the moisture content in different layers was assessed every 10 cm to a depth of 100 cm by drying at a temperature of 105°C. Overall sunflower plant productivity data, including the diameter of the boll and the weight of 1000 seeds, were determined directly at harvest by measuring and weighing. The crude fat content of the seeds was determined by the defatted residue (according to Rushkovsky method), and the oleic acid content of the oil was determined by the refractometric method. Harvest accounting was carried out by the method of continuous harvesting on the accounting plot, with further conversion per hectare.

All experiments were repeated three times for each variant of the experiment. The obtained research results were processed for reliability by applying the multivariate method of MANOVA analysis of variance using Microsoft Excel software and the Statistica 10 software package. Differences in the results obtained are possible at a significance level of $P \leqslant 0.05$ according to the Student's criterion. The authors adhered to the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

Different tillage methods can significantly change the soil structure, water regime and aeration, which in turn affects plant growth and development. Soil cultivation is also one of the key agronomic operations that affect the agrophysical properties of the soil, particularly its density. The study found that there is an influence of tillage methods (traditional, minimal and no-till) on soil density at different depths before sowing and before harvesting sunflower during 2021-2023. In particular, under traditional tillage, the lowest density was found in the topsoil (0-10 cm) before sowing – 1.02 g/cm^3, which indicates sufficient soil loosening. Minimal tillage led to an increase in soil density compared to the conventional method at all depths, which may be due to a reduction in the number of mechanical tillage operations and less intensive loosening. No-till tillage has the highest soil density among all tillage methods, which is due to the absence of mechanical tillage, which leads to the accumulation of organic residues on the soil surface (Table 1).

***Table 1**. Influence of tillage methods on soil density (average for 2021-2023)*

Soil cultivation method	Soil layer, cm	Soil density, g/cm^3	
		before sowing	before harvesting
Traditional soil cultivation	0-10	1.02	1.1
	10-20	1.12	1.16
	20-30	1.21	1.25
Minimum soil cultivation	0-10	1.06	1.13
	10-20	1.16	1.2
	20-30	1.28	1.33
No-till tillage	0-10	1.11	1.21
	10-20	1.22	1.3
	20-30	1.31	1.36

***Source:** compiled by the authors*

Thus, a decrease in the intensity of tillage leads to an increase in soil density at all depths, which should be addressed when choosing a tillage method to ensure optimal conditions for sunflower plant growth. Furthermore, productive soil moisture reserves are one of the key factors affecting the growth and development of crops, including sunflowers. Soil moisture depends on many factors, including soil tillage methods, which can significantly affect the soil water regime. Analysis of the data shows that a decrease in tillage intensity (from conventional to no-till) causes an increase in productive moisture reserves at any specific depths. The no-till method is regarded as the most effective in preserving soil moisture, which can contribute to better conditions for plant growth, especially in the context of insufficient moisture. Soil moisture before harvesting under no-till in the 0-100 cm layer was 135 mm, which is 9 mm more than under minimum tillage and 25 mm more than under conventional tillage (Table 2).

***Table 2**. Impact of tillage methods on productive moisture reserves, mm (average for 2021-2023)*

Soil cultivation method	Soil layer, cm	Soil moisture content, %	
		before sowing	before harvesting
Traditional soil cultivation	0-20	25	31
	20-50	46	61
	50-100	39	41
	0-100	94	110
Minimum soil cultivation	0-20	26	32
	20-50	50	68
	50-100	42	49
	0-100	104	126
No-till tillage	0-20	30	35
	20-50	50	71
	50-100	47	62
	0-100	114	135

***Source:** compiled by the authors*

The content of water-resistant soil aggregates is an important indicator that characterises the structural stability of the soil and its ability to resist erosion. At the same time, the ability of the soil to retain its structure under the influence of water depends on the method of tillage, which affects the size and stability of the aggregates. The study confirms that all three tillage methods lead to an increase in the content of water-resistant aggregates in the soil before harvest. No-mouldboard tillage demonstrates the largest increase in the total content of water-resistant aggregates (+10%) at the time of sunflower harvest (Table 3).

***Table 3**. Content of water-rich aggregates (>0.25) under different tillage methods, % (average for 2021-2023)*

Soil cultivation method	Soil layer, cm	Number of water-intensive aggregates (>0.25), %	
		before sowing	before harvesting
Traditional soil cultivation	0-10	32.3	32.6
	10-20	32.5	33.2
	20-30	32	32.5
	30-40	31.3	31.8
	0-40	32.1	32.7
Minimum soil cultivation	0-10	32.1	35.3
	10-20	32.8	34.8
	20-30	32.5	34
	30-40	31.2	31.4
	0-40	32.3	32.8
No-till tillage	0-10	32.4	35.9
	10-20	32.9	35
	20-30	32.6	34.5
	30-40	31.7	33.4
	0-40	32.4	33.2

***Source:** compiled by the authors*

In general, tillage methods are important for ensuring the growth and development of sunflower plants under optimal conditions. Reducing the intensity of tillage leads to an increase in soil density and moisture

reserves, while conventional tillage and no-till tillage show the lowest and highest soil density, respectively. At the same time, no-till is the most effective in preserving soil moisture, which can contribute to better conditions for plant growth and development, especially in conditions of insufficient moisture. In addition, all three tillage methods lead to an increase in the content of water-resistant aggregates in the soil before harvesting, with no-till showing the largest increase at the time of sunflower harvesting. Thus, the choice of tillage method is crucial for ensuring the growth and development of sunflower plants in optimal conditions, addressing soil density, water regime and soil structure. Sunflower productivity indicators, such as 1000-seed weight and kernel diameter, are important because they help to assess the efficiency of growing the crop and have a direct impact on its yield. An increase in the weight of 1000 seeds may indicate a higher number of seeds per boll, which in turn will lead to higher yields. A larger basket diameter may indicate a larger number of flowers and, consequently, a larger number of seeds. Thus, high values of these parameters lead to higher sunflower yields, while lower values lead to lower yields. This data is important for producers as it helps them choose the best agronomic practices and identify ways to improve sunflower cultivation to obtain high and stable yields.

In the study, under no-till tillage, sunflower plants formed the highest values for both the weight of 1000 seeds (71.3 g) and the diameter of the sunflower basket (16.2 cm). This indicates that this method provides the best conditions for the growth and development of culture. Minimum tillage provided slightly lower values compared to conventional tillage. The weight of 1000 seeds (65.4 g) and the diameter of the head (15.9 cm) of sunflower were reduced, but not significantly. This may be a result of less soil disturbance, which helps to preserve its structure. Traditional cultivation demonstrates the lowest values for both indicators. The weight of 1000 seeds (63.2 g) and the diameter of the basket (15.3 cm) are significantly lower compared to the other two methods (Table 4).

***Table 4**. Weight of 1,000 seeds and diameter of the sunflower basket (average for 2021-2023)*

Soil cultivation method	Mass of 1000 seeds, g	Basket diameter, cm
Traditional soil cultivation	63.2 ± 0.6	15.3 ± 0.4
Minimum soil cultivation	65.4 ± 0.3	15.9 ± 0.2
No-till tillage	71.3 ± 0.2	16.2 ± 0.5

***Source:** compiled by the authors*

The study also found that the method of soil cultivation significantly affected sunflower yields. Thus, the yield of the crop under conventional tillage ranged from 3.54 to 3.58 t/ha over the three years, with an average of 3.56 t/ha. Yields under minimum tillage ranged from 3.81 to 3.89 t/ha with an average of 3.85 t/ha and remained close to the conventional tillage. However, under no-till cultivation, sunflower yields were higher and ranged from 3.91 to 3.98 t/ha with an average of 3.95 t/ha for the period 2021-2023 (Table 5).

***Table 5**. Sunflower seed yield, t/ha*

Soil cultivation method	Year			Average for 2021-2023
	2021	2022	2023	
Traditional soil cultivation	3.57	3.58	3.54	3.56
Minimum soil cultivation	3.85	3.81	3.89	3.85
No-till tillage, cm	3.91	3.95	3.98	3.95
$Hip_{0.05}$	0.05	0.12	0.08	0.12

***Source:** compiled by the authors*

Analysis of the quality of oilseeds is an integral part of sunflower product evaluation. Oilseeds are a key component to produce sunflower seed oil, so it is important to have a clear understanding of their quality. Quality indicators, such as crude fat content and oleic acid content, help to evaluate the raw material and determine its suitability to produce high-quality sunflower oil. The crude fat content of sunflower seeds is determined by the amount of fat-like substances contained in one gram of seeds. This indicator is relevant as it determines the oil content that can be extracted from the seeds and, accordingly, the production of a quantitatively significant amount of oil. Oleic acid, a monounsaturated fatty acid, is one of the key components of sunflower oil. Its content in the raw material determines the quality of the oil and its beneficial properties. A high oleic acid content often indicates a high quality of raw materials and the potential for producing high-quality oil. The results of the study confirmed that soil cultivation methods affect the quality composition of sunflower seeds. Thus, the content of oleic acid in sunflower oil under conventional tillage

was 88.8%, and the content of crude fat was 50.6%. With minimal tillage, the oleic acid content was 89.7% and the crude fat content was 51.2%. Under no-mouldboard tillage, the quality characteristics of sunflower seeds were the highest and amounted to an oleic acid content – of 90.5%, and crude fat content – of 52.5% (Table 6).

***Table 6**. Oleic acid content in sunflower oil and crude fat in seeds, % (average for 2021-2023)*

Soil cultivation method	Oleic acid content	Crude fat content
Traditional soil cultivation	88.8	50.6
Minimum soil cultivation	89.7	51.2
No-till tillage, cm	90.5	52.5

***Source:** compiled by the authors*

Thus, conventional tillage accumulated the highest content of oleic acid in oil and crude fat in sunflower seeds, while no-till tillage showed the lowest values. This may be due to the varying degrees of nutrient retention in the soil and plants when different cultivation methods are used. According to the study, the problem with no-till tillage is that considering all aspects (moisture, soil aggregates, seeds), the yield increase with such tillage may be insignificant. Therefore, to increase yields in such conditions, other methods can be used, such as minimum tillage technology.

Summarising the results of the study, it is possible to state that soil tillage methods affect soil density, productive moisture reserves, water-resistant soil aggregates, 1000-seed weight and sunflower head diameter, as well as the yield of the crop itself. Traditional tillage provided the best conditions for sunflower growth and development, while no-till tillage showed the lowest values for most indicators. To increase yields in southern Ukraine, farmers can take measures to improve soil quality, such as using minimum or combined tillage technologies. Thus, the development and implementation of energy-saving technologies for growing sunflower hybrids in southern Ukraine is a key step towards optimising agricultural practices in this part of Ukraine.

DISCUSSION

The development and implementation of energy-saving technologies in sunflower cultivation is an urgent task due to the need to ensure sustainable development and reduce the negative impact of the agricultural sector on the environment. The use of such technologies can help reduce energy and resource consumption, which in turn will reduce emissions into the atmosphere and ensure more environmentally friendly crop cultivation (Avgoustaki & Xydis, 2020; Sydiakina & Ivaniv, 2023). Most authors agree that global warming is causing significant changes in the environment that require a response from agriculture (Casali *et al.*, 2022).

T. Kachanova *et al.* (2023) investigate the optimal rates of mineral fertilizers to enhance the yield of high-oleic sunflower hybrids in the Southern Steppe of Ukraine, revealing that the Kadet hybrid achieved the highest yield and seed quality with $N_{90}P_{90}K_{60}$ fertilization. Results indicate that proper mineral fertilization significantly boosts crop productivity, with the Kadet hybrid yielding 24.1% more than with lower fertilizer rates, while also showing superior oil quality compared to other hybrids under various fertilization conditions. V.I. Trotsenko *et al.* (2020) emphasise that the use of energy-saving technologies that help to use resources efficiently, reduce environmental impact and increase productivity is becoming an increasingly important aspect of modern agriculture. This approach not only contributes to the sustainable development of the industry but also ensures food security and preserving ecosystems for future generations. In addition, energy-saving technologies can help reduce dependence on imported oil, increase the country's energy independence and create new opportunities for agricultural development. In this regard, Y. Domaratskiy *et al.* (2023) and I.O. Kolosok (2022) note that the development and implementation of energy-saving technologies in sunflower cultivation should be one of the priority areas for agricultural development in Ukraine. This will not only reduce the negative impact of the agricultural sector on the environment but also ensure the sustainable development of the industry.

The use of modern control and automation systems for sunflower cultivation opens great opportunities for optimising the use of fertilisers and crop protection products. This is becoming a key aspect in ensuring sustainable and environmentally friendly sunflower cultivation. One of the main advantages of these systems, according to E.D.S. Coêlho *et al.* (2022), is their ability to accurately dose and distribute fertilisers and chemical protection products on the field, which avoids oversaturation of the soil with chemicals and prevents groundwater pollution and environmental degradation. In addition, according to O.I. Tsyliuryk *et al.* (2021), modern control and automation systems provide the ability to monitor the level of soil and water pollution in real-time. This makes it possible to respond promptly to problems and take the necessary measures to eliminate them. This approach helps to reduce emissions of harmful substances into the environment and improve the environmental sustainability of the agroecosystem (Demir, 2020).

The use of stress-tolerant sunflower hybrids has a significant impact on yields and resistance to pests and diseases. Stress-tolerant sunflower hybrids are characterised by their ability to adapt to adverse environmental conditions such as drought, soil salinity, or excessive irrigation (Nardón *et al.*, 2021). These hybrids demonstrate better productivity and crop preservation under stressful conditions. V. Giannini *et al.* (2022) confirm that the use of such hybrids can reduce the amount of pesticide use and increase yields by 20%. A comparison of the results with previous studies in this area confirms the consistency and complementarity of the findings. According to C.M. Nobile *et al.* (2020), this reduces production costs and the negative impact of agricultural activities on the environment. In addition, the use of no-till tillage systems reduces fuel and energy consumption, which reduces CO_2 and other harmful emissions into the environment. This contributes to a more sustainable and environmentally friendly system of growing crops, including sunflowers.

The results of the study by M. Janmohammadi and N. Sabaghnia (2023) are also echoed in the present study that the use of no-till tillage systems has a significant impact on soil fertility. The study determined that no-till tillage systems help to preserve soil structure and water permeability. This retains moisture in the soil and prevents erosion, which is important for maintaining soil fertility and increasing crop yields. V. Pichura *et al.* (2023), and A.U. Jan *et al.* (2022) point to the importance of optimising tillage technologies, especially in the southern regions. Considering the specifics of these zones, in particular, drought management and soil moisture conservation, is extremely important for achieving successful crop production results. According to research, optimal tillage practices can have a significant impact on conserving resources and increasing sunflower yields in conditions of insufficient moisture. In addition, according to R. Puttha *et al.* (2023), geospatial models can be used to analyse various factors, such as soil structure, climatic conditions, and other factors, to optimise sunflower cultivation processes. This makes it possible to accurately determine the optimal tillage and irrigation methods for each specific site, which maximises yields and reduces resource use.

In general, the various results of the researchers and the study demonstrate that the use of energy-saving technologies in sunflower cultivation is an important step towards the sustainable development of the agricultural sector. These technologies not only help to conserve natural resources and reduce the negative impact on the environment but are also an important element of economically sustainable crop production and meet modern requirements for sustainable development. Thus, the growing awareness of environmental issues and the need for sustainable production requires continuous improvement of agricultural practices. An important part of this process is the integration of scientific research, innovative technologies and efficient resource management. Modern approaches to soil cultivation, the use of resistant hybrids and crop varieties, and crop control open up new opportunities to increase production while reducing negative environmental impact. Thus, the combination of scientific knowledge, technology and environmental responsibility can contribute to a sustainable and efficient agricultural system that meets the needs of modern society without harming the environment.

CONCLUSIONS

The study found that the choice of soil cultivation method has a significant impact on its agrophysical parameters, in particular, density, productive moisture reserves and structural stability. Reducing the intensity of tillage, especially when using no-till, leads to an increase in soil density at all depths. Thus, the soil density under no-till was 1.11 g/cm³ at a depth of 0-10 cm before sowing and 1.21 g/cm³ before harvesting, while conventional tillage formed a density value of 1.02 g/cm³ and 1.1 g/cm³, respectively.

Research has confirmed that no-till is the most effective in preserving soil moisture. Before harvesting, the soil moisture content in the 0-100 cm layer under no-till was 135 mm, which is 25 mm more than under conventional tillage (110 mm) and 9 mm more than under minimum tillage (126 mm). This is especially important for conditions with insufficient moisture, where additional reserves of productive moisture can significantly improve the growth and development of crops. As for sunflower productivity indicators, no-mouldboard tillage provided the highest values for both the weight of 1000 seeds (47.3 g) and the diameter of the basket (20.2 cm), which indicates its effectiveness in creating optimal conditions for the growth and development of the crop. With minimal tillage, the weight of 1000 seeds in sunflower were 45.4 g and the diameter of the head was 19.4 cm, while traditional tillage provided the lowest values: the weight of 1000 seeds reached 38.2 g and the diameter of the head was 17.6 cm.

Sunflower yield also depended on the method of tillage. The highest yield of the crop on average over the years of research – 2.6 t/ha – was established with no-mouldboard tillage. Minimal tillage allowed form a sunflower yield of 2.53 t/ha, and the lowest yield was recorded under traditional tillage – 2.52 t/ha. In addition, the study confirmed that the choice of tillage method significantly affects the quality of the sunflower crop. Traditional cultivation provided the best results in terms of oleic acid (83.8%) and crude fat content in seeds (44.6%), which are important indicators of the quality of oilseeds. In addition, in the long term, reduced tillage methods, such as no-till, can have additional benefits, such as preserving soil structure and accumulating moisture. The prospect of further research

is to study the impact of soil cultivation methods on crop resistance to diseases and pests. The limitation of the study is that the impact of other agronomic measures, such as fertilisation, mulching and irrigation, on sunflower production results was not considered.

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CONFLICT OF INTEREST

None.

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Розроблення та впровадження енергоощадних технологій вирощування гібридів соняшнику в умовах півдня України

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Анотація. Розроблення та впровадження енергоощадних технологій вирощування гібридів соняшнику є важливим напрямком досліджень для забезпечення стійкого розвитку аграрного сектора та збереження навколишнього середовища. Метою дослідження було проаналізувати вплив різних способів обробітку ґрунту на врожайність соняшнику в умовах півдня України. Для досягнення мети проведено польове дослідження на полях Навчально-науково-практичного центру Миколаївського національного аграрного університету у 2021-2023 роках. В результаті виконаного дослідження встановлено, що спосіб обробітку ґрунту має суттєвий вплив на його щільність, запаси вологи та структурну стабільність. Зменшення інтенсивності обробітку, особливо при використанні безвідвального способу (no-till), ефективніше зберігає вологу в ґрунті, проте збільшує його щільність. Зокрема, при no-till перед сівбою соняшника вона становила 1,11 г/см^3 на глибині 0-10 см та 1,21 г/см^3 перед збиранням культури, тоді як за традиційного обробітку щільність ґрунту була 1.02 г/см^3 і 1.1 г/см^3 відповідно. Крім того, безвідвальний обробіток ґрунту забезпечив найкращі показники продуктивності соняшника, включаючи масу 1,000 насінин (47,3 г), діаметр кошика (20,2 см) та урожайність (2,6 т/га). Безвідвальний обробіток також покращує якість врожаю соняшника, підвищуючи вміст олеїнової кислоти (86,5 %) та сирого жиру в насінні (48,3 %). Отримані результати сприяють розробленню комплексних підходів до впровадження енергоощадних технологій у вирощуванні гібридів соняшнику на півдні України, що дозволить підвищити ефективність виробництва та знизити витрати на виробництво

Ключові слова: обробіток ґрунту; врожайність; якість насіння; польові та лабораторні досліди; агрофізичні показники ґрунту

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Nutrient regime and balance of nutrients in soil under forage crops under application of different types of fertilizers (on the example of Kyzylorda region)

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Abstract. Modern agriculture is facing a number of challenges, among which the efficient use of fertilisers to provide plants with the necessary nutrients is of particular importance. In particular, the growing focus on sustainable agriculture and the need to preserve soil resources underline the relevance of research into optimising fertiliser use. The purpose of the study was to identify effective methods of fertiliser

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use to provide plants with nutrients. To achieve this goal, the effectiveness of green manure, organic (manure) and mineral fertilisers under *Sorghum* and perennial grasses (*Medicago sativa*, *Elytrigia*, *Agropyron*) on saline soil was investigated. The study founded that organic fertilisers, such as manure and green manure, contribute to a more even supply of nutrients to plants compared to mineral fertilisers. This is particularly important in the context of nitrogen and phosphorus balance, where *Medicago sativa* has a positive nitrogen balance due to its ability to symbiotically fix nitrogen. Other crops studied, such as *Elytrigia*, *Agropyron* and *Sorghum*, showed a negative nitrogen balance on the control variant, but the application of $N_{100}P_{50}K_{110}$ mineral fertiliser resulted in a positive nitrogen balance. The replacement of mineral fertilisers with organic fertilisers such as manure and green manure increased nitrogen inputs but also increased nitrogen removal from the soil due to the increase in phytomass yields. The results of the study confirmed the importance of transitioning to a more sustainable and environmentally friendly way of production in agriculture, which will ensure the development of the industry and increase its competitiveness in the international market. The practical significance of the study is to provide farmers with the opportunity to increase the yield of their crops and at the same time preserve soil fertility through the optimal use of nutrients contained in fertilisers

Keywords: exchangeable potassium; phosphorus; nitrogen; humus; *Sorghum*; *Medicago sativa*

INTRODUCTION

Agriculture is a key component of the economy of many regions, including Kazakhstan, where the development of this sector often depends on soil fertility and efficient use of fertilisers. Over the past decades, much attention has been paid to studying the impact of different types of fertilisers on the soil nutrient regime and nutrient balance in the fodder crops growing system (Carr *et al.*, 2020; Asaye *et al.*, 2022). The Kyzylorda region, located in the southern part of Kazakhstan, is an important agricultural centre where a variety of fodder crops are grown for animal feeding. However, due to the region's specific conditions, such as dry climate and saline soils, the issue of soil fertility and balanced crop nutrition becomes extremely important. One of the main methods of maintaining soil fertility is the use of different types of fertilisers (Allam *et al.*, 2022).

The World Meteorological Organization calls the drying up of the Aral Sea one of the largest anthropogenic ecological crises of the 20th century. The disappearance of the sea has had a systemic negative effect on the flora, fauna, landscape, and climate of the Aral Sea region. The drying up of the Aral Sea has led to the sharp desertification of the Aral Sea region and provoked the salinization of its lands. Due to lack of moisture, former hydromorphic soils turn into salt marsh in 3-5 years (Ismayilzada *et al.*, 2023). According to the latest data, the area of saline irrigated lands in Kyzylorda region is about 225.9 thousand ha, of which slightly saline – 87.6 thousand ha, moderately saline – 73.3 thousand ha, strongly and very strongly saline – 65.1 thousand ha. Therefore, this article presents the increase in adaptive potential of crops by optimizing nutrient regime, and dynamics of ingredients content in the soil layer under fodder crops depending on the types of fertilizers. In recent years, against the background of increasing rates of soil degradation, the biological cycle of substances in agriculture has been disturbed, and a sharply negative balance of substances has been formed. According to scientists' data, soil organic matter is lost mainly as a result of water-erosion and deflation processes – 1 t/ha or more of organic matter is alienated from the biological cycle together with fine-grained soils (Palchikov *et al.*, 2018; Tanchyk *et al.*, 2021). The results of research for the reproduction of soil fertility, compensation of unproductive erosion, and other losses in them according to the calculations of the same author require annual application of 6-7 t/ha of organic fertilizers in terms of litter manure. But the actual need for organic fertilizers is satisfied only by 10%. According to his data, the main reserve for replenishment of organic matter reserves in the soil is the phytomass of agrocenoses, and the share of side dressing in the future should account for 27-30% of fertilized arable land, which will amount to 15 kg nitrogen, phosphorus, and potassium (NPK) per 1 ha on a national scale (Rosemarin *et al.*, 2020; Pahalvi *et al.*, 2021).

In this regard, firstly, to maintain and restore soil fertility, it was necessary to eliminate or minimize soil erosion and deflation, and secondly, for the sustainable functioning of agroecosystems, it was necessary to ensure a balanced cycle of biophilic elements and the reproduction of the humus state of soils by applying organic fertilizers, which led to the purpose of the current study.

MATERIALS AND METHODS

The research was conducted in three districts of the Kyzylorda region, i.e., on weakly and strongly saline agricultural lands of the Shiyeli, Zhanakorgan, and Kazaly districts. In general, about 150 thousand ha out of 225.9 thousand ha of lands belonging to Kyzylorda region were covered (Fig. 1).

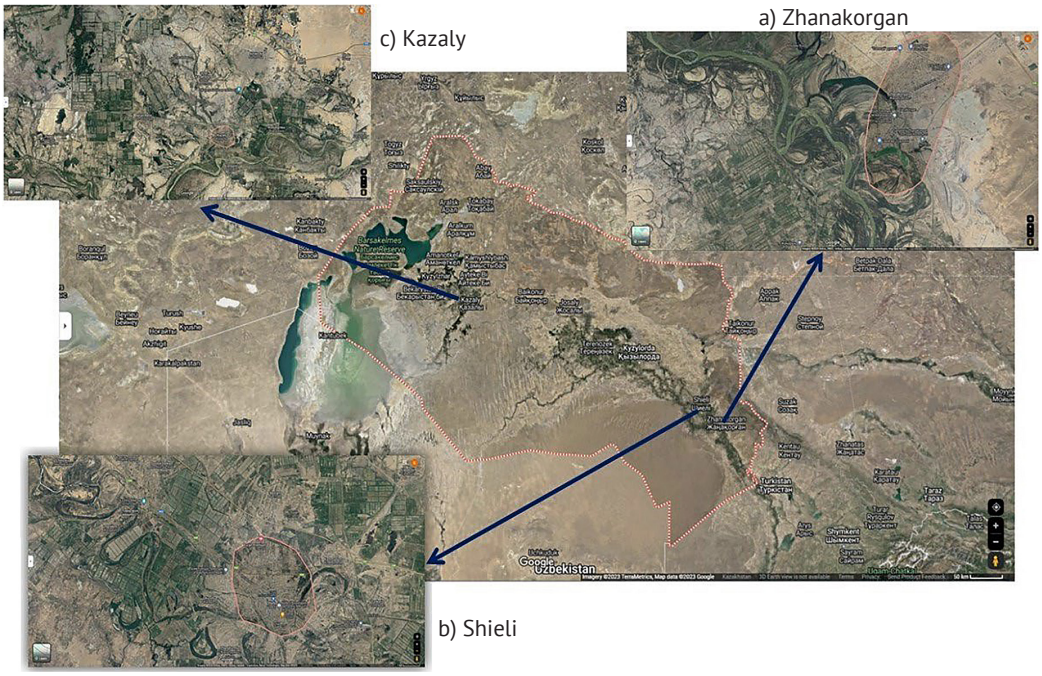

Figure 1. *Study area of Kyzylorda region*

Source: *compiled by the authors*

A study of crop productivity potential (phytomeliorants) under different methods of enrichment of saline soils with nutrient elements was carried out on medium and highly saline soils. The efficiency of separate and joint application of manure and different doses and types of mineral fertilizers for fodder agrocenoses was studied on slightly saline soil:

1. Without fertilizer (control).
2. Manure 40 t/ha.
3. Manure 40 t/ha+P60 (basic fertilizer).
4. Basic fertilizer+N120 P120.
5. Basic fertilizer+N180P120.
6. Basic fertilizer+N240P120.
7. Basic fertilizer+N120P90.
8. Basic fertilizer+N120P120 + N120 in top dressing.

The efficiency of sideral, organic (manure), and mineral fertilizers for *Sorghum* and perennial grasses (*Medicago sativa, Elytrigia, Agropyron*) was studied on strongly saline soil. A green mass of barley and *Medicago sativa* was used as a green manure crop, manure was applied at the rate of 20 t/ha. The dose of mineral fertilizers corresponded to the nutrient elements contained in the specified amount of manure (N100P50K110). In case of a discrepancy of elements entering the soil with barley and *Medicago sativa* biomass to this amount, the missing part was replenished with mineral fertilizers.

Studies on the optimization of plant water availability conditions were carried out under all three soil salinity degrees. On slightly saline soil irrigation of the studied crops – *Medicago sativa* and *Sorghum* – was carried out at the lower moisture threshold of 70-75% field moisture capacity (FMC). Only the depth of soil moistening and alternation of irrigation differed:

1. Soil moistening depth of 0.4 m.
2. Soil moistening depth of 0.6 m.
3. Soil moistening depth of 0.8 (0.9) m – control.
4. Alternating irrigation with soil moistening to 0.4 m and 0.8-0.9 m.

On medium saline soil, studies were carried out on three variants of *Sorghum* irrigation: no irrigation, control; irrigation at the lower threshold of soil moisture 80% of the FMC; irrigation at the lower threshold of soil moisture 70% FMC before flush, 80% in the subsequent vegetation period. Variants with two thresholds of pre-watering soil moisture – 70-75% and 80-85% of FMC (factor A), three depths of moistening – 0.4 m, 0.6 m, and 1.0 m (factor B) of four crops – *Sorghum*, *Medicago sativa*, *Elytrigia* and *Agropyron* (factor C) – were tested on strongly saline soil. Experiments were laid out using the organized repetition method. Within the repetitions, plots were placed randomly.

Root mass accumulation by plants was determined according to the method of N.Z. Stankov. Monolith was taken in layers 0-0.2; 0.2-0.4 and 0.4-0.6 m, with dimensions 0.331×0.302 m for perennial grasses, 0.24-0.70 m for row crops. To determine the volumetric mass, a soil sample with an undisturbed structure was taken with a cutting cylinder, 200 cm in volume; the density of the solid phase was determined by picnometric method; the lowest water capacity – by the method of flooded sites (2×2 m), structural aggregate composition –

by N.I. Savvinov method; water permeability – by Nesterov device; productive moisture reserves in soil – by calculation method.

Soil nutrient regime was determined in experiments by fertilizer, tillage practices, and irrigation regime. Soil samples for analysis were taken before the main tillage, at sowing, in the phases: tillering, flush, and at *Sorghum* harvesting; at harvesting of each cutting of perennial grasses on layers 0-0.2 m and 0.2-0.4 m in each variant of experiment I and III repetitions. The chemical composition of aboveground mass and root residues was determined according to the methods of biochemical study of plants: total nitrogen – by Kjeldahl, phosphorus – by Levitsky, potassium – on a flame photometer, fat – by Soxhlet, fiber – by Gennesberg and Stamman. All photographs in the manuscript were taken by the lead author. The majority of the identifiable images feature doctoral students from Kazakh National Agrarian Research University. Before taking these photographs, all doctoral students were informed of their intended use and gave their consent to exposing these photos. Any remaining identifiable individuals in the photographs are co-authors of this manuscript and have also given their consent for publication. The authors followed the standards of the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979).

RESULTS

Organic fertilizers used in the authors' study – manure and green mass of barley and *Medicago sativa* – contribute to a more uniform provision of plants with nutrients than when mineral fertilizers are applied to the soil. Thus, the content of hydrolyzable nitrogen in the arable layer of soil in the first year of use of perennial grasses in the variant where fertilizers were not applied, the highest was at the first date of determination – 15 May – on average under blue grass and *Sorghum* – 34.9 mg, under *Medicago sativa* – 43.0 mg/kg. It was also high enough when determined a month later – 33.7 and 37.5 mg/kg, respectively (Fig. 2). Further, the specified form of nitrogen in soil continues to decrease and at the harvesting of the second cutting of blue grasses (15 September) compared to the determination in the middle of August either did not change (*Elytrigia*) or slightly (by 0.2-0.4 mg/kg) increased (*Sorghum, Agropyron*). A slight increase (by 3.9 mg/kg) was also noted under *Medicago sativa*.

Average nitrogen content (on 5 determinations) in the soil under *Medicago sativa* from 33.3 mg on control increases up to 47.0 mg at the application of mineral fertilizers, up to 54.7 mg – at manure application, up to 63.3 mg – at sideration. The nitrogen regime of soil under *Elytrigia* and *Agropyron* under these types of fertilizers remains practically the same. Nitrogen content in the soil under them on mineral fertilizer background increases by 25.2 and 22.0%, on manure – by 45.0-43.6%, and on sidedress – by 49.1 and 46.2%. The content of hydrolyzable nitrogen under *Sorghum* at the application of manure and mineral fertilizers increases in comparison with the control by the same value (by 36.1-36.5%), but at sideration its index was higher – 72.8%.

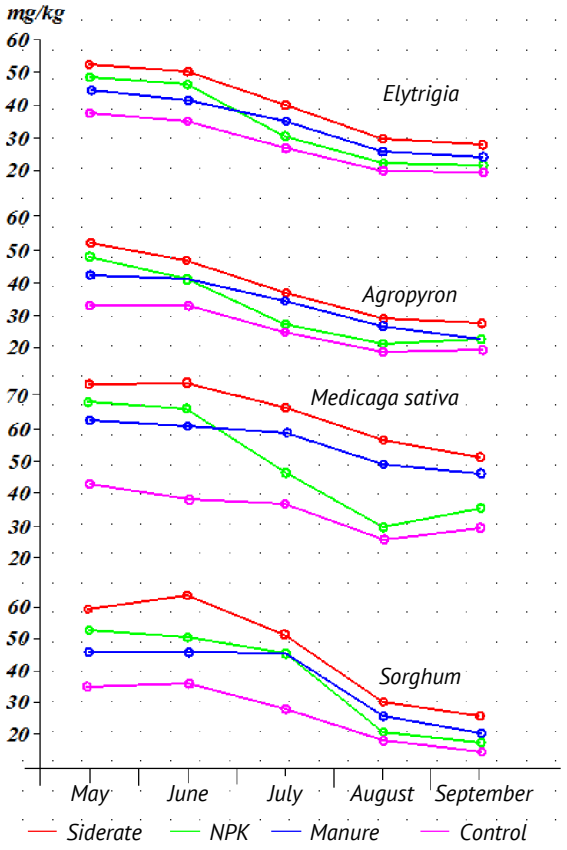

***Figure 2**. Dynamics of hydrolysable nitrogen content in arable soil layer under forage crops depending on types of fertilizers*
***Source:** compiled by the authors*

It is known that in irrigated conditions the main form of assimilated nitrogen is nitrate. In irrigated conditions of Kyzylorda region nitrogen, even from fertilizers applied in ammonia form, very quickly passes to nitrate form and during the whole vegetation period, it is represented by very mobile nitrate form. The most favorable environment for nitrification is soil moisture between 60-80% and a temperature of 20-30°C. Such conditions in the authors' study were formed exactly in the first two terms of determination of hydrolyzable nitrogen in the soil – in May and the first half of June. The maximum amount of nitrogen in the soil under forage crops falls on this period.

In the subsequent period, due to soil compaction after irrigation, leaching by irrigation water, as well as denitrification by water stagnation during irrigation,

the content of assimilable nitrogen in the soil decreases, especially in the mineral fertilizer background. This is also caused by its consumption by plants for crop formation, which is confirmed by the results of studies. The significant increase of hydrolyzable nitrogen in the soil in comparison with this variant when manure is applied to forage crops is explained by the fact that this not only adds nutrients to the soil but also creates conditions for the formation and development of microorganisms that contribute to the transition of nutrient elements into mobile compounds. In this case, nitrogen losses for leaching and denitrification are minimal, as nitrogen release from organic matter is gradual rather than simultaneous, as in the case of mineral fertilizer application.

Tilling the soil with a green mass of plants, especially legumes, increases the biological activity of the soil and increases the content of nutrients, including nitrogen. It acts as a kind of "biological fire starter" for the decomposition of not only fresh green mass but also other organic residues in the soil. However, when plowed in the first half of summer, the green mass of siderates decomposes 1.5-2.0 times faster than straw, crop, and root residues of grain crops. In the beginning, there is a rapid release of carbon dioxide, simultaneously the formation of a significant amount of ammonia, then its accumulation is weakened and in aerobic conditions nitrate formation processes intensify.

For these processes, microorganisms need additional energy material in the form of nitrogen and other elements, in connection with which there is even a slight decrease in the yield of subsequent crops. In autumn sidedressing into the soil siderates creates different conditions for supplying plants with nitrogen. Between the fallow pea green mass and active consumption of nitrogen by forage crops, a relatively long time passes, and the phenomenon of biological nitrogen fixation in this case is no longer observed. For these reasons, the nitrogen content in the soil under *Medicago sativa* after sideration increases by 90.1%, *Sorghum* – by 72.8%, *Agropyron*, and *Elytrigia* – by 46.2 and 49.1%, respectively, which indicates the most favorable effect of green mass *Medicago sativa* on the nutrient regime of the soil compared to other fertilizer options. The dynamics of phosphate content in soil are essentially similar to the dynamics of hydrolyzable nitrogen, except for the autumn increase of P_2O_5 (Fig. 3). But their total content in the soil is much lower. In the control, it decreases from 22.5-24.3 mg/kg at the first determination in mid-May to 15.6-17.8 mg/kg at the last one in mid-September, which is a consequence of increasing plant consumption.

The amount of phosphorus available for plants depends to a greater extent on soil fertilization than on seasonality because, during the whole vegetation period on fertilized variants, its content is significantly higher than on unfertilized ones. Thus, the application of mineral fertilizers N100P50 contributes to the increase of phosphate in the arable layer on average for five terms of determination for the growing season of fodder crops by 38.7% (from 20.4 to 28.3 mg/kg). Organic fertilizers contribute to the increase of P_2O_5 content in the soil: manure by 41.7%, siderate – by 59.6%, compared to the control. As in the case of hydrolyzable nitrogen, a more uniform supply of assimilable phosphorus as a result of the decomposition of manure and siderate in the soil contributes to its greater accumulation in the soil than in the case of mineral fertilizers. This fact is related to the fact that on highly saline soil single application of the whole dose of phosphorus fertilizer (except for 10 kg/ha, which was given at sowing) leads to the precipitation of part of assimilable phosphorus (PO_4) into sediment.

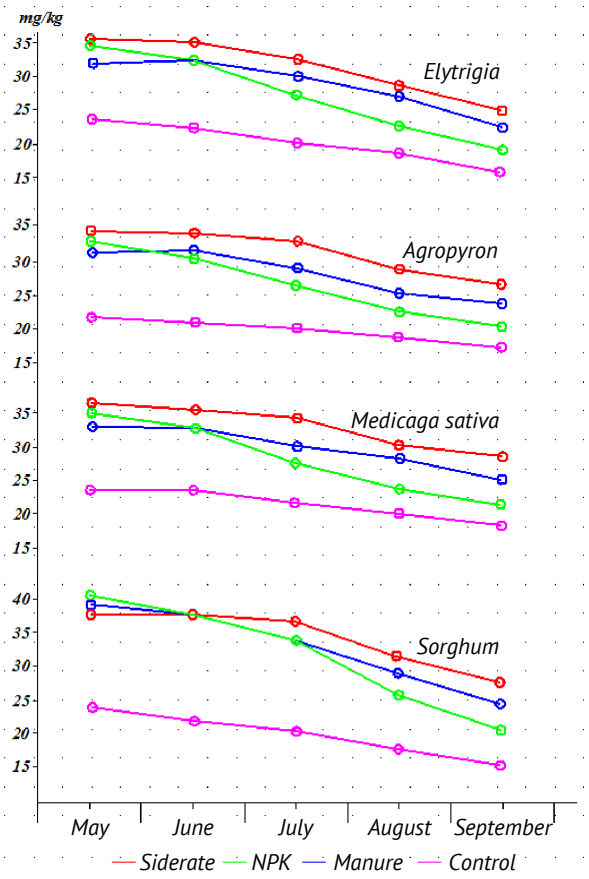

***Figure 3**. Dynamics of P_{205} content in an arable layer of soil under forage crops depending on types of fertilizers*
***Source:** compiled by the authors*

Among the studied crops, the highest phosphate content in soil was under sugar *Sorghum*, which is apparently due to the higher nitrogen demand of this crop and inadequate (disproportionate) consumption. Soils of the considered region are characterized by sufficient content of assimilable potassium. The arable layer of soil contains 420-470 kg/ha of exchangeable potassium, and with 10 t/ha of perennial grasses only 150-200 kg/ha

is taken out. Apparently, for this reason, little change in potassium content was observed under the tested crops in the study (Fig. 4). The average amount of K_2O on the control variant ranged from 351.6 to 352.0 mg/kg for crops, in the setting of mineral from 353.7 to 355.2 mg, in the setting of manure from 353.8 to 355.7 mg and from 355.9 to 356.9 mg/kg on average for all terms of determination. It follows from the same data that the types of fertilizers do not have a noticeable effect on the content of exchangeable potassium in the soil. Its increase in the arable layer of the soil was observed at the application of mineral fertilizers only by 0.5-1.1%, manure by 0.5-1.2% and soil sideration by 1.1-1.5%.

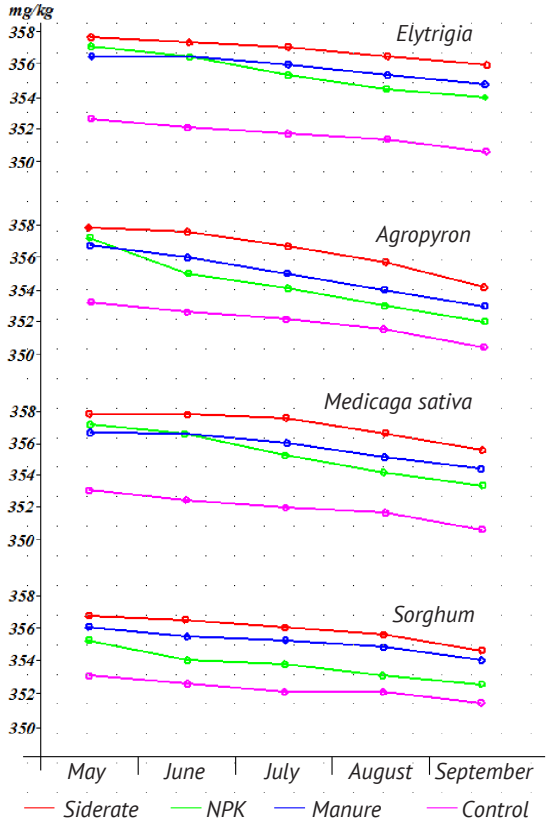

***Figure 4**. Dynamics of K_2O content in the topsoil layer under forage crops depending on types of fertilizers*
***Source:** compiled by the authors*

An insignificant change of mobile potassium content during the vegetation period on meadow-chestnut soils is explained by the fact that it is rich in potassium and its exchangeable form is always maintained at a constant level due to the transition of a part of its total amount to the exchangeable state, instead of extracted by plant roots for the formation of yield. How the nutrient regime of the soil is formed and what measures should be taken to improve it can be judged by the balance of nutrients in the soil.

Its incoming part includes nutrient inputs from fertilizers, seeds, plant residues, precipitation, and symbiotic and non-symbiotic fixation of atmospheric nitrogen. The expenditure part takes into account the removal with economic yield, gaseous losses of nitrogen as a result of denitrification, as well as leaching into deep layers during irrigation, heavy precipitation, and losses from soil erosion (deflation). Looking ahead, it should be noted (since the issue of crop yields about the applied fertilizers has not yet been considered) that in the study with the economic yield of fodder crops *Medicago sativa* takes out from the soil from 62.5 to 132.2 kg/ha of nitrogen, from 15.5 to 30.1 kg of phosphorus and from 39.3 to 72 kg/ha of potassium depending in the setting of fertilizers (Table 1).

Bluegrasses are somewhat less tolerant of nitrogen and phosphorus, but much more potassium 51.6-127.7 kg/ha. The harvested *Sorghum* crop contains 1.72 times more nitrogen than *Medicago sativa*, 2.13 times more nitrogen than *Agropyron*, and 1.78 times more nitrogen than *Elytrigia*. It also takes more phosphorus – 3.2; 3.3 and 3.6 times and potassium – 2.47; 1.50 and 1.78 times. This is not due to its high percentage content in *Sorghum* phytomass but to the higher yield of this crop compared to others. A significant amount of nutrients is accumulated in the soil and with stubble (crop residues) – root residues (SRR). The average nitrogen content in such mass of *Medicago sativa* is 26.4 kg/ha, in *Elytrigia* – 24.4; in *Agropyron* – 21.7 and least of all – 7.5 kg/ha – in *Sorghum* SRR. P_2O_5 is most accumulated in the considered mass of *Medicago sativa* – 8.1 kg/ha against 6.8; 6.4 and 3.4 kg/ha of other crops, respectively (Table 2).

***Table 1**. Content of main nutrients in above-ground phytomass of fodder crops depending on types of fertilizers for 2021-2022*

Types of fertilizer	Feeding elements	In 1 kg air-dry weight, %				In phytomass yield, kg/ha			
		Medicago sativa	*Elytrigia*	*Agropyron*	*Sorghum*	*Medicago sativa*	*Elytrigia*	*Agropyron*	*Sorghum*
Without fertilizer, control	N	2.10	2.1	2.00	2.40	62.5	57.7	50.5	95.4
	P_2O_5	0.52	0.48	0.55	0.80	15.5	13.2	13.9	31.8
	K_2O	1.32	2.18	2.04	1.95	39.3	59.9	51.6	77.5
NPK	N	2.42	2.2	2.0	2.39	95.4	96.8	76.0	172.1
	P_2O_5	0.56	0.50	0.54	1.00	22.2	22.0	20.5	72.0
	K_2O	1.33	2.20	2.10	2.00	52.9	96.8	79.8	144.0

Table 1. Continued

Types of fertilizer	Feeding elements	In 1 kg air-dry weight, %				In phytomass yield, kg/ha			
		Medicago sativa	*Elytrigia*	*Agropyron*	*Sorghum*	*Medicago sativa*	*Elytrigia*	*Agropyron*	*Sorghum*
Manure	N	2.46	2.2	2.1	2.41	11.75	110.5	94.0	201.8
	P_2O_5	0.56	0.52	0.55	1.10	26.7	26.1	24.6	92.1
	K_2O	1.33	2.26	2.15	2.11	63.5	113.6	96.2	176.7
Siderate	N	2.46	2.2	2.1	2.42	132.2	124.3	105.5	225.7
	P_2O_5	0.56	0.53	0.55	1.13	30.1	30.0	27.6	105.4
	K_2O	1.34	2.26	2.17	2.15	72.0	127.7	109.0	200.5

Source: *compiled by the authors*

Table 2*. Content of main nutrition elements in stubble (crop residues) – root residues for 2021-2022*

Types of fertilizer	Nutritional elements	In 1 kg air-dry weight, %				In total mass, kg/ha			
		Medicago sativa	*Elytrigia*	*Agropyron*	*Sorghum*	*Medicago sativa*	*Elytrigia*	*Agropyron*	*Sorghum*
Without fertilizer, control	N	1.60	1.12	1.05	0.85	17.8	15.7	13.2	4.7
	P_2O_5	0.46	0.30	0.32	0.39	5.1	3.9	4.0	2.0
	K_2O	0.94	1.04	1.00	1.30	10.4	13.6	12.6	7.2
NPK	N	1.64	1.13	1.05	0.81	24.5	23.7	21.3	6.9
	P_2O_5	0.49	0.32	0.31	0.38	7.3	6.7	6.0	3.2
	K_2O	0.96	1.05	1.02	1.29	14.3	22.0	19.7	11.0
Manure	N	1.66	1.15	1.05	0.86	29.9	27.6	24.0	8.8
	P_2O_5	0.51	0.33	0.32	0.38	9.2	7.9	7.3	3.9
	K_2O	1.04	1.06	1.02	1.30	18.8	25.4	23.3	13.3
Siderate	N	1.67	1.14	1.06	0.85	33.4	30.8	27.3	9.6
	P_2O_5	0.55	0.32	0.31	0.38	11.0	8.6	8.2	4.3
	K_2O	1.11	1.04	1.02	1.29	22.2	28.1	26.3	14.6

Source: *compiled by the authors*

In terms of potassium content in SRR on average for all fertilizer variants, *Elytrigia* and *Agropyron* surpassed *Medicago sativa*, they accumulated 2.3 and 18.2 kg/ha, respectively, against 16.4 kg/ha for *Medicago sativa*, and the minimum amount was observed in *Sorghum* residues – 11.5 kg/ha. The data on nutrient removal by plants and their accumulation in SRR the authors obtained were used in the preparation of the balance of nutrients in the soil under forage agrocenoses in connection with the applied fertilizers. Other balance items are given based on available literature sources, taking into account the natural conditions in which the authors' research was conducted. Taking into account the insufficient amount of precipitation during the years of research and the absence of large industrial facilities in the areas of the experiments, it took the average for the main agricultural areas of nutrients in the soil with precipitation: 5 kg/ha of nitrogen and 0.1 kg/ha of phosphorus.

The most important item of nitrogen input into the soil is its fixation from the air by leguminous crops, in the authors' case *Medicago sativa*. Many scientists have calculated that this crop, with a yield of 100 kg of hay annually accumulates 100 kg of nitrogen in the roots and 200 kg of nitrogen per hectare in the above-ground part. The same ratio between yield and nitrogen accumulation is given by other researchers (Tomaz *et al.*, 2021). In the current study, it was assumed that free-living microorganisms fix 2.0 kg/ha of nitrogen, taking into account the available humus stock and 10 kg/ha of fresh organic matter entering the soil, for a total of 12 kg/ha (Sapkota *et al.*, 2020).

A certain amount of nutrients is leached from the soil each year. According to the study of 1 ha annually leached nutrients available or applied with fertilizers: in England on clay soil 18-27 kg of nitrogen and 1.9-3.9 kg of potassium; in the USA – respectively 31-104 and 0.9-2.4 kg; in Germany – 10-20 and 20-60 kg; in Sweden – 0.8-24 and 16-37 kg. From the given data it is clear that the intensity of nitrogen and potassium leaching from the soil is influenced by many factors and they have been arranged in the following order of importance: rainfall and irrigation intensity, the granulometric composition of the soil, doses, forms, timing, and methods of fertilizer application, etc.

Under conditions of the Kyzylorda region, studies on accounting for nutrient leaching in soil have not been conducted. There is only data that at irrigation rates of 17.8-19.9 thousand meters of water per 1 ha 10.5-20.5 kg/ha of nitrogen is lost. Based on these data, taking into account also the irrigation norm adopted for field crops in the zone (3.5-4.0 thousand m/ha) and

the difference in the amount of precipitation (100 mm), nitrogen losses due to leaching in the area under study are equated to 6 kg/ha. Phosphorus leaching in the size of practical importance was not observed by the research. A certain part of nitrogen applied to the soil with fertilizers is lost (carried away from the soil in the form of volatile compounds – nitrogen oxides, elemental nitrogen, and ammonia). Depending on the type and dose of fertilizer, soil type and land use 10-20% (Slaton *et al.*, 2022) and sometimes up to 30-41.8% of nitrogen is lost for this reason (Klimczyk *et al.*, 2021). Other reports indicate that between 8 and 21.1 kg/ha of applied N are lost from the soil or between 0% on heavy soils and 7% on sandy soils (Xie *et al.*, 2021; Tadesse *et al.*, 2022).

In Kyzylorda region, where the authors' research was conducted, there is no need for potassium fertilizers, because the reserves of its assimilable form significantly exceed the removal with economic yield. Therefore, the authors have carried out balance calculations only for two main elements of plant nutrition – nitrogen and phosphorus, the content of which in the soils of the region under consideration is minimal. According to the authors calculations, in the incoming part of the nitrogen balance of *Medicago sativa* in the control variant, where fertilizers were not applied, the share of symbiotically fixed nitrogen is 46.2 kg/ha (57.0%), the share of nitrogen supplied with plant residues is about 23.0%, and the rest of it is non-symbiotically fixed and supplied with atmospheric precipitation. Despite a rather large removal with harvest (62.5%), mainly due to nitrogen fixation from the atmosphere, a positive balance of nitrogen was formed here (Table 3).

Table 3. *Nitrogen and phosphorus balance in arable layers of soil under forage crops under different types of fertilizers for 2021-2022 (kg/ha)*

Types of fertilizer	Balance sheet items	*Medicago sativa*	*Elytrigia*	*Agropyron*	*Sorghum*
		Nitrogen			
No fertilizer, control	Parish	81.0	32.7	30.2	21.7
	Expenditure	68.5	63.7	56.5	101.4
	Balance	+12.5	-31.0	-26.3	-79.7
Npk	Parish	214.1	142.7	140.3	125.9
	Expenditure	116.7	108.1	97.3	193.4
	Balance	+97.4	+34.6	+43.0	-67.5
Manure	Parish	235.8	146.6	143.0	127.8
	Expenditure	123.5	116.5	100.0	207.8
	Balance	+112.3	+30.1	+43.0	-80.0
Siderate	Parish	250.4	149.8	146.3	128.6
	Expenditure	138.2	130.3	111.5	231.7
	Balance	+114.2	+19.5	+34.8	-103.1
		Phosphorus			
Without fertilizer, control	Parish	5.1	3.9	4.0	2.0
	Expenditure	15.5	13.2	13.9	31.8
	Balance	-10.4	-9.3	-9.1	-29.8
Npk	Parish	57.3	56.7	56.0	53.2
	Expenditure	22.2	22.0	20.5	72.0
	Balance	35.0	34.7	35.5	-18.8
Manure	Parish	59.2	57.9	57.3	53.9
	Expenditure	26.7	26.1	24.6	92.1
	Balance	32.5	31.8	32.7	-38.2
Siderate	Parish	61.0	58.6	58.2	54.3
	Expenditure	30.1	30.0	27.6	105.4
	Balance	30.9	28.6	30.6	-51.1

Source: *compiled by the authors*

For other tested crops, due to the absence of this main item of the incoming part, a negative balance of humus was formed on the control, which was: *Elytrigia* – 31.0; *Agropyron* – 26.3; *Sorghum* – 79.7 kg of nitrogen per 1 ha. Application of N100P50K110 to the soil allowed a positive balance of nitrogen for all three perennial grasses, but even in this case, its index for *Medicago sativa* was higher than for bluegrass by 6.2-5.0 times for the same reason mentioned above. Application of manure and siderate to *Medicago sativa* instead of mineral fertilizers allows for an increase in the input part of the balance due to the increase of symbiotically fixed part of nitrogen, as well as the input due to plant residues by 21.7 and 36.3 kg/ha, respectively. This led to an increase in nitrogen balance by 14.9 and 16.8 kg/ha, although at the same time, its removal from the soil with higher phytomass yield increased by 22.1 and 49.7 kg/ha.

And under bluegrasses similar growth of balance index is not observed due to the increase of phytomass yield at organic fertilizer application and corresponding increase of its removal from the soil. Under sugar *Sorghum*, there is a negative balance of nitrogen not only on the control but also on all variants (types of fertilizers). The reason for this is one – failure to replenish nitrogen removal from the soil by the fertilizer doses the authors made. The same regularity is observed for phosphorus balance – a positive balance under perennial grasses under all types of applied fertilizers and a negative balance under control. Under sugar *Sorghum*, it was negative at the application of all types of fertilizers, even though there was a decrease of the balance indicator at the application of organic fertilizers in comparison with the application of mineral fertilizers, due to an increase of its removal with higher yields of phytomass.

DISCUSSION

Ensuring high quality and stable yields of fodder crops depends on the rational use of fertilisers and optimisation of the soil's nutrient regime. In modern agricultural practice, much attention is paid to the selection and application of different types of fertilisers aimed at improving soil fertility and providing a fodder base for livestock. In recent years, research in the field of agronomy and soil science has revealed a significant impact of different types of fertilisers on soil nutrition and growth parameters of forage crops. In particular, the use of various fertilisers, such as mineral, organic or combined fertilisers, can play a key role in providing the necessary nutrients for plant growth and development (Lynch *et al.*, 2021; Kong *et al.*, 2022).

The authors' research shows that different types of fertiliser can affect the concentration of nitrogen, phosphorus, potassium and other nutrients in the soil. For example, mineral fertilisers that dissolve quickly in water can provide plants with the necessary nutrients immediately after application (Panfilova *et al.*, 2019). This is especially important when you need to quickly improve crop growth or increase yields. Organic fertilisers, on the other hand, such as compost or manure, can gradually release nutrients over a long period of time. This can be useful when it is desirable to maintain a steady, long-term plant nutrition or to facilitate the control of soil nutrient levels over a longer period. Scientific studies presented by scientists such as M. Stepaniuk and A. Głowacka (2022) showed that different types of fertilisers can play an important role in changing the chemical composition of animal feed. In particular, the addition of fertilisers containing certain elements such as potassium, phosphorus or nitrogen can significantly affect the content of these elements in feed. For example, fertilisers rich in potassium can increase the concentration of potassium in feed, which in turn is important for providing animals with the necessary nutrients. Such studies point to the importance of the correct selection and application of different types of fertilisers to improve feed quality and ensure optimal conditions for the development of livestock farming.

Research also indicates that different types of fertilisers can have different effects on the adaptive potential of plants to environmental changes. In particular, some organic fertilisers, such as compost or crop residues, can improve soil structure and increase organic matter content, which helps to retain moisture and nutrients in the soil during periods of drought. On the other hand, micronutrients added to mineral fertilisers can increase plant resistance to certain diseases or stressful conditions, for example, boron can help plants better tolerate periods of high temperature or drought (Ostapenko, 2024). Such fertilisation strategies help crops to adapt to adverse conditions, which ensures more stable and productive cultivation in the face of climate change (Cai *et al.*, 2020).

Scientists emphasise the need to consider the environmental and biodiversity impact of different types of fertiliser. Some types of fertiliser may have less negative environmental impact than others. For example, the use of organic fertilisers such as manure, composts or biodegradable materials can help to conserve biodiversity and reduce soil and water pollution (Shahini *et al.*, 2024). On the other hand, some mineral fertilisers can have potentially harmful effects on the environment, such as pollution of soil and aquatic ecosystems with chemicals. Therefore, it is important to choose fertilisers based on their impact on environmental sustainability and conservation of natural resources (Zhang *et al.*, 2021).

The studies by M. Chilundo *et al.* (2018) emphasise the importance of taking into account the specific agro-climatic conditions of the region when choosing the type of fertiliser and its dosage. Thus, according to the authors, in the severely arid conditions typical for Kyzylorda region, the use of organic fertilisers can be important for ensuring the moisture retention properties of the soil and improving its structure. However, at the same time, mineral fertilisers may be necessary to provide plants with nutrients, which is also reflected in the study. In support of this view, the authors' research demonstrates the benefits of mineral fertilisers in increasing the yield and quality of fodder crops, emphasising their rapid availability to plants and high concentration of nutrients. In contrast, other studies focus on the use of organic fertilisers, which help to improve soil structure, preserve its water-air regime and provide a long-term fertilisation effect.

However, X. Chen *et al.* (2022) note that combined fertilisation approaches that use both mineral and organic components are extremely important to achieve an optimal balance of nutrients in the soil and maintain sustainable crop growth. This combination allows to determine the optimal fertilisation strategies to ensure

a balanced soil nutrient regime and increase the yield and quality of fodder crops in different agroclimatic conditions. S.J. Yan *et al*. (2021) focus on analysing the impact of different types of fertilisers on soil biological activity and microbiological processes that can affect the nutrient regime and health of the soil system. They also emphasise the cost-effectiveness of using different types of fertilisers, taking into account their cost and potential income from increased crop yields and quality, as economic profitability is of great importance in agriculture today.

S. Huang *et al*. (2021) note that successful fertiliser use involves not only choosing the right types of fertiliser, but also considering the optimal sequence and doses to achieve the best results in plant nutrition and soil fertility. It is important to take into account the individual characteristics of each field, such as its structure and physicochemical properties, as well as the specific needs and requirements of different crop types, as demonstrated in the study. Thus, the authors' research and this study confirm that, given the potentially negative impact of mineral fertilisers on the ecological state of soil and water resources, it is important to actively promote the use of organic fertilisers. Organic fertilisers, such as composts, vermicompost or natural plant-based fertilisers, have a lower environmental impact and contribute to the conservation of biodiversity. Their use helps maintain soil fertility and reduce erosion and water pollution. In order to support the transition to organic farming, it is important to take into account the diversity of conditions and needs of each field, as these may affect the effectiveness of different types of fertilisers (Tonkha *et al.*, 2024). An individual approach to the selection and application of fertilisers allows us to maximise crop yields while maintaining the environmental sustainability of soil and aquatic ecosystems.

It is also important to systematically monitor soil conditions and nutrient levels to ensure sustainable production. This allows you to identify problems in time and take the necessary measures to resolve them. Adaptability in the use of fertilisers and crop cultivation technologies is key to successful agricultural production in a changing climate and resource environment (Ivanova *et al.*, 2022). Thus, the results of research on the impact of different types of fertilisers on soil nutrient status and growth parameters of fodder crops emphasise the importance of rational and balanced fertiliser use to ensure sustainable and productive agriculture. Overall, the study of soil nutrient balance and optimisation of fodder crop nutrition in Kyzylorda oblast has great potential to improve the sustainability and productivity of the agricultural sector, as well as to provide food for the local population.

CONCLUSIONS

The agricultural sector is constantly facing challenges related to the lack of nutrients in the soil and their insufficient supply for various crops, including fodder. An important aspect of ensuring balanced plant nutrition is to study the impact of different types of fertilisers on the soil's nutrient regime and nutrient balance. The study found that organic fertilisers, such as manure and green manure, contribute to a more even supply of nutrients to plants than when using mineral fertilisers. The study reveals profound patterns in the nitrogen and phosphorus balance of different crops, particularly highlighting the distinctive behaviour of *Medicago sativa*. In the control variant without fertilisation, *Medicago sativa* showed a positive nitrogen balance: 46.2 kg/ha, 57.0% of which was attributed to symbiotic fixation and approximately 23.0% to plant residues. Despite a significant level of removal (62.5%) at harvest, mainly due to atmospheric nitrogen fixation, the crop maintained a positive nitrogen balance.

Other crops studied without the benefit of symbiotic nitrogen fixation showed a negative nitrogen balance. Thus, *Elytrigia*, *Agropyron* and *Sorghum* suffered from nitrogen deficiency on the control variant, respectively: 31.0 kg/ha, 26.3 kg/ha and 79.7 kg/ha. However, the application of N100P50K110 resulted in a positive nitrogen balance for all three perennial grasses, although *Medicago sativa* showed significantly higher results due to its excellent symbiotic nitrogen fixation ability. In addition, the replacement of mineral fertilisers with manure and green manure for *Medicago sativa* resulted in an increase in N application of 21.7 kg/ha and 36.3 kg/ha, respectively. However, the simultaneous increase in phytomass yields required higher nitrogen removal rates, mitigating the overall increase in nitrogen balance. Similar trends were observed in the phosphorus balance, with perennial grasses showing a positive balance for all fertiliser types, while *Sorghum* consistently showed a negative balance for all options. It was also found that organic fertilisers contribute to increased soil biological activity and nutrient accumulation, while mineral fertilisers can cause greater mobilisation of substances and increased losses. Thus, the efficient use of organic fertilisers can be key to maintaining a sustainable agro-ecosystem and ensuring high yields.

Thus, the use of different types of fertiliser can affect the nutrient balance in the soil under forage crops, which is important for planning flexible and efficient fertilisation strategies. Taking these results into account can help to optimise fertiliser use and ensure sustainable growth and development of forage crops without undue stress on the environment.

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CONFLICT OF INTEREST

The authors of this study declare no conflict of interest.

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Поживний режим і баланс поживних речовин у ґрунті під кормовими культурами при застосуванні різних видів добрив (на прикладі Кизилординської області)

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Анотація. Сучасне сільське господарство стикається з низкою викликів, серед яких особливе значення має ефективне використання добрив для забезпечення рослин необхідними поживними речовинами. Зокрема, зростаюча увага до сталого сільського господарства та необхідність збереження ґрунтових ресурсів підкреслюють актуальність досліджень з оптимізації використання добрив. Метою дослідження було визначення ефективних методів використання добрив для забезпечення рослин поживними речовинами. Для досягнення поставленої мети досліджували ефективність сидератів, органічних (гній) та мінеральних добрив під сорго та багаторічні трави (*Medicago sativa*, *Elytrigia*, *Agropyron*) на засоленому ґрунті. Дослідження показало, що органічні добрива, такі як гній та сидерати, сприяють більш рівномірному забезпеченню рослин поживними речовинами порівняно з мінеральними добривами. Це особливо важливо в контексті балансу азоту та фосфору, де *Medicago sativa* має позитивний баланс азоту завдяки своїй здатності до симбіотичної фіксації азоту. Інші досліджувані культури, такі як *Elytrigia*, *Agropyron* і *Sorghum*, показали негативний баланс азоту на контрольному варіанті, але внесення мінеральних добрив $N_{100}P_{50}K_{110}$ призвело до позитивного балансу азоту. Заміна мінеральних добрив органічними добривами, такими як гній та сидерати, збільшила внесення азоту, але також збільшила винос азоту з ґрунту завдяки збільшенню врожайності фітомаси. Результати дослідження підтверджують важливість переходу до більш сталого та екологічно безпечного способу виробництва в сільському господарстві, що забезпечить розвиток галузі та підвищить її конкурентоспроможність на міжнародному ринку. Практичне значення дослідження полягає у наданні аграріям можливості підвищити врожайність вирощуваних ними культур і водночас зберегти родючість ґрунту за рахунок оптимального використання поживних речовин, що містяться в добривах

Ключові слова: обмінний калій; фосфор; азот; гумус; *Sorghum*; *Medicago sativa*

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Investigation of the influence of milk protein genotype on the process of fermentation of milk curds by mesophilic lactic acid streptococci

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Abstract. The relevance of this study lies in the fact that the majority of commercial milk processed into fermented dairy products is a mixture of β-casein genotypes. The increasing use of A2 milk in the dairy industry necessitates the development of scientifically grounded technologies for the production of fermented products, as casein genotype modifications can affect the course of technological processes and require adjustments to production parameters. The study aimed to determine the impact of genetic modification of the β-casein protein in cow's milk on the

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fermentation process of milk mixtures during the production of fermented dairy products. Research methods included chemical, physical, organoleptic, and microbiological methods (determination of the quality indicators of raw milk and fermented milk curds), and technological methods (determination of acid formation activity and viscosity). The initial characteristics of raw milk were investigated according to genotype, revealing no direct correlation. Changes in the physicochemical, microbiological, and organoleptic properties of fermented milk curds during biotechnological processing and storage were examined. Optimal technological process regimes were selected, and technological methods were chosen to minimise the influence of secondary factors on the experiment. A mixed culture preparation of mesophilic lactic acid lactococci, including *L. Lactis ssp.*, was chosen as a starter culture. It was established that all 13 milk samples were suitable for biotechnological processing using mixed cultures of mesophilic lactic acid bacteria. As a result, it was concluded that the production of fermented dairy products from raw milk with the presented β-casein genetic modifications, A1A1, A1A2, and A2A2 – using *L. lactis ssp.* cultures – is possible using the classical technology and does not require adjustment of the technological conditions. The obtained results can be used in the dairy industry when developing technologies for fermented dairy products from A2 raw milk

Keywords: A2 milk; technological properties; biotechnological processing; starter culture; fermented dairy products

INTRODUCTION

The advancement of biotechnology and genetics could be a pivotal approach to addressing a global human problem such as food security. This encompasses not only the quantity of food but also its impact on the human body. Thanks to breakthroughs in agricultural animal genetics, it has become possible to address one of civilization's challenges – food allergies. Fermented dairy products remain the most consumed segment within dairy products but are inaccessible to those with milk protein allergies. Milk protein, specifically casein, which constitutes about 80% of milk proteins, is heterogeneous – represented by fractions α_{s1}-, α_{s2}-, β-, and κ-casein (Daniloski *et al.*, 2021; Lewis, 2022). The ratio of these protein fractions in milk is not influenced by the animal's diet, housing, age, or lactation period but is solely determined by the animal's genetic makeup.

According to C. Sebastiani *et al.* (2022), genetic variations in casein fractions depend on the cow breed. The most common genetic modifications of β-casein in commercial milk (A1 and A2) can occur in three variations: A1A1, A1A2, and A2A2. Researchers B. Guantario *et al.* (2020) established that β-casein of the A1 genotype is the cause of discomfort when consuming bovine milk. β-casein of the A1 genotype, as a result of proteolytic cleavage by gastrointestinal enzymes, produces a higher amount of β-casomorphin compared to β-casein of the A2 genotype.

The majority of commercial milk used for the production of fermented dairy products contains β-casein of the A1A2 genotype. However, research by M. Ramakrishnan *et al.* (2020) indicates the potential for developing dairy farming with the A2A2 genotype as a raw material for a wide range of food products. To produce A2 milk, cows must possess the appropriate genetic inheritance. The probability of forming a herd with 100% A2A2 genes is only possible if two animals carrying the A2A2 genotype are mated. M. Samilyk *et al.* (2022), O. Bordunova *et al.* (2023), and A. Dantas *et al.* (2023) have determined that milk, as a raw material for dairy product production, in addition to being safe and beneficial for the end consumer, must also possess certain technological properties that determine its processing direction and the specific production process for each type of product. These properties include rennet curdling ability, souring ability, heat resistance, and others. These technological properties of the raw material ensure the correct execution of the technological process and the production of a product that meets quality standards.

The technological properties of raw milk are directly dependent on the quantitative and qualitative content of its protein, fat, and carbohydrate components, acidity, and salt balance. Consequently, genetic variation in casein fractions can influence the technological process and the quality of the final product (Sokoliuk *et al.*, 2022). Therefore, it is worth investigating the impact of the milk protein genotype on biotechnological processing to understand the significance of this influence and to adjust the technological process if necessary. To study the impact of milk protein genotype on the technological process, it was decided to investigate the fermentation process of pasteurised milk blends (Giribaldi *et al.*, 2022).

T. Bintsis and P. Papademas (2022), and N. Bolgova *et al.* (2023) highlight that fermentation is the cornerstone of most fermented dairy product manufacturing processes. Milk fermentation is a process where the components of milk undergo biochemical changes under the influence of enzymes. Raw milk contains approximately 100 enzymes from various classes, which, if the primary milk processing is disrupted, can lead to spoilage. In pasteurised milk, the primary source of enzymes is starter cultures. To activate a controlled fermentation process, specially selected strains of lactic acid bacteria, propionic acid bacteria, yeasts, as well

as prebiotics and their combinations, are added to the pasteurised milk blend. The activity of these starter microorganisms leads to significant biochemical changes in all milk components, leading to the formation of various chemical substances (Liu *et al.*, 2020).

Lactose undergoes the most significant changes during directed fermentation. Under the influence of β-galactosidase, it is broken down into galactose and glucose, which, in the case of anaerobic carbohydrate oxidation via the Embden-Meyerhof-Parnas pathway, forms lactic acid as the final fermentation product (Romanchuk *et al.*, 2020; Sreenivas, 2024). Milk proteins also undergo enzymatic changes due to the action of microbial proteolytic enzymes. Proteins experience the most significant enzymatic transformation due to the action of proteases. Proteases catalyse the hydrolysis of peptide bonds in protein molecules. In the production of fermented dairy products, starter culture strains that carry out moderate proteolysis are used. Proteases produced by starter culture microflora more readily attack α_s-casein compared to β- and κ-casein, although some microorganism strains break down α- and β-fractions equally effectively (Helikh *et al.*, 2021; Kieliszek *et al.*, 2021).

In the production of fermented dairy products mixed mesophilic cultures starter cultures of *Lactococcus lactis ssp*. are commonly used. Lactococci do not possess high proteolytic activity, however, the limited breakdown of casein provides optimal consistency and structure while simultaneously increasing casein digestibility in the gastrointestinal tract and ensuring storage stability. This is because the intensity of proteolysis is somewhat inhibited by changes in hydrogen ion concentration, leading to a decrease in pH (Wang *et al.*, 2021). As a result of the biotechnological processing of milk blends, the fat component also undergoes changes, albeit to a lesser extent. The degree of lipolysis depends on the composition of the microflora, both initial and introduced and on the quantity and state of the fat globules. Uncontrolled lipolysis leads to defects and spoilage of products (Tsisaryk *et al.*, 2022; Thum *et al.*, 2022). Therefore, when selecting starter cultures, this fact is taken into account.

The aim of this study was to investigate the fermentation process of milk blends using mesophilic lactic acid bacteria *Lactococcus lactis ssp.*, to determine the impact of genetic modification of milk protein on the souring process, and to assess the physicochemical, microbiological, and organoleptic properties of milk curds both during fermentation and during storage.

MATERIALS AND METHODS

The experimental part of the study was conducted in November-December 2023 at the interdepartmental laboratories of the Faculty of Food Technology, Sumy National Agrarian University. To determine the influence of the β-casein genotype of milk protein on the fermentation process of milk curds, raw cow's milk from cows with different genotypes was used. Thirteen milk samples were collected during morning milking from cows with different β-casein genotypes (A1A1, A1A2, A2A2) at the farm of the Institute of Agriculture of the North-East of NAAS. To track the impact of the β-casein genotype on the biotechnological processing of milk, samples were grouped by genotype and initial control of all raw milk samples was conducted, as presented in Table 1. Samples 1-3 were milk from cows with an undetermined genotype, samples 4-6 from cows with the A1A2 genotype, 7-10 from cows with the A1A1 β-casein protein genotype, and samples 11-13 were A2 raw milk.

***Table 1**. Raw milk characteristics by genotype, (n = & & &, p < 0,05)*

Sample No.	β-casein genotype	Physicochemical parameters						MAFAnM, CFU/cm³
		Fat, %	DSMS, %	Protein, %	Density, °A	Acidity,°T	pH	
No. 1	Without genotype identification	4.32	8.75	3.13	28.6	19	6.61	
No. 2		4.54	8.86	3.17	28.9	22	6.45	
No. 3		4.65	8.69	3.11	28.1	16	6.68	
No. 4	A1A2	4.24	7.91	2.82	25.3	17	6.58	
No. 5	A1A2	3.83	8.08	2.88	26.4	21	6.51	
No. 6	A1A2	2.67	8.1	2.87	27.5	15	6.74	
No. 7	A1A1	3.87	8.09	2.88	26.4	17	6.65	$4 \pm 0.5 \times 10^3$
No. 8	A1A1	4.69	8.48	3.03	27.2	23	6.4	
No. 9	A1A1	3.84	8.22	2.93	26.9	16	6.65	
No. 10	A1A1	4.09	8.36	2.98	27.2	15	6.72	
No. 11	A2A2	4.69	9.1	3.26	29.7	21	6.46	
No. 12	A2A2	4.54	8.06	2.88	25.6	21	6.5	
No. 13	A2A2	5.25	8.64	3.1	27.3	18	6.59	

***Source:** compiled by the authors*

Standard methods were used to determine the physicochemical and microbiological parameters. Fat content (Fat, %), mass fraction of dry skimmed milk solids (DSMS, %), protein content (Protein, %), and density

(°A) were determined using an EKOMILK Standard ultrasonic analyser without the use of any chemical reagents. The titratable acidity (°T) of the samples was determined by titrating the diluted milk samples (1:2 with distilled water) with a 0.1 N sodium hydroxide solution, using a 1% alcoholic solution of triphenylmethane dye as an indicator. The active acidity (pH) was determined using an Apera Instruments PH8500-DP device according to the standard (DSTU 8550:2015, 2015). Conditional viscosity was determined using a VZ-246 viscometer by measuring the time in seconds (s) for 100 cm^3 of thoroughly mixed product to flow through a 5 mm diameter nozzle of the viscometer.

Total bacterial count, characterised by the number of mesophilic aerobic and facultatively anaerobic microorganisms (MAFAnM) colony-forming units per cubic centimetre (CFU/cm^3), (MAFAnM, CFU/cm^3), was determined as a sanitary indicator of raw milk quality using the plate count method. One cm^3 of each sample was plated onto solid nutrient agar and incubated at 30 ± 1°C for 72 hours. The most probable number of viable lactococci cells (CFU/cm^3) in the fermented curds was determined using the liquid nutrient medium inoculation method. The sample of the curd was diluted in a series of ten-fold dilutions, with the last three dilutions being plated into two tubes each containing 10 cm^3 of sterilised skimmed milk. This was done to ensure that the final dilution contained no microorganisms. The inoculated tubes were incubated at 30 ± 1°C for 7 days. After incubation, the tubes were examined and those showing milk curtailment were recorded. A numerical characteristic was compiled, and the most probable number of viable cells was calculated.

Before biotechnological processing, milk samples were subjected to clarification, separation, and pasteurisation at 90 ± 2°C for 5 minutes. To minimise the impact of the milk fat fraction on the objectivity of the results, it was decided to ferment pre-skimmed samples. Skimming was carried out by separating heated (41 ± 1°C) whole milk twice using a Motor Sich-100 separator. The skimmed milk was pasteurised and cooled to the fermentation temperature of 29 ± 2°C, bypassing the cooling process. The skimmed milk was inoculated at 29 ± 2°C with a starter culture of mixed mesophilic lactic acid lactococci, trade mark "VIVO-Cottage cheese", consisting of *L. lactis ssp.* cultures. The starter culture was added in an amount sufficient to provide an initial concentration of lactobacilli cells of at least 1×10^6 CFU/cm^3. Experimental studies were conducted by current standards, using modern, generally accepted methods (Directive 2010/63/EC, 2010) and adhering to the Procedure for conducting scientific research and experiments on animals (Law of Ukraine No. 249, 2012).

RESULTS AND DISCUSSION

Analysis of the initial control of all raw milk samples from cows with different β-casein protein types did not reveal any significant differences in the analysed parameters, which is consistent with the data presented in the study of V.I. Ladyka *et al.* (2021) and the research conducted K. De Vitte *et al.* (2022). All groups of samples had average values for fat content (except for sample No. 6), protein content, and density (except for samples No. 4 and No. 12). Biotechnological processing of the experimental milk samples was carried out for 10 hours at a temperature of 29 ± 2°C, with the inoculated samples incubated in a thermostat in hermetically sealed, pre-sterilised containers. The results of the study of the fermented milk curds are presented in Table 2.

***Table 2**. Characteristics of fermented curds (n = &&&, p < 0.05)*

Sample No.	Acidity, °T	pH	Conditional viscosity, s	The most probable number of lactococci, CFU/cm^3
No. 1	77	4.66	28	$3.0 \pm 0.5 \times 10^{10}$
No. 2	73	4.63	29	$5.5 \pm 0.5 \times 10^{9}$
No. 3	76	4.5	30	$5.0 \pm 0.5 \times 10^{8}$
No. 4	73	4.74	22	$8.0 \pm 0.5 \times 10^{8}$
No. 5	70	4.6	27	$4.6 \pm 0.5 \times 10^{9}$
No. 6	72	4.6	20	$2.0 \pm 0.5 \times 10^{9}$
No. 7	76	4.6	20	$5.5 \pm 0.5 \times 10^{9}$
No. 8	70	4.71	27	$3.0 \pm 0.5 \times 10^{9}$
No. 9	71	4.58	28	$9.0 \pm 0.5 \times 10^{8}$
No. 10	75	4.59	26	$1.5 \pm 0.5 \times 10^{9}$
No. 11	75	4.59	30	$8.0 \pm 0.5 \times 10^{8}$
No. 12	76	4.6	23	$5.5 \pm 0.5 \times 10^{9}$
No. 13	78	4.53	28	$1.5 \pm 0.5 \times 10^{8}$

***Source:** compiled by the authors*

All fermented samples exhibited acidity levels consistent with those of products fermented by mesophilic lactic acid lactococci (Cheng *et al.*, 2022; Sakihara *et al.*, 2022). No deviations from the process parameters were observed. Contrary to the results obtained in the study (Kyselová *et al.,* 2019), which indicated that genetic polymorphisms of milk proteins significantly affect titratable and active acidity, the samples in this study had different combinations of protein genotypes. All fermented samples, regardless of the protein genotype in the initial raw material, had homogeneous curds with moderate acidity and viscosity after 10 hours of fermentation. Samples from A2 milk had titratable acidity in the range of 75 to 78°T and pH of 4.6 to 4.53 after 10 hours of fermentation.

Microbiological analysis of the samples to determine the influence of the β-casein genotype of cow's milk protein on the growth of lactic acid microorganisms also did not reveal any significant correlation. The sensory evaluation did not reveal any noticeable difference between the fermented samples, however, research (Gai *et al.*, 2021) indicates that curds obtained from A2 milk have l lower firmness of the formed gels, so the product may have a less firm curd but, on the other hand, it tends to be better digestible.

By analysing the research data, it is possible to compare the conditional viscosity of the samples within each group. In the group of samples from A2 milk, sample No. 12 stood out as the most fluid, with a viscosity of only 100 cm^3 in 23 seconds. The low protein content and low density of the raw material in this sample can explain this. A similar pattern can be observed in other groups of samples. For example, in samples with the A1A1 protein genotype, there was also a decrease in viscosity with low protein and density in the raw material (sample 7). In the group of samples from A1A2 milk, samples No. 4 and No. 6 had a viscosity of 20-22 seconds, and the raw material had a low protein content (2.82 and 2.87%, respectively), although only sample No. 4 had a density below the norm (25.3°A). Therefore, the data from this study confirms the direct proportionality between the viscosity of fermented curds and the protein content of the raw material (Čítek *et al.,* 2020), and does not reveal any influence of the casein genotype on the quality of fermented curds produced by mesophilic lactic acid lactococci.

Biochemical changes to the components of milk can continue even during the storage of fermented curds. While the reduced positive temperatures and increased acidity can slow down enzymatic processes, they do not completely stop them. The fermented samples were stored at 4-6°C in hermetically sealed containers, protected from light, for 14 days. The titratable and active acidity were monitored on the 3rd, 7th, 10th, and 14th days (Fig. 1a, b).

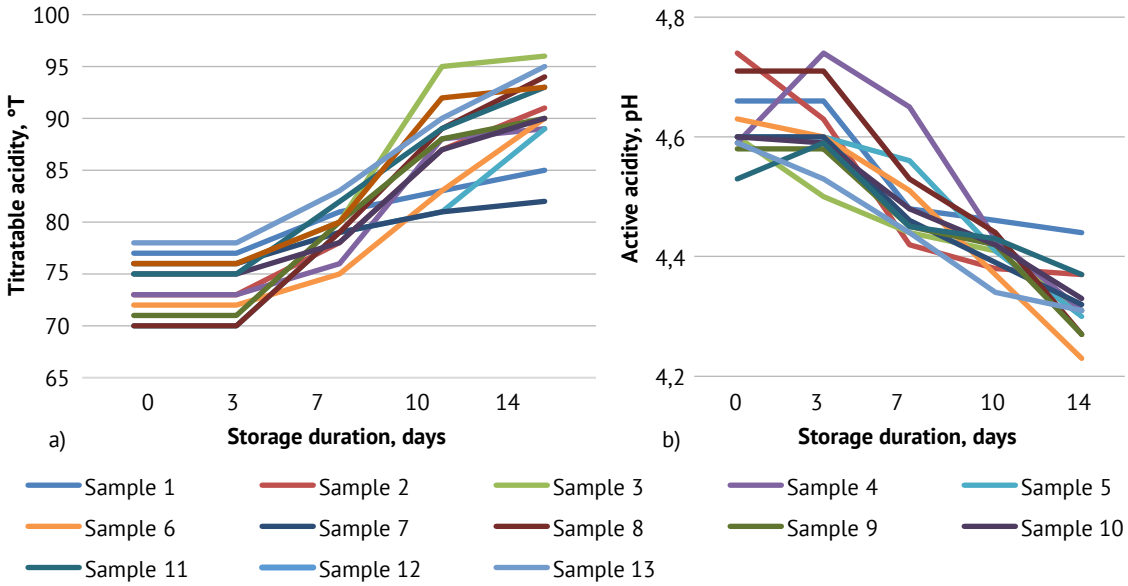

Figure 1. *Changes in titratable (a) and active (b) acidity in the fermented samples during storage*
Source: *compiled by the authors*

By analysing the data from the figures, a gradual increase in titratable acidity (Fig. 1a) and a change in active acidity (Fig. 1b) can be observed in all samples throughout storage, which is normal when using mesophilic lactococcal cultures as a starter. The conditional viscosity was determined by the duration of the flow of 100 cm^3 of curd from a viscometer with an outlet of 5 mm (Fig. 2).

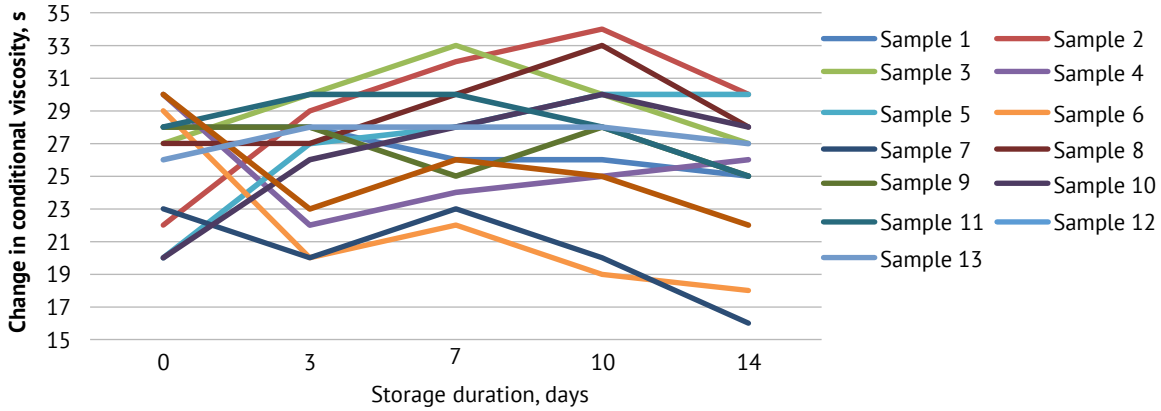

***Figure 2**. Changes in the conditional viscosity of fermented samples during storage*
***Source:** compiled by the authors*

Based on the studies on the determination of the conditional viscosity of fermented curds, no significant differences were found either at the end of the technological process or during storage (Table 2, Fig. 2). The degree of syneresis in all samples was low. As a result of microbiological studies of fermented samples during storage, the number of viable lactic acid bacteria cells was determined (Fig. 3). The study of the influence of the β-casein genotype of milk on the growth of mesophilic lactic acid lactococci was carried out by inoculating milk samples into tubes with sterilised skimmed milk immediately after the fermentation process and on the 3rd, 7th, 10th, and 14th days of storage, following the methodology for inoculation (DSTU 7357:2013, 2013).

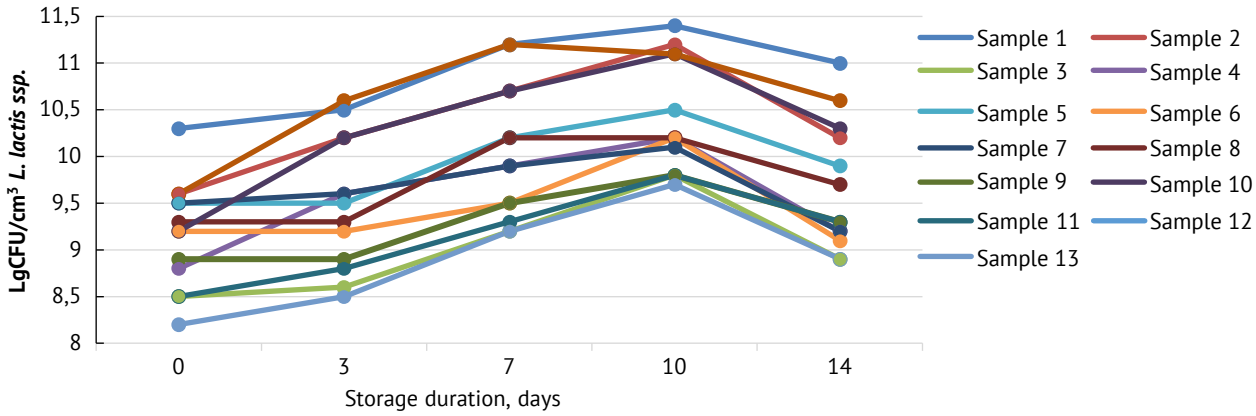

***Figure 3**. Changes in the number of viable lactococci during storage*
***Source:** compiled by the authors*

The organoleptic analysis during the storage of fermented curds involved monitoring changes in taste, smell, and texture of the samples. The duration and frequency of monitoring were similar to those of the aforementioned studies. No numerical scores were assigned. The taste of all samples changed, becoming more acidic and pronounced, corresponding relatively to the decrease in pH and increase in titratable acidity. Throughout storage, the smell of all samples remained lactic with no foreign odours. T The consistency of intact curds was firm with minor whey separation on the surface, occasionally leading to curd cracking and filling of the voids with whey. After stirring, the curds became homogeneous with satisfactory viscosity, as detailed in Figure 2.

The research results indicate a normal growth pattern of the culture in the dairy curd. Figure 3 clearly shows a stable increase in the number of viable cells up to 10 days inclusive, and the results obtained from the inoculation on the 14th day indicate a slowing down of growth and a slight decrease in viable cells. This can be explained by the biochemical conversion of lactose, the formation of lactic acid, and changes in the concentration of hydrogen ions, which negatively affect the growth of lactic acid lactococci. Similar results have not been observed in other studies. Therefore, to provide a comprehensive view of the impact of β-casein genotype on the fermentation processes of dairy mixtures in the production of fermented milk products during storage, research was conducted to monitor changes in

the physicochemical, organoleptic, and microbiological properties of fermented dairy curds during storage.

CONCLUSIONS

Given the potential for increased production of A2 milk, there is a need to develop scientifically sound technologies for processing this milk into various dairy products. Fermentation is the basis for the production of most dairy products, therefore, research into the impact of β-casein genetic modifications on this process is relevant. Based on the results obtained through theoretical and experimental research, it can be concluded that A2 milk is suitable for the production of fermented dairy products using mesophilic lactic acid lactococci starter cultures, without significant changes to existing technological instructions and production processes. Milk with the A2A2 β-casein genotype can be fermented without any additional processing, and the resulting curds have high sensory qualities, while the physicochemical and microbiological parameters are within the norms of current regulatory documents for fermented dairy products.

Based on the theoretical and experimental research conducted, it was established that all sample groups of the milk studied were suitable for biotechnological processing using mixed cultures of mesophilic lactic acid bacteria. By the 10th hour of fermentation, the fermented samples from A2 milk had a titratable acidity within the range of 75-78°C and a pH of 4.6-4.53, which is within the normal range for fermentation using such a starter culture. Studies of changes in physicochemical, organoleptic, and microbiological parameters during storage confirmed the hypothesis that the β-casein genotype has a negligible impact on acid formation processes and the growth of microorganisms in fermented curds. The production of fermented dairy products from the studied milk using *L. Lactis ssp*. cultures can be carried out using the general technological scheme and do not require adjustment of the technological parameters.

Future research plans to investigate the impact of the genetic configuration of cow's milk proteins on the fermentation processes of milk mixtures using mixed cultures of lactic acid microorganisms and a range of probiotic cultures. The aim is to develop scientifically-based technologies for producing a wide range of hypoallergenic dairy products based on milk from cows with the A2A2 β-casein protein genotype.

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CONFLICT OF INTEREST

None.

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Дослідження впливу генотипу білка молока на процес ферментації молочних згустків мезофільними молочнокислими стрептококами

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Анотація. Актуальність роботи полягає в тому, що переважна більшість товарного молока, що переробляється на кисломолочні продукти є змішаним за генотипом β-казеїну, а поширення використання молока А2 в молокопереробній галузі потребує розробки науково-обґрунтованих технологій виробництва ферментованих продуктів, тому що модифікації генотипу казеїну можуть впливати на хід технологічних процесів та потребують коректування технологічних параметрів виробництва. Метою проведення дослідження було встановлення впливу генетичної модифікації β-казеїну білка молока корів на процес ферментації молочних сумішей під час виробництва кисломолочних ферментованих молочних продуктів. Методи дослідження – хімічні, фізичні, органолептичні, мікробіологічні (визначення якісних показників молока-сировини та ферментованих молочних згустків), технологічні (визначення активності кислотоутворення, в'язкості). Було досліджено вихідні показники молока-сировини відповідно до генотипу – прямої залежності не встановлено. Було досліджено зміни фізико-хімічних, мікробіологічних та органолептичних показників ферментованих молочних згустків в процесі біотехнологічного оброблення та протягом зберігання. Було обрано оптимальні режими технологічного процесу та обрано технологічні прийоми для мінімізації впливу другорядних чинників на хід експерименту. В якості закваски було обрано препарат змішаних культур молочнокислих мезофільних лактококів, до якого входили культури *L. Lactis ssp*. Встановлено, що всі 13 зразків молока придатні для біотехнологічної обробки змішаними культурами мезофільних молочнокислих бактерій. В результаті було узагальнено, виробництво кисломолочних продуктів з молока-сировини з представленими генними модифікаціями β-казеїну, A1A1, A1A2 та A2A2 з використанням культур *L. lactis ssp*, можливе за класичною технологією і не потребує коригування технологічних умов. Отримані результати роботи можна використовувати в молокопереробній промисловості при розробці технологій кисломолочних продуктів з молока-сировини А2

Ключові слова: молоко А2; технологічні властивості; біотехнологічна обробка; закваска; кисломолочні продукти

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Development of recommendations for Ukrainian farming crediting based on the experience of other countries

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Abstract. The study aimed to address the farmers financing practices in Poland, France, Germany and Romania and to develop recommendations for reducing credit constraints in Ukrainian agriculture. Providing farms with financial resources is one of the most critical tasks for maintaining national resilience and stability in difficult times of military resistance. The study analysed statistical and economic indicators, the structure of farms and land use, financial instruments, features of financial

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institutions, practices and experience in lending in Poland, France, Germany, Romania and Ukraine. The impact of gross fixed capital formation on the volume of farm sales in comparable countries was addressed. The main reasons for the shortage of financing for medium, small, and micro-enterprises in the agro-industrial sector and numerous households that run private farms without establishing a legal entity were identified. The study noted that the main consequences of limited access to credit are low efficiency of land use, a decrease in gross domestic product and a deterioration in the viability of farms. The study analysed the impact of the state programme "Affordable Loans 5-7-9%" and other programmes to support medium, small and micro enterprises created with the help of international partners on the financial support of agricultural businesses. In recent years, these new financial instruments have significantly increased access to loans for farmers. The study addressed proposals of economic scientists of these countries on the elimination of credit restrictions in the activity of small agricultural producers. The analysis highlights the problems of farmers' lending that are common to all countries, as well as the many years of experience that have gradually resolved these issues. Recommendations on the implementation of the necessary measures for the timely receipt of affordable credit resources by small rural enterprises and family farms in Ukraine have been developed

Keywords: agricultural support; investment; limited resources; agricultural sector; small and micro enterprises; financial instruments

INTRODUCTION

As of 2020, agricultural land occupied 68.5% of the total land area of Ukraine (State Service of Ukraine for Geodesy, Cartography and Cadastre, 2020). The share of agriculture, forestry and fishery production in the country's total sales over the same period was 6.3% (State Statistics Service of Ukraine, 2022). For comparison: Poland's agricultural sector accounts for 16% of industrial output, while cultivated land accounts for 41.2% of the national total area (European Investment Bank, 2020). The state of the industry directly depends on the funds invested in its development. While large and medium-sized enterprises can still manage to get timely lending, small and micro enterprises are on the verge of survival. First and foremost, this is reflected in a decline in agricultural production and its competitiveness.

The problem of the shortage of credit resources in the agricultural sector has been repeatedly addressed in recent years in scientific economic studies by domestic scholars. S.V. Andros and V.H. Gerasymchuk (2023) formulated several strategic measures aimed at eliminating restrictions on obtaining loans. Y.O. Platonova (2024) and D.B. Klimenko (2018) addressed the positive impact on the financing of the agricultural sector through the introduction of new agricultural protection mechanisms (state subsidies, repayable financial assistance, special budgetary subsidies, lending under the general state programme "Affordable Loans 5-7-9%").

D. Artemenko (2020) highlighted a direct correlation between agricultural production and credit provision to the agricultural sector and highlighted the main problems of attracting credit resources. Yu.O. Lupenko and S.V. Andros (2019) also addressed the financial and agricultural expertise of borrowers, and the quality and reliability of documents and data provided to credit institutions. The paper notes that out of the total number of applications for long-term loans, banks approve 2% of them and 50% of short-term loans. N. Trusova *et al.* (2021) conducted a thorough analysis of the range of banking products and lending terms offered recently by credit institutions working with agribusinesses in Ukraine. The study noted that although banks have become more interested in cooperating with farmers than a few years ago, they still maintain strict requirements for financial reporting, stable positive performance over several years and a clean credit history. Farms are usually unable to meet these requirements.

S. Arzhevitin *et al.* (2021) proposed the global practice approach of lending to farmers, namely a different form of loan relations. It should account for preferential terms and careful accounting of the use of earmarked resources. The study addressed mainly lending to large enterprises, but it also points out the need to create credit unions in rural areas to meet the financial needs of small farmers. Although the topic of agricultural lending has been widely covered, research in recent years has mainly focused on large and medium-sized agricultural producers. Farmers face much greater difficulties in obtaining loans. Many of them are unable to provide banking institutions with the proper package of documents to obtain a loan for current needs, let alone for investment. On the other hand, banks perceive farms as risky (seasonality, high dependence on climatic conditions, long production cycles) and too costly (a large number of small borrowers with insignificant lending volumes) (Foltovych & Blashchuk-Devyatkina, 2024). In addition, a significant proportion of farms do not have legal entity status at all, do not keep records and do not prepare financial statements. The shortage of credit resources is becoming an insurmountable obstacle to the development of modern farming, the use of efficient land cultivation mechanisms, and the generation of decent profits. The products produced on farms

cannot compete with agricultural holdings in terms of cost and sometimes even quality.

Farming in Ukraine is a fairly young form of business. Most countries in the world have centuries of experience and achievements in this area. A.R. Khanal and O. Omobitan (2020) highlighted the path that US lawmakers took in addressing farm credit and concluded that improvements in agricultural lending practices at US rural institutions have led to improved access to credit and financial performance of small farms. The topic of financial innovations in Polish agriculture, which is relevant to Ukraine, was studied by M. Soliwoda (2020). The author identified the problems and prospects for the development of financial innovations in agriculture and analysed the typology and examples of foreign and Polish credit institutions working with farmers, their methods and efficiency. The author also noted that the rationale for implementing financial innovations in agriculture by non-governmental is different in developed and developing countries.

The study addressed issues related to solving the problems of Ukrainian farms with a shortage of credit resources based on the experience of Poland, France, Germany and Romania, such as the availability of the necessary financial instruments, guarantee provision, the cost of banking products, a complex mechanism for obtaining them, the low interest of credit institutions in working with small farms, etc.

MATERIALS AND METHODS

The study analyses statistical indicators that reflect the structure of land use, the number of agricultural enterprises, and the average size of farms in Poland, France, Germany, Romania and Ukraine and characterise the subject of the study – the farm. The latest Statistical collection "Agriculture of Ukraine" (State Statistics Service of Ukraine, 2021a) on the official website of the State Statistics Service was published in 2021 with data for 2020. There is no publicly available data for 2022-2023, which is necessary for the calculations. Given this, the calculation tables were based on statistical data from Poland, France, Germany, and Romania compared to Ukraine for 2020.

There is a significant difference between the concept of "farming" in Ukraine and the European Union. Hence, according to the Law of Ukraine No. 973-IV (2003), the term "farm" can only be used for small, micro-enterprises and family farms that consist of only family members and do not employ workers permanently. Unlike Ukraine, the above-mentioned EU countries use the EU Regulation, according to which all enterprises in the agro-industrial sector are considered farms (Sarkisova, 2024). Thus, to obtain comparable data from the EU and Ukraine, the study uses the EU terminology for the concepts of "farmer" and "farm".

The study analyses the state of farm lending in Poland, France, Germany and Romania, their similarities and differences in comparison with Ukraine with the help of

- calculating the dependence of agricultural sales on the level of gross fixed capital formation per hectare of land used;
- review of the state of investment lending and the role played by investments in the development of the national agricultural sector, as well as the main areas of investment;
- structures of financial institutions that provide lending services to agricultural producers and financial instruments to support farms;
- the percentage of rejected loan applications, the main reasons for loan rejections.

The current state programmes to support farms and their conditions were studied, namely the Law of Ukraine No. 973-IV (2003), Law of Ukraine No. 1877-IV (2004), Law of Ukraine No. 3254-IX (2023), Law of Ukraine No. 4618-VI (2012), Resolution of the Cabinet of Ministers of Ukraine No. 106-2018-p (2018) and Resolution of the Cabinet of Ministers of Ukraine No. 28-2020-p (2020). Programmes and practices on affordable lending to farmers, and recommendations of Western scientists to improve access to finance for farmers were also considered, namely reports to the European Investment Bank (2020), Romania (Dobre, 2020), European Commission (2023), European Union scientific publications (2023), N. Key (2020), U. Kambali and N. Panakaje (2022), etc.

RESULTS AND DISCUSSION

Land use and structure of farms. Table 1 shows statistical and economic indicators characterising the amount of land resources, the number of farms, and their average size in hectares.

***Table 1**. Agricultural land and the average size of farmland*

Indicators	Poland	France	Germany	Romania	Ukraine
Agricultural land, thousand ha	14.733	28.573	16.592	12.951	41.310
Share of the national total area, %	47	53	47	48	68
Number of farms, thousand units	1.301	393	262	2.887	49
Average farm size, ha	11	73	63	4	835

***Source:** developed by the authors based on European Commission (2023), State Statistics Service of Ukraine (2021a, 2021b)*

Poland's agricultural land is divided into arable land (76%), pastures (22%) and perennial crops (2%). The main agricultural activities in Poland are the production of animal products (52.7%), cereals (19.1%), vegetables and horticultural crops (9%), and industrial crops (8.2%) (European Commission, 2023). The average size of a farm is 11 hectares. The structure of Polish agricultural enterprises is dominated by small farms. More than half of the farms cover an area of less than 5 hectares. Over the past decade, there has been a decrease in the total number of farms, in particular farms under 10 hectares, and an increase in the number of farms over 20 hectares (Badach *et al*., 2023). Agriholdings account for 3% of the number of enterprises, and their size is growing annually due to the expansion and acquisition of small and medium-sized farms (European Investment Bank, 2020).

France is the largest agricultural producer in the EU, accounting for 18% of agricultural production (European Investment Bank, 2020). France is one of the first countries to develop an agroecology policy and translate it into specific programmes and laws (Wezel & David, 2020). Agricultural land by land use category is divided into arable land (60%), pasture (37%) and perennial crops (4%) (European Commission, 2023). Winemaking (14.3%) and cereals (15.1%) are the dominant sub-sectors in crop production, while animal production accounted for 37.5% in 2020(European Commission, 2023). The average size of a farm is 73 hectares. Almost half of French farms have 20-100 hectares of land and are classified as medium-sized family farms (European Investment Bank, 2020). The organisational and legal form of agricultural enterprises is gradually changing towards more cooperative farms. This trend is driven by more efficient management of resources, production systems, marketing methods, etc. (Smedescu *et al*., 2023).

By land use category, Germany's agricultural land is divided into arable land (70%), pasture (29%) and perennial crops (1%) (European Commission, 2023). Livestock and meat production are the mainstays of farming. Dairy production (21.1%) and pig production (12.6%) are the sub-sectors that contribute the most to total agricultural production. They are followed by vegetables and horticultural crops (12.2%), cereals (11.9%), industrial (9.1%) and fodder plants (7.9%) as the most important crops. The average farm size in Germany is 63 hectares. Farms are becoming increasingly specialised in production: 47% of them are engaged in livestock production, 30% in crop production, and only 13% in mixed agriculture (European Investment Bank, 2020). The structure of agricultural enterprises is still characterised by a large number of small to medium-sized family farms. However, in recent years there has been a shift towards large farms. Many small farms are unable to compete with medium and large farms because they do not produce enough for the needs of large retail chains, lack economies of scale, and cannot cope with high price fluctuations (Heinrichs *et al*., 2021).

With about 13 million hectares of agricultural land, 66% of Romanian arable crops are allocated to arable crops. In 2020, crop production accounted for the largest share of the national output (75%), with the most important sub-sectors: cereals (25.5%), vegetables and horticultural crops (20.9%), and industrial crops (9.8%) (World Bank, 2020). Agricultural production is characterised by a highly polarised farm structure, with large agricultural holdings favoured. Starting in 1997, foreign investors were allowed to buy land mainly because local farmers did not have access to capital. In addition, unlike its neighbours Poland and Bulgaria, Romania has not yet established a viable, commercially oriented medium-sized farming sector (Andreica, 2022). The average size of a farm in the country is 4 hectares. Around 75% of farms own land plots of less than 2 hectares and only 0.5% of enterprises manage agricultural land of more than 100 hectares. Over the past 5 years, Romania has seen a trend towards the creation of agricultural cooperatives.

Ukraine has excellent opportunities for agriculture, including about a third of the world's most fertile land, 79% of which was devoted to arable crops in 2020. Three crops dominate agricultural production: wheat, corn and sunflower, mainly for export. By 2021, agriculture will account for 41% of Ukrainian exports, up from 27% in 2013. Cereals (56%) and industrial crops (32.3%) account for the bulk of agricultural production (European Commission, 2023). Since the start of full-scale Russian aggression, Ukraine has lost millions of hectares of agricultural land. The area from which arable crops were harvested in 2023 decreased by 21.2% compared to 2021(State Statistics Service of Ukraine, 2022). The average size of a farm in the country in 2020 was 835 hectares. This figure, which is dozens or even hundreds of times higher than in the European Union, is a direct result of Soviet collectivisation and the agricultural policies adopted after Ukraine gained independence in 1991. The key players in Ukrainian agriculture in 2020 were 8,600 medium-sized farms with an area of 200 to 2,000 hectares, producing more than 50% of grain and industrial crops. The structure of the country's very large agricultural enterprises included 22 agroholdings with leased land of over 50,000 hectares, and 10 of them cultivated over 100,000 hectares. Kernel, with about 500,000 hectares of leased land, is the largest land user in Ukraine (Román, 2024).

The calculation of the average size of an agricultural enterprise does not include data on individual peasant farms. They are covered separately in state statistical reports because they are not legal entities. In total, as of January 2021, there were 4 million private peasant farms owning 5.3 million hectares of land. Most of them are responsible for the majority of Ukraine's fruit and vegetable production, which is

almost entirely destined for domestic consumption (State Statistics Service of Ukraine, 2024). In addition, they compete in markets with large livestock producers. The average size of a private farm in 2020 was 1.4 hectares. K. Prib *et al.* (2021) noted the need to equate private peasant farms with business entities, which would allow them to access investment and credit programmes, but the direction taken by state legislation seems more appropriate. Recent amendments to the Law of Ukraine No. 973-IV (2003) should facilitate the gradual and voluntary re-registration of individual peasant farms into family farms. This is one of the moves towards European standards of operation in the agricultural market. In addition, the status of a family farm provides access to state support and the possibility to legally receive pensions and social guarantees.

The state of lending to agricultural enterprises. The decisions made by different countries around the world regarding the availability of loans and support for agricultural producers indicate that this topic is of equal importance to all countries. The main goal (increasing productivity, achieving socio-economic stability, food and environmental safety) is achieved through various financial and legal instruments. The data shown in Figure 1 confirm that the state of the agricultural sector directly depends on the amount of funds invested in its development.

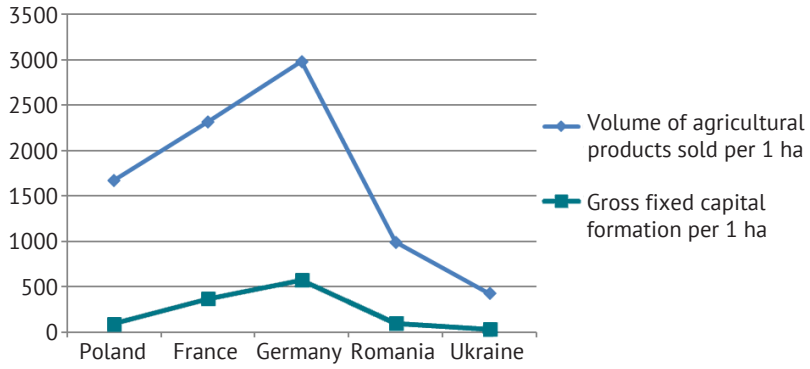

Figure 1. *Dependence of agricultural sales on the level of gross fixed capital formation per 1 hectare of land in use in 2020, EUR*
Source: *developed by the authors based on European Commission (2023)*

Investment in Poland's agricultural sector is growing annually, but the overall level is still low. In 2020, gross fixed capital formation per hectare of agricultural land amounted to €93, while in France and Germany, it was €369 and €575 per hectare respectively. The European Union Common Agricultural Policy (CAP) is an important incentive for investment in the Polish agricultural sector. Integration with the EU has resulted in an influx of modern machinery and investments in buildings, which has increased production and improved conditions for animals and land investments (Bórawski *et al.*, 2020). In terms of disbursements, Poland is the fifth largest recipient of CAP aid in the EU. Direct payments help to stabilise cash flows and thus make it easier for farmers to access finance. In addition, to increase the viability and competitiveness of farms, the Polish government has introduced several measures under the Rural Development Programme. To receive funding from these measures, farmers need to supplement the grant with their resources, which in many cases comes from bank loans. Subsidised loans account for more than a third of the loan portfolio granted to agricultural enterprises.

More than half of the loans are provided by cooperative banks. Since 2019, problems with the collateral of agricultural enterprises have been partially resolved with the help of the European Agricultural Fund for Rural Development (EAFRD). The shortage of credit resources mainly affects small farms and long-term loans. According to surveys, rejected loan applications from agricultural enterprises account for 10% (European Investment Bank, 2020). Reasons for rejections include lack of collateral; insufficient information on the financial condition of the enterprise; inability to present a business plan due to lack of management knowledge and low financial literacy. The large share of rejected loan applications indicates that banks perceive the agricultural sector as risky and tend to apply less favourable pricing policies. One of the main elements limiting banks' interest in lending to small farms is the higher transaction costs associated with the evaluation of small loans, which leads to lower profitability for the lending institution.

The demand for agricultural finance in France is driven by farm expansion, diversification of income into non-agricultural activities (electricity generation, eco-tourism, etc.), modernisation (more efficient equipment, changes in production processes, energy-efficient buildings, etc.), and improved regulatory requirements

(compliance with organic or local production standards, animal welfare standards), digital information (smart equipment, drones, sensor technologies), adaptation to climate change (irrigation, water reservoirs, winter cover of land, etc.). As in all EU countries, French farmers benefit from financial and investment support from the CAP and the EAFRD guarantee fund. Demand for loans in the agricultural sector is highly concentrated, with most of it coming from large enterprises (over 100 hectares). In total, 15% of farms account for 65% of total loans. Surveys show that 75% of bank loans are used for investment and 25% for working capital (European Investment Bank, 2020). Most of the working capital is also provided by suppliers of raw materials.

Financing for the French agricultural sector is highly concentrated. Four co-operative banks account for 97% of the credit market: Crédit Agricole 68%; Crédit Mutuel 16%; Banque Populaire-Caissed'Epargne (BPCE) 9%; Crédit MutuelArkéa 4% (European Investment Bank, 2020). Due to the decline in the national interest rate and intense competition among banks, interest rates on medium- and long-term loans are low. The rejection rate of loan applications from farms ranges from 1% to 3%, depending on the financial condition of the enterprise. Main reasons for rejections: low return on investment, especially under the new rules (animal welfare, organic production); low farm income; reducing the possibility of personal bail; lack of financial history (applies to newly established farms).

The main areas of investment in the German agricultural sector are the expansion and specialisation of farms, modern production technologies that meet the trend towards more capital-intensive farming, meeting the requirements of EU agricultural production standards, investment in non-agricultural activities as a guarantee of financial stability of farms, and adaptation to climate change. A substantial driver of investment in Germany is the support provided to farmers by the Common Agricultural Policy (CAP) programme. At the national level, Rentenbank offers a special concessional loan for agribusinesses, while the largest state-owned lender, Kreditanstaltfür Wiederaufbau, provides several financial instruments to support small farms. In addition, at the federal level, farms can apply to state financial institutions (development agencies, guarantee banks, equity funds, etc.).

Agricultural lending in Germany is predominantly the domain of cooperative banks. They are followed by savings banks, and only a few commercial banks consider the agricultural sector a priority. The rejection rate for loan applications in 2020 was 10-12% (European Investment Bank, 2020). The rejections were mostly for small and medium-sized farms. Most difficulties in accessing finance are related to long-term loans. The main reasons for refusing to lend to farmers are lack of collateral; low profit margins; and poor credit history. Banks are also cautious about lending to higher-risk projects, such as start-ups or projects focused on innovative products.

Romania is a net supplier of unprocessed agricultural products to the EU. Grains and oilseeds account for the lion's share of total exports. Due to low productivity, underinvestment, and low capitalisation, demand for agricultural finance is limited. One of the major factors limiting access to credit for small farms is the small area under cultivation (Topor *et al*., 2023). Also, many farmers lack the financial literacy to approach investments from a commercial perspective. The main influence on agricultural development policy is the EU's Common Agricultural Policy. Although it contains various instruments, the most common in Romania are subsidies and grants, while loans and guarantees are promoted to a limited extent. Lending by financial institutions to Romanian farms depends on the size of the farm (Table 2).

Table 2. *Structure of farm lending in Romania*

Financial institution	Farm size	Lending objectives
Banks	More than 1,000 ha	Investments, working capital replenishment
Leasing companies	From 40 ha	Agricultural equipment
Non-bank financial institutions	40-1,000 ha	Working capital replenishment
EU subsidies	Mostly large farms	Working capital replenishment
Supply chain financing	Small farms	Working capital replenishment
Microfinance institutions	Small farms and individuals	Working capital replenishment

Source: *developed by the authors based on D. Harangus (2019)*

In Romania, bank lending is focused on large and medium-sized agricultural enterprises. Clients are typically farmers with loan sizes above €50000, supported by EU grants and government guarantees. Banks provide loans for grain, oilseeds and livestock production, while financing for fruit and vegetable production is limited. Small farms are perceived as uncollectible and costly to service due to their fragmentation. About 75% of loans are for long-term investment (machinery, equipment, land, etc.). The remainder is used for working

capital and interim subsidy financing, as farmers receive subsidies with a delay (Harangus, 2019).

Non-bank financial institutions have several advantages over banks in agricultural financing in Romania. These include leasing companies that provide financing for agricultural equipment, as well as other agribusiness financing institutions that provide loans for working capital. These non-bank financial institutions cover the lending sector for small (40-100 hectares) and medium-sized (100-1,000 hectares) farms that are registered as legal entities. They are linked to agribusiness and have direct information and contacts with customers, as they are present in rural areas. The most important non-bank financial institution in Romania is Agricover Credit. Supply chain finance is an important source of non-bank credit for small farms. Typically, the loan, which farmers repay after harvest, is provided in kind in the form of inputs.

Direct subsidies from the European Union are received by large farms and only a small share of small farms. Funds are distributed by the Agency for Payments and Interventions for Agriculture under the Ministry of Agriculture and Food of Romania (World Bank, 2020). There is no specific legislation on lending to small businesses or individuals in the agricultural sector. Many farmers work informally and face problems in providing documented income statements and tax returns, which leads to their exclusion from the financial system. These farmers usually turn to microfinance institutions. According to the analysis of the dependence of agricultural sales on the level of gross fixed capital formation per hectare, in 2020, Ukraine ranked the lowest in terms of gross fixed capital formation per hectare of agricultural land (35 EUR), even compared to Poland (93 EUR) and Romania (98 EUR). This indicator is a direct consequence of the lack of funding for Ukrainian farmers, which leads to losses in productivity. A model connecting access to credit to farm productivity was presented by A.R. Khanal and O. Omobitan (2020), which is fully consistent with this conclusion.

Notably, the volume of products sold per hectare depends on several factors, among which the structure of products sold is a significant one. The fact that Ukraine, similarly to Romania, is a net supplier of unprocessed agricultural products to various countries around the world also plays a major role. In recent years, the situation with lending to farmers has gradually started to improve. The structure of targeted financing of the agricultural sector by banking institutions is changing. While in 2022, working capital financing accounted for 80% of all agricultural lending programmes, in 2023, most loans received were for investment projects. Since 2021, despite the withdrawal of a significant amount of arable land from Ukraine's turnover as a result of full-scale hostilities, the volume of lending to farms has increased by 33%, and by another 44% in the following year (Fig. 2).

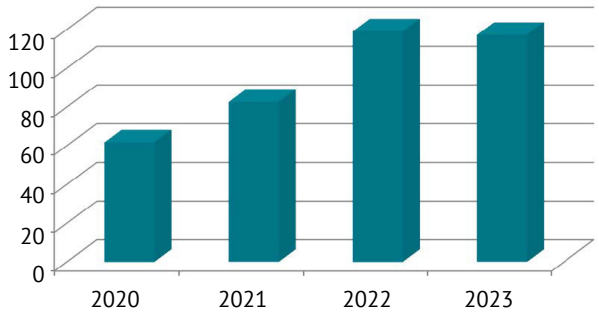

***Figure 2**. Dynamics of lending to farmers in 2020-2023, billion UAH*

***Source:** developed by the authors based on Lending to farmers almost doubled in 2022. Which banks in Ukraine support farmers? (2023)*

Until 2023, Raiffeisen Bank was the leader in financing farmers, but in 2024, state-owned banks took the key positions in the agricultural lending market: Privatbank, Oschadbank, Ukreximbank, and Sensbank. The top ten also include large commercial banks: Raiffeisen Bank, FUIB, Credit Agricole, and OTP Bank (Financing of the agricultural..., 2024). The shift in agricultural lending towards state-owned banks is explained by the expansion of state support for lending to small and medium-sized farms in Ukraine, as well as funding under joint programmes with international partners:

- The European Bank for Reconstruction and Development;
- The European Investment Bank;
- The International Bank for Reconstruction and Development;
- European Investment Fund;
- The European Union;
- The World Bank and other donors.

Most initiatives from international partners can be combined with the Affordable Loans 5-7-9% Programme and other farm support programmes. Currently, several financial products are offered, aimed at small and medium-sized agribusinesses, as a basis for the development of the agricultural sector of the economy. The "5-7-9%" support programme. As of December 2023, loans at preferential rates under the 5-7-9% programme accounted for about 40% of the loan portfolio of Ukrainian banks, with Privatbank leading the way (Entrepreneurship Development Fund, n.d.) (Fig. 3). In the face of extreme turbulence and business disruption since the start of the full-scale war, the programme has become the basis for economic stabilisation, providing timely financing for agricultural enterprises, supporting exports and increasing the chances of survival for numerous small and medium-sized farms. The government programme to support small business development, Affordable Loans 5-7-9%, was launched in Ukraine in 2000 and immediately became a point of contact between banks and farmers. The purpose of the loans is to purchase and

repair premises, purchase or upgrade fixed assets, acquire intellectual property rights, and refinance existing debt. Loan terms and conditions in force in 2024: for borrowers conducting business activities in the area of high military risk – 1%, up to 150 million UAH; for small and micro enterprises – 7%, up to 90 million UAH; for medium-sized enterprises – 9%, up to 90 million UAH; for all others – 13%, up to 90 million UAH.

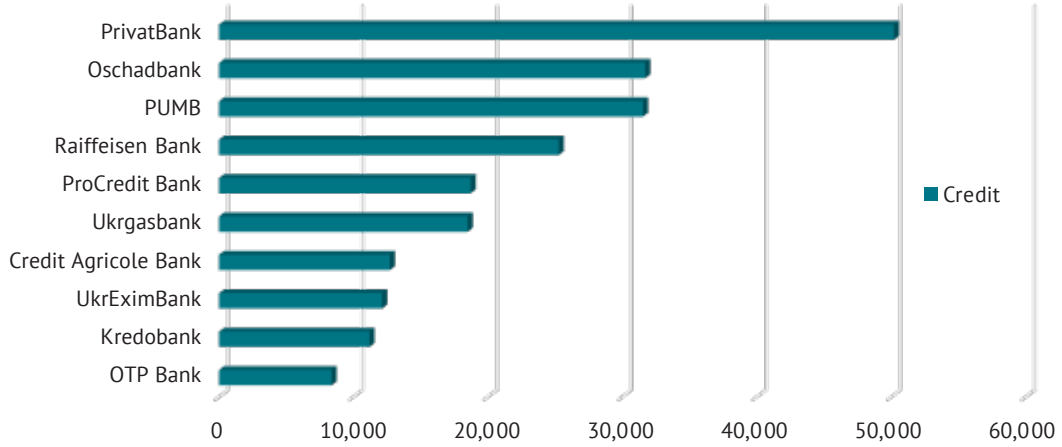

***Figure 3**. Top 10 banks that lent to farms under the support programme "Affordable Loans 5-7-9%" in 2023*
***Source:** developed by the authors based on the Ministry of Finance of Ukraine (2023)*

In addition, the 7% or 9% rates can be reduced by creating new jobs. The rate is reduced by 0.5% per annum for each new employee, but in the end cannot be less than 5% (Resolution of the Cabinet of Ministers..., 2020). During the programme's existence (2020-2023), agricultural enterprises received 49% of all soft loans under the programme. The national policy of supporting agriculture contributed to the growth of this share in 2023 to 68% of all active hryvnia loans in this sector of the economy, and agricultural producers who used such loans generated about a third of the total income of the sector (Ministry of Finance of Ukraine, 2023). The important role of the "Affordable Loans 5-7-9%" programme in reviving business activity and ensuring the country's economic security was also noted by I. Chugunov *et al.* (2024).

Financial leasing is available at 5-7-9%. Interest rate for leasing agricultural machinery and equipment with a 5-year term: 11% for large and medium-sized enterprises; and 9% for small and micro enterprises. It can be combined with partnership programmes from John Deere, CLAAS and other well-known agricultural machinery manufacturers at 0.01% per annum. The lease term is up to 5 years with an adapted repayment schedule. Partner lending from 0.01%. Loans of up to 6 million UAH for the purchase of seeds, pesticides, agrochemicals and mineral fertilisers from producers on special terms from banks at 0.01% per annum.

Commodity financing. Before the start of the full-scale Russian aggression, commodity financing was as good as bank lending, and even better during the sowing season. However, after the war broke out, major suppliers suspended instalment programmes for distributors and farmers (Malik *et al.*, 2023). The US project USAID AGRO (United States Agency for International Development, n.d.), which aims to accelerate the economic development of rural communities and micro, small and medium-sized agricultural enterprises, helped to restart commodity finance with grant support in 2023. ADAMA, Ukravit, Agro Arena, ALFA Smart Agro, LNZ, Agrosem, Ukragrokom, Plant Agro, and other suppliers of the necessary inputs for sowing have introduced commodity financing, including in combination with barter instruments for grain purchase.

Loan with a cashback of up to 15% of the amount from the European Bank for Reconstruction and Development. The loan can be used for agricultural and construction equipment, vehicles, and renewable energy. This loan programme is aimed at small and medium-sized enterprises with up to 250 employees and an annual turnover of up to 50 million EUR. Agents of the programme are Ukrgasbank, Kredobank and OTP Leasing. Terms of financing: interest rate from 7% per annum; currency – hryvnia or euro; the possibility of financing without collateral (with a state guarantee); cashback up to 15% of the financing amount; term – up to 5 years; amount – up to 3 million EUR (in equivalent).

Lending for the purchase of land. OTP Bank offers a loan at a rate of 12% in UAH for up to 10 years for the amount of 1-30 million UAH. The usual requirements for borrowers include a land bank of 400 hectares or more. Loan guarantee fund for farmers. On 1 January 2024, the Agricultural Loan Guarantee Fund, launched by the European Union and the World Bank Group together with the Government of Ukraine, became operational. The Fund covers up to 50% of liabilities on investment and working capital loans to borrowers – small and medium-sized farms that own or use an area

of up to 500 hectares. In addition, the mission of the Partial Guarantee Fund for Agricultural Loans is also to encourage Ukrainian banks to diversify their portfolios to agriculture. The Fund has sufficient capitalisation due to a 10 million EUR grant from the European Union under the "Strengthening the Partial Credit Guarantee Fund for Small Farmers in Ukraine Project" (World Bank, 2023b) and "Accelerating Private Investment in Agriculture Programme: Environmental and Social Systems Assessment" (World Bank, 2023a). The Loan Guarantee Fund will make it easier for small and medium-sized agribusinesses to access bank loans and minimise the risks of possible non-repayment to banks:

- guaranteeing the credit risks of banks. The World Bank, together with the European Bank for Reconstruction and Development, has launched portfolio guarantee instruments, which allow Ukrainian banks to share their credit risks 50/50, thereby providing financing to small and medium-sized businesses with more confidence;
- a loan against agricultural receipts. For agricultural producers engaged in the cultivation of grain and industrial crops with a land bank of more than 200 hectares, banks have simplified the process of attracting additional financing and introduced the option of financial agricultural receipts as collateral. This type of collateral can be combined with the "Affordable Loans 5-7-9%" programme.

Financial support from the Ukrainian State Farm Support Fund is provided on a repayable basis and a competitive basis in the amount not exceeding 1 million UAH: to newly established farms with separate farmsteads for a period of 3 to 5 years for the production, processing and marketing of their products; to other farms for up to 5 years to purchase machinery, and equipment, renew working capital, plant perennial crops, and develop credit and service cooperation; family farms without obtaining the status of a legal entity to purchase agricultural land of up to 20 hectares for up to 10 years (State Service of Ukraine for Geodesy, Cartography and Cadastre, 2020).

Grants are provided by the Ministry of Economic Development and Trade (Resolution of the Cabinet of Ministers..., 2022) through Oschadbank for planting and arranging a new garden, berry or vineyard with an area of 1 to 25 hectares, and for the construction of greenhouses with an area of 0.4 to 2.4 hectares. At the same time, in 2022, more than 3,000 farms received financial assistance from the State Agrarian Register, which has been distributing various types of support to farmers from the Ukrainian budget and grants from international partners since August 2022. The amount of assistance provided for growing crops is 3,100 UAH per hectare. It is available to farms with at least 1 hectare and no more than 120 hectares of land, and the amount of assistance is limited to 372,000 UAH. The budget subsidy for cow breeding of 5,300 UAH per head is paid for cattle from 3 to 100 heads, and the amount of assistance is limited to 530,000 UAH (More than 3,000..., 2023).

Local regional and city administrations are also beginning to allocate funds to support small and medium-sized farms (Lych & Korsun, 2023). For instance, the Kyiv Regional State Administration additionally reimburses interest on loans under the Affordable Loans 5-7-9% programme for investment purposes up to 0% per annum, and the Dnipro City State Administration reimburses it by 25%. Despite the twenty years of experience of Law of Ukraine No. 3254-IX (2023), this practice has not been developed in Ukraine, unlike in France and Poland. On the contrary, the number of credit unions more than halved between 2017 and 2023 (from 378 to 151). The new version of Law of Ukraine No. 3254-IX (2023) provides for: expanding membership in credit unions, including farms, microenterprises, cooperatives, trade unions, etc; expanding services, including the ability to transfer funds and pay supplier bills without going to the bank; introducing early intervention measures in cases of critical problems with credit union loyalty.

Discussing the potential for the development of credit unions in the agricultural sector of Ukraine with L. Kostyrko and T. Solomatina (2020), the authors of the study, despite several advantages of credit unions financing small farms (representation in rural areas, the ability to lend small amounts, etc.), do not believe that this financial institution will be widespread among farmers due to too high interest rates and distrust of the credit union institution on the part of farmers. Micro-, small and medium-sized agricultural enterprises up to 200 hectares, family farms and individuals running private farms, as in Romania, usually turn to financial, leasing and factoring companies, whose products cost up to 40% per annum. Financial companies such as Activitis, Nadezhda Ukrainy, ESKA Capital, Enira and others operate in this market.

Recently, free online platforms to facilitate lending to farmers have appeared in the financial services market**.** They allow agricultural producers to quickly make the best choice of lending, submit an online application for financing or a grant, and receive a bank decision. Such platforms include AgroApp, AgriAnalytics, and Uteka. Other digital banking tools include the Oschadbusiness platform, where an agricultural producer can receive a loan in a fully digital format. As can be noted, the financial services market offers a wide range of preferential offers aimed directly at supporting small and medium-sized farms. Nevertheless, according to a survey conducted on the Kurkul.com website, the rejection rate of loan applications is about 40%, 15% of farmers received a loan, and 45% did not apply to banks (Makovey, 2022). According to the Ukrainian Bureau of Credit Histories (n.d.), the most common reasons for loan rejection are absent or insufficiently informative

credit history; low income or large financial liabilities; damaged credit history; errors and inaccuracies in filling out the application form; and unreliability.

Recommendations for solving lending problems for farmers. The European Investment Bank (2020c) report formulated the following recommendations: continuity of the EAFRD guarantee instrument; introducing a special mechanism for microcredit in the form of a guarantee or a credit risk-sharing fund; the possibility of combining a financial instrument with grants; establishment of a pilot credit risk-sharing fund to address banks' problems with loan repayments and their perception of the high risks of lending to the agricultural sector; providing technical support to farmers in the form of financial training and advisory services in the process of preparing loan applications.

The European Investment Bank (2020) report highlighted the following areas of work to strengthen support for farmers, namely the creation of a special instrument in the form of a guarantee or a risk-sharing loan fund with a strong focus on start-ups and small and medium-sized farms; a combination of financial instruments and grants; and the creation of a pilot equity or quasi-equity financial instrument to support start-ups. European Investment Bank (2020) formulated the following proposals: to facilitate access to finance for new farmers and small farms that face certain collateral constraints or have acquired farms with existing debt, introduce EAFRD financial instruments as part of the new CAP Strategic Plan; the ability of EAFRD to support counter-guarantees with a higher guarantee rate than the current guarantee rate; and "one-stop shop" options that combine one scheme with one-time grants and financial instruments.

E.A. Dumitru *et al.* (2023) see the development of lending to the Romanian agricultural sector through increasing the economic size of small farms by establishing agricultural cooperatives, including the full cycle of production, processing and marketing. Analysing the structure of farms, the specifics of production, and the financing instruments used by farmers in Poland, France, Germany, and Romania, it is possible to conclude that in 2024, Ukraine will have almost all the lending opportunities available in other countries. However, despite the positive dynamics of lending to farmers in 2020-2022, which was largely due to the implementation of the government programme "Affordable Loans 5-7-9%", growth stopped in 2023. According to the authors of the study, this is due to the active expansion of lending to the medium-sized sector, the most active in Ukraine, of agricultural enterprises with land use of more than 1000 hectares in 2020-2022, which did not extend to smaller farms in 2023. Thus, the problem of lending to farms is not the lack of necessary financial instruments, but the volume, distribution and accessibility of existing mechanisms in Ukraine.

The vast majority of micro, small, and medium-sized farms with less than 200 hectares of land are experiencing limited access to credit, and they are still being ignored by banks. Tens of thousands of enterprises in this segment and millions of individual farmers engaged in growing wheat and corn, vegetables, fruits and berries, and raising poultry and livestock remain within the scope of shadow cash payments. The study revealed that the solution to the problems of farm financing lies in two areas. On the one hand, there is a complete lack of interest in banks in lending to small and medium-sized farms for the following reasons: higher transaction costs associated with servicing many contracts with small amounts, which leads to a decrease in bank profitability; the perception of small farms as insolvent enterprises with a high degree of risk.

T. Bondaruk and M. Lukashuk (2020) also believe that one of the ways to solve such problems in Ukraine could be the creation of a specialised agricultural bank or the use of economic incentives by the state for banks that lend to the agricultural sector. Another aspect of the problem of lending to medium, small and family farms is the inertia and lack of awareness of farmers about the opportunities available in the financial services market. It is very difficult for an average farmer to navigate through the variety of financial products available on the Ukrainian market (Lopatynskyi *et al.*, 2023). If banking institutions are interested in lending to small agricultural businesses, their advisors will be more active in helping farmers choose the best loan programme for them, combined with grants and partnership programmes, and will consider various options for loan guarantees, including the Farm Credit Guarantee Fund.

Local Employment Centres could be involved in this work, with training sessions for managers of small and medium-sized agricultural enterprises, family farms and individuals running private farms. Training on how to prepare a correct loan application, calculate the return on investment, and draw up a business plan, etc. can be provided by experts in economics and credit. Yu.O. Lupenko and S.V. Andros (2019) also note that the possibility of obtaining a loan is maximised if the farmer convinces the bank that the loan will be repaid within the timeframe specified in a clear business plan. A relevant example for Ukraine is the investment of farms in France and Germany in electricity production (Shahini *et al.*, 2024). The creation of a separate area of lending to small and micro enterprises under the state support programme "Affordable Loans 5-7-9%" in combination with grants will not only diversify incomes and stabilise farmers' financial flows, but also strengthen Ukraine's energy independence. N. Key (2020) confirmed that higher off-farm income can increase farmers' access to credit, stimulate investment, expand production, and improve the financial stability of the farm. Support the further development of online lending platforms

for farmers as a means of facilitating access to credit. N. Trusova *et al.* (2021) also discuss the widespread introduction of FINTECH solutions as a means of ensuring an effective communication process between all parties to credit relations. L. Si *et al.* (2021) also note that a financial platform can integrate the capital flow, logistics, and information flow of small and micro enterprises into the entire supply chain and effectively identify the risks of financing small and micro enterprises.

The Ukrainian agricultural sector is currently facing the most challenging times since independence. As a result of the war, agricultural enterprises have been suffering daily losses for more than two years due to blocked ports, destroyed elevators, logistical problems, low commodity prices, rising costs and an acute shortage of labour. In these conditions, solving the problems with timely financing of farmers is the key to Ukrainian food security.

CONCLUSIONS

The study has identified the reasons why the average size of land use of Ukrainian farmers is significantly higher than the average size of farms in Poland, France, Germany and Romania. Normally, such a large average farm size (839 hectares versus 83 hectares in France and 73 in Germany) should indicate the high economic performance of enterprises, since the more land under cultivation, the more efficiently it operates. However, in the case of Ukraine, this axiom is not confirmed, mainly because the state of the agricultural sector directly depends on the level of investment in its development. The gross accumulation per hectare in Ukraine is 2.6 times lower than in Poland, 2.8 times lower than in Romania, 10.4 times lower than in France, and 16.2 times lower than in Germany.

The research examines the state of lending to agricultural enterprises, the structure of financial institutions providing lending services to farmers, and farm support programmes in the EU countries selected for the article in comparison with Ukraine. The study proved that as of mid-2024, almost all financial instruments for lending that are available in other countries are present in Ukraine. The study found that the limited access to credit mainly affects medium, small and micro farms that cultivate less than 1,000 hectares of agricultural land. Based on the results of the research, the article formulates the necessary measures to increase the interest of banking institutions in providing loans to this category of agricultural producers.

The significance of the study lies in the recommendations for facilitating access to credit for medium, small and micro enterprises in the agricultural sector, both by credit institutions and farmers, and the introduction of a special programme of lending to farms for investments in electricity production as a means of supporting and stabilising farmers' financial flows in difficult times for Ukraine. An important topic for further research is access to credit for medium, small, and micro enterprises and individual farmers based on farm survey data disaggregated by the number of lands in cultivation. The study of the experience of international institutions in supporting farms through grants, subsidies and other direct payments, and the development of recommendations for their implementation in Ukraine, is also relevant for the agricultural sector. The study is limited to lending to farms and does not cover such possible instruments to support farmers as compensation for the difference in selling prices for key products below the fixed price and other direct payments and subsidies to farmers. The survey did not include a survey of farms by land use category on problems and access to credit.

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CONFLICT OF INTEREST

None.

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Розробка рекомендацій з вирішення проблем кредитування фермерів України на основі досвіду інших країн

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Анотація. Метою дослідження було вивчення практик фінансування фермерів Польщі, Франції, Німеччині та Румунії та розробка рекомендацій щодо зменшення кредитних обмежень сільських господарств України. Забезпечення фермерських господарств фінансовими ресурсами є одним із найважливіших завдань підтримки стійкості та стабільності країни у важкі часи воєнного спротиву. У роботі проаналізовані статистично-економічні показники, структура господарств та землекористування, фінансові інструменти, особливості фінансових інститутів, практики та досвід у кредитуванні Польщі, Франції, Німеччини, Румунії та України. Був досліджений вплив валового нагромадження основного капіталу на обсяг реалізованої продукції фермерських господарств у порівнювальних країнах. Виявлені основні причини виникнення дефіциту фінансування середніх, малих, мікропідприємств агропромислової галузі та чисельних домогосподарств, які ведуть особисте селянське господарство без створення юридичної особи. Зазначено, що основними наслідками обмеженого доступу до кредитування є низька ефективність використання земельних ресурсів, зменшення отриманого валового продукту та погіршення життєздатності ферм. Проаналізовано вплив на фінансове забезпечення аграрного бізнесу державної програми «Доступні кредити 5-7-9%» та інших програм для підтримки середніх, малих та мікропідприємств, створених за допомогою міжнародних партнерів. За останні роки ці нові фінансові інструменти суттєво збільшили доступ фермерських господарств до кредитування. Розглянуто пропозиції економічних науковців цих країн щодо усунення кредитних обмежень у діяльності аграрних виробників малих форм власності. Аналіз висвітлює спільні для всіх країн проблеми кредитування фермерів, а також багаторічний досвід, завдяки якому ці питання поступово вирішуються. Розроблені рекомендації щодо впровадження необхідних заходів для своєчасного отримання доступних кредитних ресурсів дрібними сільськими підприємствами та сімейними фермерськими господарствами України

Ключові слова: підтримка сільського господарства; інвестиції; обмеженість ресурсів; аграрна галузь; малі та мікропідприємства; фінансові інструменти

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Cross-commodity market integration and price transmission in Thailand's livestock sector

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Abstract. The ability to substitute goods and services is crucial for maintaining market stability during price fluctuations, particularly in the livestock market, where products are interchangeable. This study aimed to analyse market integration and asymmetric price transmission concerning livestock commodity prices in Thailand. Specifically, it focused on beef cattle, swine, broiler chicken, and chicken egg prices, using time-series data from January 2011 to December 2022. The analysis employed unit root tests to check if the time series data were stationary, Granger causality tests to determine the direction of relationships among livestock prices and an asymmetric price transmission model to examine short-term asymmetry and adjustment in cross-commodity prices. The findings indicate three directions of price integration in Thailand's livestock market: from broiler chicken price to chicken egg price, from swine price to chicken egg price, and from swine price to broiler chicken price. The results suggest that price transmission in Thailand is symmetrical, demonstrating an efficient interdependent relationship. Thus, the findings indicate that chicken eggs are a substitute for broiler chickens and swine when prices fluctuate, while broiler chickens are a substitute for swine. The results reveal that chicken eggs can replace swine consumption more effectively than broiler chickens within Thailand. This study highlights that chicken eggs are the most effective substitute during livestock price fluctuations in Thailand, with broiler chickens being the second most effective. Consequently, stakeholders in the livestock supply chain, such as policymakers, entrepreneurs, and farmers, should understand the integration of different commodities and price transmission in Thailand's livestock market. To guarantee market stability, stakeholders should manage the demand and supply of livestock commodities and acquire chicken eggs and broiler chickens during significant fluctuations in domestic livestock commodity prices

Keywords: market power; price stability; price adjustment; commodity; substitute; asymmetry

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INTRODUCTION

The livestock sector has played an important role in Thailand's agricultural development. It has advanced with modern production technology, meeting high international standards. Moreover, livestock production is a crucial source of income for agricultural households at both the farm and industrial levels. It generates substantial revenue for the agricultural sector and contributes significantly to export earnings from livestock products, which can amount to hundreds of billions of baht per year. The main types of livestock, including beef cattle, dairy cows, swine, broilers, and laying hens, have been developed through modern production management systems, hygienic and standardised animal housing, and government support for research and development in livestock production. As a result, farmers have demonstrated increased interest in raising animals and producing high-quality livestock products for domestic and international markets. That has led to increased investment in livestock businesses to meet consumer demands.

According to the 2022 report by the Office of Agricultural Economics (2023), the main livestock products exported by Thailand comprised chicken meat and products (141,962 million baht), dairy products (14,759 million baht), live beef cattle and products (3,428 million baht), pork products (1,351 million baht), and chicken eggs (1,162 million baht). The average exchange rate between the Thai baht and the US dollar was 35.0653 baht per US dollar in 2022. The report emphasises that demand for livestock products has been growing domestically and internationally, with countries such as Japan, the EU, and ASEAN member states being significant markets for Thai livestock products.

The livestock production sector in Thailand is positioned for expansion, driven by increasing domestic and international demand. However, the country's animal feed production relies heavily on imported raw materials, making the cost of domestic feed vulnerable to fluctuations in feedstuff raw material prices. Changing global supply and demand also contribute to substantial fluctuations in animal feed prices. External factors, such as climate change and conflicts in major producing countries of feedstuff raw materials like Russia and Ukraine, could also influence global feed costs. Animal feed constitutes an average of 60-70 per cent of the overall cost of livestock production in the country, making its cost a significant contributor to the prices of livestock products (Vorapojwisit, 2023). Thailand has been affected by African Swine Fever (ASF), which has severely impacted the economy and swine farming industry. The impact of the swine disease has caused the price of pork to increase dramatically, resulting in consumers opting for other products such as chicken, eggs, and beef. Therefore, it can be concluded that the prices of livestock products in Thailand are subject to high volatility, which can be attributed to several factors, including rising production costs, dependence on raw materials for animal feed from foreign sources, and the outbreak of animal diseases that can disrupt production. Despite these challenges, consumers can opt for alternative livestock commodities as substitute goods that may be more readily available, mitigating the impact of price volatility on their consumption habits.

This study aimed to analyse market integration and asymmetric price transmission in Thailand's livestock products (cross-commodity), focusing on beef cattle, swine, broiler chickens, and chicken eggs.

LITERATURE REVIEW

Several studies have analysed the price transmission of agricultural commodities, both vertically and horizontally, as well as the price integration among them that determines the market price. Vertical price integration occurs when price impacts are transmitted within the same commodity at different price levels, such as farm-gate, wholesale, retail, and export prices. In contrast, horizontal price integration occurs at the same price level but with varying transmission across different market regions, such as northern, central, and southern market prices. For instance, L. Deb *et al.* (2020) analysed market integration and price transmission in the vertical rice markets of Bangladesh using monthly time series data from November 2006 to June 2017. This study applied various econometric methodologies, including ADF and PP unit root tests for stationarity, Granger causality tests for identifying price transmission, and threshold autoregressive (TAR) and momentum threshold autoregressive (M-TAR) models for detecting asymmetric impacts among rice market prices in Bangladesh. The results indicated that a long-run equilibrium exists among farm-gate, wholesale, and retail rice prices. Asymmetric testing revealed both the short-run and long-run asymmetries in price transmission within vertical supply chains, affecting both the producers and consumers due to positive and negative asymmetries.

Shortly thereafter, T. Rudinskaya and I. Boskova (2021) investigated asymmetric price transmission in the dairy supply chain in the Czech Republic using the vector error correction model (VECM). Firstly, the study revealed that an increase in farm-gate prices had a greater impact on processor prices for drinking milk than a decrease in the same price level. Moreover, an increase in processor prices had a smaller effect on retail prices than a decrease in the same price level. Secondly, for butter, an increase in processor prices led to a greater impact on retail prices than a decrease in the unit price. Finally, for cheese, an increase in processor prices had a stronger effect on retail prices than a decrease in the unit price. The findings of T. Rudinskaya and I. Boskova (2021) provide a better understanding of the dynamics of price transmission in the dairy supply chain and have significant implications for producers, processors, and retailers in the industry. Furthermore, M.C. Rahman *et al.* (2022) analysed rice price transmission

in Bangladesh using time series methods from October 2005 to June 2017. The study found that the rice market in Bangladesh exhibits a long-run asymmetric relationship among the farm-gate, wholesale, and retail prices. The findings of V. Onegina *et al.* (2022) also support the concept of vertical price transmission in the agricultural market, especially in the case of the milk market in Ukraine, which is asymmetrical. Specifically, when the price of raw milk increases, the prices of processors and retailers rise by a larger magnitude. Additionally, when a shock occurs in the price of raw milk, it immediately impacts the prices of processors and retailers.

The impact of price changes can be transmitted to different types of commodities that serve as substitutes, particularly evident in agricultural markets. For example, O.H. Onubogu and A.O. Dipeolu (2021) studied the price transmission between cowpea and yam markets in Nigeria using Johansen cointegration, Granger causality, and VECM. Their findings confirmed the market integration between cowpea and yam prices. Similarly, the findings of S. Saghaian *et al.* (2018) indicated that price volatility can be transmitted asymmetrically about the prices of biofuels and maize in the United States. Furthermore, M. Zungo and F.T.M. Kilima (2019) estimated the price integration between maize and rice markets in Tanzania by employing cointegration and ECM analysis. Their study found strong evidence of market integration between the two price series. In addition, the study by P. Ramoroka and C.L. Muchopa (2022) analysed the cross-commodity price transmission between maize and wheat in South Africa using the Granger causality approach. The results revealed that changes in maize prices significantly affected wheat prices. Furthermore, M.A. Monteiro and B.D. Jammer (2024) supported the inter-commodity relationship in the case of grain and livestock prices in South Africa by employing time series analysis.

MATERIALS AND METHODS

This study employed secondary data in the form of monthly time series spanning the period from January 2011 to December 2022, totalling 144 months. The data were obtained from the Office of Agricultural Economics (2023) of Thailand. Notably, the analysis excludes livestock price data from 2023, as the government commenced intervening in the market during that time to stabilise swine prices, which had become volatile due to disease outbreaks. These interventions involved short-term adjustments to better align supply and demand with domestic needs. Additionally, around this time, Thailand detected smuggled pork imports, which could have distorted livestock prices, inducing them to deviate from true market conditions and potentially causing price distortions. The study analysed the market integration and price transmission in the major livestock commodities in Thailand using farm-gate price levels consisting of four variables: (1) the price of medium-sized live beef cattle (unit: baht per head) representing the price of beef cattle (P_C), (2) the price of live swine weighing 100 kilograms or more (unit: baht per kilogram) representing the price of swine (P_S), (3) the price of broiler chickens (unit: baht per kilogram) representing the price of broiler chickens (P_B), and (4) the price of assorted chicken eggs (unit: baht per hundred bubbles) representing the price of chicken eggs (P_E). To describe the relationship between the variables as a percentage change, known as elasticity, the variables were adjusted using the natural logarithmic function (ln). The time series plot of the variables, including P_C, P_S, P_B, and P_E, is presented in Figure 1.

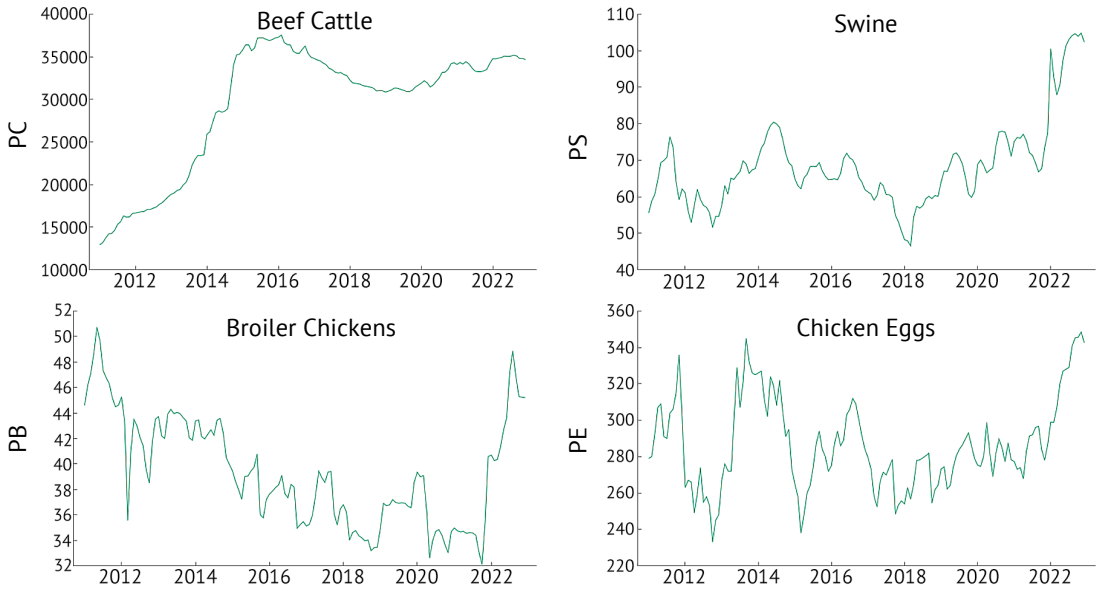

Figure 1. *Monthly beef cattle (P_C), swine (P_S), broiler chicken (P_B), and chicken egg (P_E) prices*
Source: *compiled by the author based on data from the Office of Agricultural Economics (2023), Thailand*

Figure 1 illustrates a time series of farm-gate price levels for four different livestock commodities: beef cattle, swine, broiler chickens, and chicken eggs. In 2022, there was a significant upward trend in the prices of three variables: P_S, P_B, and P_E, while P_C showed only a slight increase. The descriptive statistics and correlation matrix of the variables, including beef cattle price (P_C), swine price (P_S), broiler chicken price (P_B), and chicken egg price (P_E), are presented in Tables 1 and 2, respectively.

***Table 1**. Descriptive statistics of the variables*

Variable	Mean	Maximum	Minimum	S.D.	Skewness	Kurtosis
P_C	29,490.653	37,560.000	12,935.000	7,251.252	-1.001	2.511
P_S	68.425	104.835	46.546	11.839	1.357	5.231
P_B	39.373	50.740	32.100	4.279	0.420	2.289
P_E	286.613	348.540	233.000	24.893	0.520	2.796

***Source:** author's calculation*

Table 1 presents the mean, maximum, minimum, standard deviation (S.D.), skewness, and kurtosis of each variable. Table 2 displays the correlation coefficients between the four variables. The coefficient values in Table 2 indicate the strength and direction of the relationship between each pair of variables. The results suggest a positive correlation between P_S and P_E (0.685), and a weaker positive correlation between P_B and P_E (0.493), between P_S and P_B (0.317), and between P_C and P_S (0.316). Conversely, there is a negative correlation between P_C and P_B (-0.594), and a weak negative correlation between P_C and P_E (-0.002).

***Table 2**. Correlation matrix*

Variable	P_C	P_S	P_B	P_E
P_C	1.000	0.316	-0.594	-0.002
P_S	0.316	1.000	0.317	0.685
P_B	-0.594	0.317	1.000	0.493
P_E	-0.002	0.685	0.493	1.000

***Source:** author's calculation*

Before conducting a causal relationship analysis to detect market integration, it is essential to verify the stationarity of the time series variables to avoid spurious results (Granger & Newbold, 1974). In this study, the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests (Dickey & Fuller, 1979; Phillips & Perron, 1988) were utilised to assess the data properties. Both methods are based on one-sided p-values from J.G. MacKinnon (1996). If the level data of the variables are non-stationary, then first differencing is required until the variables exhibit stationarity. After identifying the stationarity of the variables, Granger causality is employed to test the relationships among the variables using a vector autoregressive (VAR) model (Granger, 1969). The multivariate VAR model, which incorporates the variables of P_C, P_S, P_B, and P_E, is presented as Eq. (1)-Eq. (4) below.

$$\Delta P_{C,t} = \alpha_1 + \sum_{i=1}^{p} \beta_{1i} \Delta P_{C,t-i} + \sum_{i=1}^{p} \theta_{1i} \Delta P_{S,t-i} + \sum_{i=1}^{p} \phi_{1i} \Delta P_{B,t-i} + \sum_{i=1}^{p} \omega_{1i} \Delta P_{E,t-i} + \varepsilon_{1t}, \quad (1)$$

$$\Delta P_{S,t} = \alpha_2 + \sum_{i=1}^{p} \beta_{2i} \Delta P_{C,t-i} + \sum_{i=1}^{p} \theta_{2i} \Delta P_{S,t-i} + \sum_{i=1}^{p} \phi_{2i} \Delta P_{B,t-i} + \sum_{i=1}^{p} \omega_{2i} \Delta P_{E,t-i} + \varepsilon_{2t}, \quad (2)$$

$$\Delta P_{B,t} = \alpha_3 + \sum_{i=1}^{p} \beta_{3i} \Delta P_{C,t-i} + \sum_{i=1}^{p} \theta_{3i} \Delta P_{S,t-i} + \sum_{i=1}^{p} \phi_{3i} \Delta P_{B,t-i} + \sum_{i=1}^{p} \omega_{3i} \Delta P_{E,t-i} + \varepsilon_{3t}, \quad (3)$$

$$\Delta P_{E,t} = \alpha_4 + \sum_{i=1}^{p} \beta_{4i} \Delta P_{C,t-i} + \sum_{i=1}^{p} \theta_{4i} \Delta P_{S,t-i} + \sum_{i=1}^{p} \phi_{4i} \Delta P_{B,t-i} + \sum_{i=1}^{p} \omega_{4i} \Delta P_{E,t-i} + \varepsilon_{4t}, \quad (4)$$

where Δ is the differencing order, t represents time, α is the constant, β denotes estimated coefficients, and ε is the error term. The optimal lag order for the VAR(p) model is determined using the lowest values of the Akaike information criterion (AIC). To identify the causal relationship, short-run causality using the standard

F-statistic and long-run block exogeneity using the Wald (χ^2) test are employed to test the null hypothesis (H_0), defined as follows. The null hypothesis of Eq. (1) can be expressed as $\sum_{i=1}^{p}\theta_{1i} = \sum_{i=1}^{p}\phi_{1i} = \sum_{i=1}^{p}\omega_{1i} = 0$. Similarly, the null hypothesis of Eq. (2) is $\sum_{i=1}^{p}\beta_{2i} = \sum_{i=1}^{p}\phi_{2i} = \sum_{i=1}^{p}\omega_{2i} = 0$, while the null hypothesis of Eq. (3) is $\sum_{i=1}^{p}\beta_{3i} = \sum_{i=1}^{p}\theta_{3i} = \sum_{i=1}^{p}\omega_{3i} = 0$. Finally, the null hypothesis of Eq. (4) is $\sum_{i=1}^{p}\beta_{4i} = \sum_{i=1}^{p}\theta_{4i} = \sum_{i=1}^{p}\phi_{4i} = 0$.

After identifying the causal relationship, the outputs were used to analyse price transmission between variables by employing R.F. Engle and C.W.J. Granger's (1987) cointegration and error correction model (ECM) approaches. The cointegration and error correction methods involve three steps. Firstly, the long-run equilibrium was determined by testing for possible cointegration and estimating the residual series from the estimation of Eq. (5). Secondly, the residual series was tested for stationarity, which could lead to two outcomes. If the residual series was stationary at the level stage with a contained unit root I(0) process, it would imply that the variables in the first step are cointegrated with a long-run equilibrium. However, if the residual series could not be stationary at the I(0) process, the estimation in the first step would have spurious results. Finally, if the analysis confirms that the variables are cointegrated with a long-run relationship, it is possible to test short-run adjustments returning to equilibrium using the error correction model (Asteriou & Hall, 2011). The processes of the cointegration and error correction model are described below.

In the first step, the existence of cointegration between Y and X is tested by using the linear combination shown in Eq. (5). The residual series ($\hat{\varepsilon}_t$) is obtained from Eq. (5) as presented in Eq. (6).

$$Y_t = \alpha_0 + \beta_1 X_t + \varepsilon_t, \quad (5)$$

$$\hat{\varepsilon}_t = Y_t - \hat{\alpha}_0 - \hat{\beta}_1 X_t, \quad (6)$$

where Y and X are the time series variables, $\hat{\varepsilon}_t$ is the estimated residual series, and $\hat{\alpha}_0$ and $\hat{\beta}_1$ are the estimated coefficients. If $\hat{\varepsilon}_t \sim I(0)$, it indicates that the relationship between Y and X is cointegrated without any spurious results.

In the second step, the stationarity of the residual series is tested using the ADF unit root test based on a model without a constant and time trend (Asteriou & Hall, 2011), as presented in Eq. (7).

$$\Delta\hat{\varepsilon}_t = \beta_1\hat{\varepsilon}_{t-1} + \sum_{i=1}^{p}\beta_2\,\Delta\hat{\varepsilon}_{t-i} + v_t, \quad (7)$$

where v is the white noise, and p is the lag length of the autoregressive (AR) process, starting from 1, 2, 3, …, i, which is selected based on the lowest values of the Schwarz information criterion (SIC). The null hypothesis of the ADF unit root test is a non-stationary time series. Therefore, if $\hat{\varepsilon}_t \sim I(0)$, the null hypothesis must be rejected at a statistical significance level of 0.05.

In the third step, the study conducted short-run dynamic adjustments using an error correction model based on an autoregressive distributed lag (ARDL) structure, as presented in Eq. (8).

$$\Delta Y_t = \alpha_0 + \beta_1\Delta X_t + \sum_{i=1}^{m}\beta_2\Delta X_{t-i} + \sum_{i=1}^{n}\beta_3\,\Delta Y_{t-i} + \gamma ECT_{t-1} + \varepsilon_t, \quad (8)$$

where n and m are the appropriately distributed lags of the variables, γ is the speed of adjustment returning to equilibrium, and ECT_{t-1} is the error correction term in the previous lag, which is part of the disequilibrium term.

This study employs an analysis of asymmetric price transmission, which assumes that the pass-through effect of price changes is not equal for negative and positive price changes of equal magnitude. The study employed an asymmetric price transmission model based on S. von Cramon-Taubadel and J.P. Loy's (1999) approach, which was initially developed by R. Wolffram (1971) and a simple asymmetric model by J.P. Houck (1977), as shown in Eq. (9).

$$\Delta Y_t = \alpha_0 + \beta_1^+\Delta X_t^+ + \beta_2^-\Delta X_t^- + \sum_{i=1}^{m}(\beta_3^+\Delta X_{t-i}^+) + \sum_{i=1}^{n}(\beta_4^-\Delta X_{t-i}^-) + \varepsilon_t, \quad (9)$$

where β_1^+ and β_3^+ are the short-run positive coefficients, β_2^- and β_4^- are the short-run negative coefficients, ΔX^+ is ΔX for all $\Delta X > 0$ and 0 otherwise, and ΔX^- is ΔX for all $\Delta X < 0$ and 0 otherwise. To test the hypothesis for short-run symmetry or short-run asymmetry of price transmission, the study used the joint F-statistic or Wald ($\chi 2$) test. The null hypothesis (H0) of short-run symmetry can be set as $\beta_1^+ = \beta_2^-$.

Furthermore, an asymmetric error correction representation using the ARDL structure was applied by S. von Cramon-Taubadel and J.P. Loy (1999), which includes ECT_{t-1}^+ and ECT_{t-1}^-. This can be expressed in Eq. (10).

$$\Delta Y_t = \alpha_0 + \beta_1^+\Delta X_t^+ + \beta_2^-\Delta X_t^- + \sum_{i=1}^{m}(\beta_3^+\Delta X_{t-i}^+) + \sum_{i=1}^{n}(\beta_4^-\Delta X_{t-i}^-) + \gamma_1^+ ECT_{t-1}^+ + \gamma_2^- ECT_{t-1}^- + \sum_{i=1}^{p}(\theta_1\Delta Y_{t-i}) + \varepsilon_t, \quad (10)$$

where γ_1^+ and γ_2^- are the positive and negative adjustment coefficients, ECT_t^+ is the ECTt for all $ECT_t > 0$ and 0 otherwise, ECT_t^- is the ECTt for all $ECT_t < 0$ and 0 otherwise, and θ is the coefficient of the lagged dependent

variable. To examine the hypothesis of symmetric or asymmetric adjustment of price transmission, the joint F-statistic or Wald (χ^2) test was also utilised. The null hypothesis (H0) of symmetric adjustment can be set as $\gamma_1^+ = \gamma_2^-$.

RESULTS AND DISCUSSION

In time series analysis, testing for data properties such as stationarity or non-stationarity is essential to avoid spurious regression problems caused by the influence of time effects. This study conducted unit root tests on lnP_C, lnP_S, lnP_B, and lnP_E using the ADF and PP methods with a model that included constants and linear time trends. The results, presented in Table 3, were analysed using the natural logarithmic function (ln). The results of the stationarity tests in Table 3 using the ADF and PP unit root methods were consistent. Specifically, at the conventional level, the variables (lnP_C, lnP_S, lnP_B, and lnP_E) failed to reject the null hypothesis (H_0: non-stationarity) at a statistical significance level of 0.05. Thus, it can be concluded that these four variables are non-stationary time series at the level stage and require the addition of the first difference order to the variables before testing for stationarity again. After adding one order of difference to the variables, stationarity tests were conducted using the ADF and PP unit root methods. The results showed that all variables had t-statistics that were significant at a level of 0.01, rejecting the null hypothesis of non-stationarity. Therefore, it can be concluded that all four variables (ΔlnP_C, ΔlnP_S, ΔlnP_B, and ΔlnP_E) are stationary at the first difference or I(1) process based on the ADF and PP unit root tests.

***Table 3**. The results of the ADF and PP unit root tests*

Variable	ADF unit root		PP unit root	
	t-statistic	p-value	t-statistic	p-value
lnP_C	-1.971	0.611	-1.925	0.635
lnP_S	-2.309	0.425	-2.009	0.590
lnP_B	-1.373	0.864	-1.847	0.676
lnP_E	-3.109	0.108	-2.779	0.207
ΔlnP_C	-7.855	<0.001	-7.846	<0.001
ΔlnP_S	-9.330	<0.001	-9.208	<0.001
ΔlnP_B	-10.989	<0.001	-11.223	<0.001
ΔlnP_E	-6.186	<0.001	-11.168	<0.001

***Note:** the null hypothesis (H0) of the ADF and PP unit roots is a non-stationary time series*
***Source:** author's calculation*

Table 4 presents the results of the Granger causality tests used to examine the cross-commodity integration of livestock product prices in Thailand, namely beef cattle (P_C), swine (P_S), broiler chicken (P_B), and chicken egg (P_E) prices. The variables (lnP_C, lnP_S, lnP_B, and lnP_E) were employed in the analysis based on the structure of the multivariate VAR(2) model selected using the lowest value of the AIC. The standard F-statistic was used to detect short-run causality, and the Wald (χ^2) test was used to detect long-run block exogeneity among the variables. These two techniques were used to examine cross-commodity market integration, and the results were applied to analyse price transmission in the next objective of the study.

***Table 4**. The results of the Granger causality tests*

Variable (Y)	Independent variable (X)			
	ΔlnP_C	ΔlnP_S	ΔlnP_B	ΔlnP_E
ΔlnP_C	-	0.076 (0.130)	1.333 (0.690)	0.277 (0.032)
ΔlnP_S	0.814 (0.617)	-	4.353 (2.060)	1.039 (0.428)
ΔlnP_B	0.595 (0.328)	6.110[b] (2.754[c])	-	2.044 (0.909)
ΔlnP_E	0.507 (0.338)	7.034[b] (5.689[a])	5.573[c] (5.215[a])	-

***Note:** the statistical significance levels are denoted by superscripts of a, b, and c for 0.01, 0.05, and 0.1 levels, respectively. The null hypothesis of Granger causality is that "X does not Granger cause Y". The statistical values in parentheses are from the standard F-statistic, while those without parentheses are from the chi-square (χ^2) statistic*
***Source:** author's calculation*

The results in Table 4 indicate that both methods used for the Granger causality tests yielded consistent results with slightly different statistical significance levels. The results reveal three one-way directional relationships that are statistically significant within the range of 0.01 to 0.1 levels. Specifically, the price of broiler chickens (P_B) has a significant impact on the price of chicken eggs (P_E), the price of swine (P_S) has a significant impact on the price of chicken eggs (P_E), and the price of swine (P_S) has a significant impact on the price of broiler chickens (P_B). The results suggest that there exists a market integration across livestock commodities in Thailand, with changes in broiler chicken prices having an impact on changes in chicken egg prices, and changes in swine prices having an impact on changes in both chicken egg and broiler chicken prices.

The results of the market integration analysis, indicating three directions of the pairwise relationship across livestock commodities, from broiler chicken price to chicken egg price, from swine price to chicken egg price, and from swine price to broiler chicken price, are presented in Table 4. The estimates of the cointegration tests in Table 5 indicate that all models have a long-run equilibrium, as the residual series based on the ADF unit root test in all models are statistically significant within the range of 0.01 to 0.05 levels. This implies that the null hypothesis of non-stationarity can be rejected and that the variables are cointegrated. The long-run elasticities between the pairwise relationships in each model can be summarised as follows. Model 1 shows that a one per cent increase in the price of broiler chickens (P_B) leads to a 0.375 per cent increase in the price of chicken eggs (P_E), while in Model 2, a one per cent increase in the price of swine (P_S) results in a 0.365 per cent increase in the price of chicken eggs (P_E). In the case of Model 3, a one per cent increase in the price of swine (P_S) leads to a 0.196 per cent increase in the price of broiler chickens (P_B).

***Table 5**. The results of the cointegration and error correction model tests*

Variable	Model 1: $\ln P_E$	Model 2: $\ln P_E$	Model 3: $\ln P_B$
α	4.277[a]	4.114[a]	2.840[a]
$\ln P_B$	0.375[a]	-	-
$\ln P_S$	-	0.365[a]	0.196[a]
ADF test ($\hat{\varepsilon}_t$)	-3.250[a]	-4.165[a]	-2.229[b]
ECT_{t-1}	-0.144[a]	-0.218[a]	-0.071[b]

***Note:** the statistical significance levels are denoted by superscripts of a, b, and c for 0.01, 0.05, and 0.1 levels, respectively*
***Source:** author's calculation*

***Table 6**. The results of the short-run symmetry and symmetric adjustment tests*

Variable	Model 1: $\Delta\ln P_E$	Model 2: $\Delta\ln P_E$	Model 3: $\Delta\ln P_B$
α	0.006	-0.001	<0.001
$\Delta\ln P_B^+$	-0.057	-	-
$\Delta\ln P_B^-$	0.352[a]	-	-
$\Delta\ln P_S^+$	-	0.207[b]	0.271[a]
$\Delta\ln P_S^-$	-	0.123	0.389[a]
ECT_{t-1}^+	-0.159[c]	-0.233[a]	-0.057
ECT_{t-1}^-	-0.153[c]	-0.256[b]	-0.066
$\Delta\ln P_{E,t-1}$	-	0.155[c]	-
$\Delta\ln P_{B,t-1}$	-	-	0.070
$\Delta\ln P_{B,t-2}$	-	-	-0.256[a]
Wald (χ^2) test			
$\beta_1^+ = \beta_2^-$	0.057[c]	0.170	0.528
$\gamma_1^+ = \gamma_2^-$	0.966	0.019	0.927

***Note:** the statistical significance levels are denoted by superscripts of a, b, and c for 0.01, 0.05, and 0.1 levels, respectively*
***Source:** author's calculation*

The ECT_{t-1} coefficients in all models are statistically significant within the range of 0.01 to 0.05 levels, indicating that the error correction mechanism is present and that the models adjust to long-run equilibrium after a short-run deviation. In the event of any price changes or shocks that affect long-run equilibrium and cause the relationship to deviate from its original equilibrium, the pairwise relationship will adjust to its equilibrium again. Thus, Table 5 can describe the speed of adjustment in all models as follows. The relationship between the prices of chicken eggs and broiler chickens will adjust to equilibrium with a speed of 14.4 per

cent, while the speed of adjustment between chicken egg and swine prices is 21.8 per cent, and the speed of adjustment of the relationship between broiler chicken and swine prices is only 7.1 per cent. Table 6 presents the hypothesis tests of short-run symmetry and symmetric adjustment to examine the existence of symmetry and asymmetry in price transmission. The results indicate that the hypothesis of short-run symmetry ($\beta_1^+ = \beta_2^-$) is weakly rejected only in the transmission of broiler chicken price (P_B) to chicken egg price (P_E), but there is no evidence of asymmetric adjustment ($\gamma_1^+ = \gamma_2^-$). Moreover, there is no evidence to support the hypothesis of short-run asymmetry and asymmetric adjustment tests for the transmission from the price of swine (P_S) to chicken egg (P_E) and broiler chicken (P_B) prices.

The results indicate that all variables are stationary at the first order of difference, and three pairwise causal relationships exist: from broiler chicken price to chicken egg price, from swine price to chicken egg price, and from swine price to broiler chicken price. These findings align with prior research confirming that chicken and pork products are close substitutes in other markets (Andersen *et al.*, 2007). However, beef cattle are not found to be close substitutes for broiler chickens and chicken eggs in Thailand. The study also finds that price transmission in Thailand's livestock market is generally symmetrical, except for a weak statistically significant result in the short-run asymmetry of broiler chicken price to chicken egg price.

Granger causality is a widely recognised empirical technique in the literature for analysing market integration across commodity prices. The causality analysis of this study indicates that three causal relationships of price integration exist in Thailand's livestock market: from broiler chicken price to chicken egg price, from swine price to chicken egg price, and from swine price to broiler chicken price. These findings are consistent with those of P. Fiszeder and P. Orzeszko (2018), who conducted both linear and non-linear Granger causality tests to examine the relationship between the returns of grains (corn, soybean, and wheat) and livestock commodities (live cattle and lean hogs). Their results revealed non-linearities in the relationship between grain and livestock returns, with mostly a two-way directional causality. Similarly, T. Govdeli (2022) utilised Granger causality tests and found a significant positive impact of oil prices on the prices of agricultural raw materials. Furthermore, the findings of P. Ramoroka and C.L. Muchopa (2022) demonstrated a unidirectional relationship in the grain market, where maize prices significantly affected wheat prices in South Africa.

Additionally, testing for asymmetry in the short-run and long-run price transmission across livestock commodities in Thailand revealed that the price transmission characteristics are symmetrical; that is, no asymmetry in price transmission can be detected among livestock prices. These findings are consistent with those of D.G. Kidane (2022), who found a symmetric relationship across regional grain prices in Ethiopia, with no evidence of asymmetric adjustment. On the other hand, these findings are inconsistent with the conclusions of M. Ben Abdallah *et al.* (2020), who found asymmetric long-run and short-run price transmission for dairy products in Hungary. However, the study by C. Jatuporn (2024) discovered that the transmission of global oil prices to domestic commodity prices in Thailand occurs in different manners. Specifically, the findings from this study indicate that the price transmission of global oil prices to most commodities is generally asymmetric (such as the producer price index, consumer price index, export price index, cassava price, diesel price, and gasohol price). The exception is the oil palm price, which has a symmetric relationship with global oil prices. In contrast, the sugarcane price does not exhibit a correlated relationship with global oil prices.

CONCLUSIONS

Thailand faces the challenge of volatile prices in agricultural commodities, particularly livestock products, due to its high dependence on imported feed raw materials. These raw material costs are susceptible to fluctuations caused by global demand and supply, conflicts in major producing countries, climate change, and variations in livestock prices worldwide. Additionally, animal disease outbreaks and economic instability in Thailand contribute to the volatility of livestock product prices. The study's findings indicate that Thailand's livestock commodities are significantly interdependent. Specifically, the results demonstrate that chicken egg prices are significantly responsive to changes in broiler chicken and swine prices, respectively. This implies that chicken eggs are substitutes in the event of shortages in broiler chickens or swine. Furthermore, the study reveals that broiler chicken prices can respond to changes in swine prices since broiler chickens are also considered substitutes in the event of swine shortages. An interesting finding is that the adjustment level in the chicken-egg market is the most effective. The study indicates that chicken egg prices quickly adjust to shocks, making them the most significant substitute during livestock price fluctuations, such as recent animal disease outbreaks in Thailand, followed by broiler chickens, particularly in the case of swine substitution. Therefore, it can be concluded that chicken eggs are among the most important substitutes for livestock commodities in Thailand due to their shorter production time and suitability as a meat substitute.

This study suggests that chicken eggs and broiler chickens can serve as substitute commodities during domestic livestock price volatility, especially during animal disease outbreaks or shortages of livestock supplies. To prevent inefficiencies in the market, the demand and supply of livestock commodities should be managed to ensure prices do not fluctuate drastically. In

the event of excessive fluctuations in domestic livestock commodity prices, stakeholders should procure and supply chicken eggs and broiler chickens to meet consumer demand and bring the market into stability. This study analyses livestock market integration and price transmission in Thailand using data from January 2011 to December 2022. The analysis does not include data from 2023, despite recent improvements in livestock disease outbreaks and sustained demand for livestock products. This exclusion is based on the possibility that 2023 data may reflect a short-term positive response, which might not fully capture long-term market dynamics. Additionally, during this period, Thailand was found to have imported smuggled pork products, leading to distortions in domestic pork prices. These smuggled imports, often priced lower than domestic products, could have affected the prices of other livestock commodities.

Furthermore, future studies should consider incorporating a broader range of factors, including both economic and non-economic indicators, to provide a more comprehensive analysis of the livestock market. Given the findings of this study, subsequent research on Thailand's livestock market should explore the use of non-linear models or other asymmetric methods to test market integration and price transmission. Additionally, it would be beneficial to analyse different market levels – such as farm-gate, wholesale, retail, and export – to gain a deeper understanding of market dynamics.

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CONFLICT OF INTEREST

None.

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Інтеграція міжсировинних ринків та цінова трансмісія у тваринницькому секторі Таїланду

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Анотація. Заміщення товарів і послуг є важливим для підтримки стабільності ринку під час цінових коливань, особливо на ринку тваринництва, де продукти є взаємозамінними. Це дослідження мало на меті проаналізувати ринкову інтеграцію та асиметричну цінову трансмісію щодо цін на продукцію тваринництва в Таїланді. Зокрема, воно було зосереджене на цінах на м'ясну худобу, свиней, курей-бройлерів та курячі яйця, використовуючи дані часових рядів з січня 2011 року по грудень 2022 року. Економетрична методологія включала тести на одиничний корінь для визначення стаціонарності часових рядів, тести причинно-наслідкових зв'язків Грейнджера для виявлення спрямованих взаємозв'язків між цінами на продукцію тваринництва та модель асиметричної цінової трансмісії для перевірки короткострокової асиметрії та асиметричного коригування міжтоварних цін. Результати вказують на три напрямки інтеграції цін на ринку тваринництва Таїланду: від ціни на курей-бройлерів до ціни на курячі яйця, від ціни на свиней до ціни на курячі яйця та від ціни на свиней до ціни на курей-бройлерів. Результати свідчать про те, що цінова трансмісія в Таїланді є симетричною, демонструючи ефективний взаємозалежний зв'язок. Таким чином, отримані дані свідчать про те, що курячі яйця є замінником курей-бройлерів та свиней в умовах цінових коливань, а курей-бройлерів - замінником свиней. Результати також показують, що курячі яйця можуть замінити споживання свиней більшою мірою, ніж курей-бройлерів у випадку Таїланду. Це дослідження підкреслює, що курячі яйця є найефективнішим замінником під час коливань цін на худобу в Таїланді, за ними слідують курчата-бройлери. Таким чином, зацікавлені сторони в ланцюгу постачання продукції тваринництва, такі як політики, підприємці та фермери, повинні розуміти міжтоварну інтеграцію та цінову трансмісію на ринку тваринництва Таїланду. Щоб забезпечити стабільність ринку, зацікавлені сторони повинні управляти попитом і пропозицією на тваринницьку продукцію та закуповувати курячі яйця і курчат-бройлерів під час надмірних коливань внутрішніх цін на тваринницьку продукцію

Ключові слова: слова: ринкова влада; цінова стабільність; регулювання цін; товар; замінник; асиметрія

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Sustainability in the winemaking industry and the assessment of grape seed characteristics during processing: Evidence from Azerbaijan

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Abstract. In the context of Azerbaijan's evolving winemaking landscape, this study investigates the sustainability of viticulture with a particular focus on grape seeds, which are crucial for grapevine propagation, oil extraction, and overall vineyard health. The research aimed to examine the morphological, technological, and biochemical characteristics of grape seeds to optimise grape production methods and promote sustainable viticultural practices. To achieve this, seed samples from twelve grape varieties, both local and introduced, were carefully collected and analysed under varying irrigation conditions, including both irrigated and rainfed settings, to allow for a comprehensive assessment. The investigation revealed significant effects of irrigation on seed properties. Specifically, seeds from irrigated grapes were found to be larger, heavier, and richer in oil content compared to those from rainfed grapes. Detailed analyses showed that the nitrogen content of the seeds ranged from 0.96% to 1.46%, cellulose content varied from 18.8% to 25.3%, ash content ranged from 1.9% to 3.1%, nitrogenous compounds fluctuated between 5.5% and 7.2%, and non-nitrogen extractive substances registered between 16.6% and 22.0%. Notably, correlations between seed properties and the efficiency of cold press oil extraction were identified, providing valuable insights. This research ultimately

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contributes to the advancement of sustainable viticulture practices in Azerbaijan, ensuring the long-term health and productivity of vineyards within the region

Keywords: agriculture; viticulture; technological characteristics; biochemical composition

INTRODUCTION

The production process of goods within the wine industry has a substantial economic impact. Unfortunately, this production also generates a considerable amount of waste, posing to significant challenges to the ecosystem. During processing, between 25% and 40% of various grape components, including stems, seeds, peels, and so forth, are disposed of as waste. Of this waste, grape seeds account for 38% to 50% of grape pomace and typically constitute approximately 5% of the total grape mass. Notably, the global wine industry annually discards approximately 3 megatons of grape seeds. Grape seeds are rich in carbohydrates, fibres, lipids, minerals, polyphenols, and proteins.

Leveraging grape seeds for various purposes in winemaking exemplifies a commendable practice within the framework of the circular economy (Vorobyiev & Lebovka, 2020). Anthocyanin dyes, oils, or catechol polymers can be extracted from grape seeds. Following the drying process, grape seeds exhibit an oil content ranging from 3.95% to 20.71%. Their composition, particularly the cell wall comprising cellulose, hemicellulose, and proteins, endows grape seeds with significant properties. Grape seed oil is notably rich in linoleic and oleic acids, both of which are monounsaturated fatty acids. Furthermore, the presence of antioxidant and anti-inflammatory bioactive compounds, alongside phenols, provides grape seeds with versatility for applications in agriculture and pharmaceuticals (Mikailov & Farzaliev, 2018; Bosso *et al.,* 2020). The extraction technique employed to obtain grape oil can potentially increase product yield by up to 13% while ensuring the production of high-quality grape oil without incurring additional costs associated with purification or chemical processing. The efficiency of oil yield during grape seed pressing is primarily determined by the degree of grinding. Notably, grape seeds are distinguished by their specific structure, characterised by a high shell content and the hardness of their shell structure.

Numerous scientific studies have been conducted focusing on sustainability, economic viability, and efficient production technologies within the winemaking sector. A. Soceanu *et al.* (2021) analysed sustainability frameworks from six wine-producing nations, seeking commonalities and opportunities for improvement, to advance sustainability practices within the wine industry. K. Abiri *et al.* (2020) conducted research investigating the morphological and pomological traits of 55 grape varieties. Their findings revealed a notable positive correlation between parameters such as bunch length and width, as well as berry length and width. The considerable morphological variability observed in Iranian grape varieties suggests a vast gene pool, which contributes to grape breeding efforts. Based on the results, it was concluded that selecting parameters based on their correlative relationships could lead to further enhancements in product quality. V. Salimov *et al.* (2022) conducted research focused on exploring the polymorphic characteristics and variability of several grape varieties discovered for the first time through scientific expeditions organised in various wine-growing regions of Azerbaijan from 1998 to 2020.

The findings revealed that the gene pool of Azerbaijani grapes is characterised by its diversity and polymorphism. T. Panakhov and M. Guseinov (2019), along with S. Takhirov and M. Guseinov (2020), conducted a study examining the morphological characteristics and chemical composition of six Vitis vinifera grape varieties. Their findings suggested that Ribier and Matrouh Eswed had the lowest seed count per berry, while Black Rose, Red Globe, and Roumi Ahmer displayed high carbohydrate and protein content, indicating their suitability for animal feed production. Additionally, Black Rose, Red Globe, Roumi Ahmer, and Rich Baba showed promise for oil production due to their elevated oil yield. Another study, led by G. Monteiro *et al.* (2021), investigated eight distinct grape cultivars – Red Globe, Michele Palieri, Balbal, Antep Karası, Alphonse Lavallee, Pembe Gemre, Uzbek, and Efes Karası – that were grown in the Tekirdag region of Turkey.

Several comprehensive studies similar to this one have been undertaken, exploring diverse aspects of grape cultivation, viticultural methods, and the evaluation of grape quality. These investigations by M. Akram *et al.* (2021) encompass a range of factors, such as grapevine genetics, environmental conditions, vineyard management practices, and processing techniques, all contributing to a deeper understanding of grape production and its significance within the wine industry. Through this research, the authors aim to provide insights that lay the groundwork for integrating grape seeds as a valuable resource within the Azerbaijani wine industry. The process of extracting oil from grape seeds represents a novel endeavour in Azerbaijan. The principal aim of the research was to determine the foundational resources for seed oil extraction. Through an analysis of Azerbaijan's vineyards as a case study, the article aims to examine the

relationship between sustainable viticultural practices and grape productivity, to advance sustainability within the Azerbaijani wine industry.

MATERIALS AND METHODS

The study utilised statistical data sourced from the State Statistics Committee of the Republic of Azerbaijan (ARDSK, 2023) to examine the current state of the viticulture and winemaking sector, assessing indicators of growth rate and sustainability depicted graphically. Moreover, productivity and harvest variables were subjected to covariance and correlation analyses for comparative evaluation. The empirical scientific and technological studies within the research were conducted in laboratory settings focusing on production-related aspects. The research involved grape variety seeds planted and cultivated at the Shamakhi Experimental Station of the Scientific Research Institute of Viticulture and Winemaking, as well as the Absheron Auxiliary Experimental Farm, during the years 2022 to 2024. The economic-technological, morphological, and biological traits of 45 recently discovered local grape varieties were examined, alongside the determination of classification features and geographical origins. Accordingly, the study encompassed an exploration of the morphological and biochemical components of seeds derived from specific grape varieties cultivated under both irrigated and rainfed conditions in Azerbaijan. The investigation extended to scrutinising seed oiliness, the efficiency of oil extraction via the screw press method, morphometric attributes of the seeds, biochemical markers, and distinctive traits of the varieties to elucidate their influence.

When researching grapevine sustainability and grape seeds, it is important to assess morphological indicators such as seed size, colour, and mass; technological indicators including germination rate, seed viability, and seedling growth parameters; as well as biochemical indicators such as oil content, nitrogen levels, cellulose content, ash content, and other compounds like phenolics and antioxidants. The grape seeds, which served as the subject of the study, were air-dried for 7 to 10 days in sunlight and 15 to 20 days in shade following their separation from grape processing residues. Subsequently, these seeds, without undergoing grinding or crushing, were processed using a screw press device (Kochmaksan, Model No. – KMS10, Turkey), and the resultant oil was extracted. No chemical or thermal treatment was applied to the seeds before pressing. Ten kilograms of seeds from each variety, cultivated under both irrigated and rainfed conditions, were subjected to the screw press, and the quantity of oil released per total seed weight was determined. Additionally, certain morphological and ampelodescriptive characteristics of grape seeds were identified using appropriate methodologies.

During the research, various measurements were conducted using specialised devices: moisture levels were assessed using the KERN DBS 60-3 device (Germany), while nitrogen and nitrogenous compounds were analysed with the KjelFlex K-360 device (Sweden). The crude ash content was determined using the Mikrotest MKF-07 device (Russia), and dry matter was calculated based on analysis results from multiple parameters and the indicator from the Perten DA-7250 device (Sweden). The oil content was assessed by washing with hydrocarbons in the BUCHI FatExtractor E-500 device (Switzerland), and cellulose NDF, ADF, and ADL analyses were conducted using the ANKOM 200 Fiber Analyzer (USA), followed by the calculation of results with specialised formulas. Vaccine content was determined through spectroscopy using the Perten DA-7250 device. Furthermore, correlation analyses employing the Pearson method were performed to explore relationships between variables and indicators that positively influence seed oil extraction. The methodology involved analysing nitrogen indicators and cellulose content in grape seeds grown under both irrigated and rainfed conditions. Additionally, the study examined ash content, nitrogenous compounds, non-nitrogen extractive substances, dry matter content, tannin content, and crude oil percentage in grape seeds from 12 varieties grown under irrigation conditions.

The research conducted on plants, including the collection of plant material, adhered to ethical standards by institutional, national, or international guidelines. Specifically, the study followed the principles outlined in the Convention on Biological Diversity (1992) and the Convention on International Trade in Endangered Species of Wild Fauna and Flora (1979), ensuring compliance with regulations designed to preserve biodiversity and protect endangered species.

RESULTS AND DISCUSSION

The pattern suggests effective selection and propagation of grape varieties by Azerbaijani viticulturists, highlighting their commitment to sustainable practices aimed at ensuring long-term economic sustainability. However, careful assessment is essential to ascertain the sustainability of the observed harvest growth, safeguarding against the depletion of critical resources. The graphical representation in Figure 1 illustrates an increasing trend in both grape productivity and total harvest in Azerbaijan over the past 22 years, indicating the genetic diversity inherent in the cultivated grapevine varieties.

Covariance and correlation analyses were utilised to explore the relationships among variables, focusing here on grape productivity and harvest in Azerbaijan. The provided table presents the covariance and correlation metrics for these variables: productivity and harvest (Table 1).

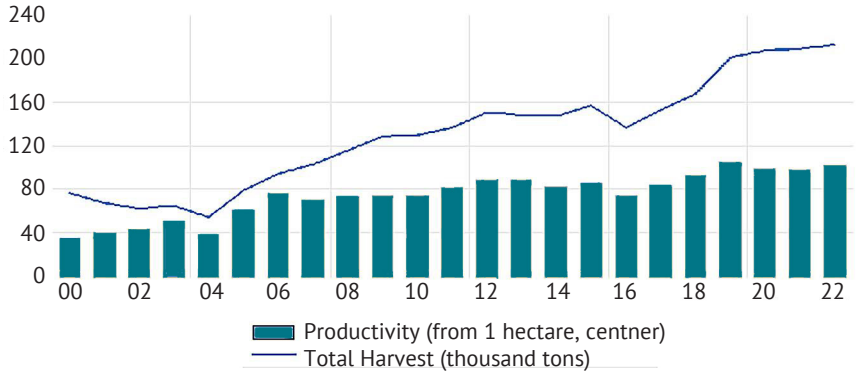

***Figure 1**. Total harvest and productivity in the viticulture sector in Azerbaijan*
***Source:** ARDSK (2023)*

***Table 1.** Covariance and correlation analysis in the viticulture sector*

Covariance	Productivity	Harvest
Productivity	418.6336	
Harvest	934.2581	2,353.287

Correlation	Productivity	Harvest
Productivity	1.000000	
Harvest	0.941266	1.000000

***Source:** compiled by the authors*

Covariance measures the joint variability of the variables, with a positive value suggesting a tendency for them to move together. In this instance, the positive covariance (418.6336) suggests a beneficial correlation between grape productivity and harvest, highlighting potential sustainability in agricultural practices. The correlation coefficient, derived from covariance and standard deviations, evaluates the strength and direction of the linear relationship, with values ranging from -1 to 1. A correlation coefficient of 1 denotes a perfect positive linear relationship, -1 signifies a perfect negative linear relationship, while 0 indicates no linear relationship between the variables, informing assessments of sustainability in grape cultivation practices. During the study, the seed mass was determined as part of the mechanical analysis of grape clusters. Following this determination, the seeds were categorised according to the descriptors established by the International Organisation of Vine and Wine. It was observed that the size and mass of grape seeds varied between varieties cultivated under irrigated and rainfed conditions.

Under irrigation, five varieties (Madrasa (technical), Khyndogny (technical), Bayanshira (technical), Cabernet Sauvignon (technical), and Merlot (technical)) exhibited large seeds, while seven varieties (Ag Kharji (technical), Hana grna (universal), Genjevi (universal), Mahmudu (table), Agadaiyee (table), Moldova (universal), and Doyna) had very large seeds. Among the varieties grown under rainfed conditions, only two (Khyndogny (technical), and Moldova (universal)) had larger seeds, while the others (Madrasa, Bayanshira, and Cabernet Sauvignon (technical)) had seeds of average mass. Overall, when comparing irrigation and rainfed conditions, it is evident that the same varieties grown under irrigation (Madrasa, Khyndogny, Bayanshira, and Cabernet Sauvignon) produce larger seeds. Additionally, notable differences were observed in the colouration of grape seeds among the various varieties grown under both conditions. The seeds of the twelve different varieties exhibited diverse colourations: three were dark brown (Madrasa, Doyna, and Moldova), three were light brown (Khyndogny, Agadaiyee, and Hana grna), two were reddish-brown (Bayanshira and Ag Kharji), three were brown (Genjvi, Mahmudu, and Merlot), and one was dark brown with a reddish tint (Cabernet Sauvignon) (Table 2). This variation is reflected in the mass of 100 seeds. In grapes cultivated under irrigation, the mass of 100 seeds ranged from 4.2 g (Madrasa) to 10.2 g (Ag Kharji). Conversely, for grapes grown under rainfed conditions, this range varied from 3.8 g (Madrasa) to 5.2 g (Moldova). Notably, among grapes grown under irrigation, relatively large seeds were observed in the Madrasa, Bayanshira, Khyndogny, Cabernet Sauvignon, Merlot, Doyna, Agadaiyee, Mahmudu, Genjevi, Moldova, Hana grna, and Ag Kharji varieties. In contrast, grapes grown under rainfed conditions tended to have relatively smaller seeds.

***Table 2**. Some morphological, technological and biochemical indicators of grape seeds*

Grape variety	Colour	Seed: mass (OIV 243)	Mass of 100 seeds, g	Seed size (length/width), mm	Moisture, %	Nitrogen,%	Cellulose, %	Ash, %	Nitrogen compounds, %	Non -nitrogenous extractive substances, %	Dry substance, %	Tannin substance, %	Oiliness, % (crude oil)	Oil extraction during cold pressing, %
In irrigation condition														
Madrasa (technical)	Dark brown	big, OİV243-7	4.2	6.4/3.8	12.4	1.17	24.0	2.1	6.0	19.0	65.0	4.0	11.9	4.00
Khyndogny (technical)	Light brown	big, OİV243-7	6.2	7.2/4.6	14.6	1.22	21.8	2.8	6.4	18.2	64.4	3.8	12.6	4.08
Bayanshira (technical)	Reddish brown	big, OİV243-7	5.2	6.7/4.2	20.0	1.18	22.4	3.1	5.5	21.4	62.4	4.6	11.2	4.42
Ag Kharji (technical)	Reddish brown	bigger, OİV243-9	10.2	7.6/4.6	18.2	0.98	25.3	2.4	7.2	20.0	67.4	3.6	14.6	6.18
Hana grna (universal)	Light brown	bigger, OİV243-9	10.0	7.8/4.8	22.3	1.42	24.4	2.8	6.5	22.0	68.4	4.2	18.8	6.80
Genjevi (universal)	Brown	bigger, OİV243-9	8.2	7.4/4.4	24.4	1.33	22.1	2.8	6.2	19.8	64.2	4.6	18.7	4.67
Mahmudu (table)	Brown	bigger, OİV243-9	8.0	7.2/4.8	14.5	1.10	18.8	2.1	6.3	18.2	63.8	4.0	18.4	4.92
Agadaiyee (table)	Light brown	bigger, OİV243-9	7.7	7.8/4.6	21.2	1.08	19.8	2.2	5.8	18.7	67.8	3.8	18.6	5.24
Cabernet Sauvignon (technical)	Dark brown with a red tint	big, OİV243-7	6.2	7.2/3.8	9.8	1.17	24.4	2.6	5.9	18.6	61.4	4.2	14.1	3.86
Moldova (universal)	Dark brown	bigger, OİV243-9	8.5	7.2/3.6	18.4	1.46	25.2	3.0	5.8	21.0	66.4	4.4	18.6	5.22
Merlot (technical)	Brown	big, OİV243-7	6.2	5.8/3.8	17.2	1.12	22.3	2.5	6.7	16.6	58.7	4.4	12.4	3.92
Doyna	Dark brown	bigger, OİV243-9	7.7	6.2/4.0	16.4	0.96	18.8	1.9	6.9	20.4	63.3	4.6	12.6	3.98
In rainfed condition														
Madrasa (technical)	Dark brown	medium, OİV243-5	3.8	5.4/3.2	6.8	0.84	25.6	2.0	5.8	17.8	58.4	4.8	11.4	1.43
Khyndogny (technical)	Light brown	big, OİV243-7	4.2	6.3/4.2	7.4	0.68	24.6	1.8	5.7	18.0	52.6	4.6	9.8	1.56
Bayanshira (technical)	Reddish brown	medium, OİV243-5	3.8	6.2/4.1	8.2	1.02	25.4	1.8	5.4	17.2	60.4	4.0	10.4	1.32
Moldova (universal)	Dark brown	big, OİV243-7	5.2	6.4/3.8	8.0	1.03	26.2	1.7	6.8	19.0	61.2	4.8	12.4	1.86
Cabernet Sauvignon (technical)	Dark brown with a red tint	medium, OİV243-5	3.8	5.2/3.2	6.2	0.78	24.6	1.7	5.6	17.6	54.8	4.2	9.2	1.38

***Source:** compiled by the authors*

S. Chelik's (2011) observations indicate that grape seeds contain moisture levels ranging from 25% to 45%, carbohydrates between 34% and 36%, fat content ranging from 13% to 20%, tannin at 4% to 6%, nitrogenous substances ranging from 4.0% to 6.5%, mineral substances at 2% to 4%, and fatty acids at 1%. As stated

by J. Yu *et al.* (2021) and D. Kök *et al.* (2017), once grape seeds are obtained from the winery and dried, the composition of the raw materials typically exhibits an oiliness indicator ranging from 15.2% to 17.5%, moisture content ranging from 6.2% to 8.0%, and a fluctuating amount of phenolic compounds within the range of 2.81% to 4.26%. The authors emphasise that the quality of seeds intended for grape oil production varies depending on factors such as variety, growing conditions, cultivation zone, and the method of seed separation from the residue.

The sizes of the grape seeds examined varied across different varieties. Specifically, the dimensions (including length and width) of grape seeds grown under irrigation conditions were measured as follows: Madrasa – 6.4/3.8 mm, Khyndogny – 7.2/4.6 mm, Bayanshira – 6.7/4.2 mm, Ag Kharji – 7.6/4.6 mm, Hana grna – 7.8/4.8 mm, Genjevi – 7.4/4.4 mm, Mahmudu – 7.2/4.8 mm, Agadaiyee – 7.8/4.6 mm, Cabernet Sauvignon – 7.2/3.8 mm, Moldova – 7.2/3.6 mm, Merlot – 5.8/3.8 mm, and Doyna – 6.2/4.0 mm. Additionally, the dimensions of grape seeds (length and width) grown under rainfed conditions were recorded as follows: Madrasa – 5.4/3.2 mm, Khyndogny – 6.3/4.2 mm, Bayanshira – 6.2/4.1 mm, Moldova – 6.4/3.8 mm, and Cabernet Sauvignon – 5.2/3.2 mm. A comparison between seeds grown under irrigation and rainfed conditions revealed that grape seeds from rainfed grapes were smaller in size compared to those from irrigated grapes. Additionally, notable differences were observed in the moisture content of grape seeds between the two growing conditions. These differences in moisture content ranged from 9.8 g (Cabernet Sauvignon) to 24.4 g (Genjevi) for seeds grown under irrigation conditions. Specifically, the moisture content of grape seeds grown under irrigation conditions was recorded as follows: Cabernet Sauvignon – 9.8%, Madrasa – 12.4%, Mahmudu – 14.5%, Khyndogny – 14.6%, Doyna – 16.4%, Merlot – 17.2%, Ag Kharji – 18.2%, Moldova – 18.4%, Bayanshira – 20.0%, Agadaiyee – 21.2%, Hana grna – 22.3%, and Genjevi – 24.4%. On the other hand, the moisture content of grape seeds grown under rainfed conditions ranged from 6.2 g (Cabernet Sauvignon) to 8.2 g (Bayanshira), with the following values: Cabernet Sauvignon – 6.2%, Madrasa – 6.8%, Khyndogny – 7.4%, Moldova – 8.0%, and Bayanshira – 8.2%.

During the research, an analysis was conducted to determine the nitrogen indicators of grape seeds grown under both conditions. It was found that the nitrogen indicators of grape seeds grown under irrigation conditions ranged from 0.96% to 1.46%. Specifically, the nitrogen indicators for grape seeds grown under irrigation conditions were as follows: in Doyna – 0.96%, Ag Kharji – 0.98%, Agadaiyee – 1.08%, Mahmudu – 1.10%, Merlot – 1.12%, Madrasa – 1.17%, Cabernet Sauvignon – 1.17%, Bayanshira – 1.18%, in Khyndogny - 1.22%, Genjevi – 1.33%, Hana grna – 1.42%, and Moldova – 1.46%. In contrast, the nitrogen indicators of grape seeds grown under rainfed conditions were found to range from 0.68 to 1.03%. These values were recorded as follows: Khyndogny – 0.68%, Cabernet Sauvignon – 0.78%, Madrasa – 0.84%, Bayanshira – 1.02%, and Moldova – 1.03%. Subsequently, analyses were conducted to determine the amount of cellulose in the seeds of grape varieties grown under both conditions was determined. The amount of this substance in the composition of seeds of grape varieties grown under irrigation conditions was in the range of 18.8 to 25.3%. Specifically, this indicator was observed in Mahmudu – 18.8%, Doyna – 18.8%, Agadaiyee – 19.8%, Khyndogny – 21.8%, Genjevi – 22.1%, Merlot – 22.3%, Bayanshira – 22.4%, Madrasa – 24.0%, Hana grna – 24.4%, Cabernet Sauvignon – 24.4%, Moldova – 25.2%, and Ag Kharji – 25.3%. The cellulose content in grape seeds grown under rainfed conditions ranged from 24.6% to 26.2%, with the following values: Khyndogny – 24.6%, Cabernet Sauvignon – 24.6%, Bayanshira – 25.4%, Madrasa – 25.6%, and Moldova – 26.2%.

When investigating the ash content in grape seeds from varieties grown under both irrigation and rainfed conditions, it was found to range from 1.9% to 3.1% in seeds from irrigated grapes. Specifically, in seeds from grapes grown under irrigation conditions, the ash content was determined as follows: Doyna – 1.9%, Madrasa – 2.1%, Mahmudu – 2.1%, Agadaiyee – 2.2%, Ag Kharji – 2.4%, Merlot – 2.5%, Cabernet Sauvignon – 2.6%, Khyndogny – 2.8%, Hana grna – 2.8%, Genjevi – 2.8%, Moldova – 3.0%, and Bayanshira – 3.1%. In contrast, the ash content in grape seeds from varieties grown under rainfed conditions ranged from 1.7% to 2.0%, with the following values: Cabernet Sauvignon – 1.7%, Moldova – 1.7%, Khyndogny – 1.8%, Bayanshira – 1.8%, and Madrasa – 2.0%. Furthermore, while conducting morphological, technological, and biochemical analyses of seeds obtained from grape varieties grown under irrigation conditions, the nitrogenous compound content in the seeds was also studied. The nitrogenous compound content in grape seeds ranged from 5.5% to 7.2%. Specifically, in seeds from grapes grown under irrigation conditions, the nitrogenous compound content was observed as follows: Bayanshira – 5.5%, Agadaiyee – 5.8%, Moldova – 5.8%, Cabernet Sauvignon – 5.9%, Madrasa – 6.0%, Genjevi – 6.2%, Mahmudu – 6.3%, Khyndogny – 6.4%, Hana grna – 6.5%, Merlot – 6.7%, Doyna – 6.9%, and Ag Kharji – 7.2%. Conversely, the nitrogenous compound content in grape seeds from varieties grown under rainfed conditions varied from 5.4% to 6.8%, with the following values: Bayanshira – 5.4%, Cabernet Sauvignon – 5.6%, Khyndogny – 5.7%, Madrasa – 5.8%, Moldova – 6.8%.

During the study, the quantity of non-nitrogen extractive substances in the seeds of twelve grape varieties grown under irrigation conditions was examined. The analysis revealed that the amount of non-nitrogen

extractive substances in the seeds ranged from 16.6% to 22.0%. This indicator varied among the different grape varieties, with values as follows: Merlot – 16.6%, Khyndogny – 18.2%, Mahmudu – 18.2%, Cabernet Sauvignon – 18.6%, Agadaiyee – 18.7%, Madrasa – 19.0%, Genjevi – 19.8%, Ag Kharji – 20.0%, Doyna – 20.4%, Moldova – 21.0%, Bayanshira – 21.4%, and Hana grna – 22.0%. In comparison, the quantity of non-nitrogen extractive substances in the seeds of grape varieties grown under rainfed conditions ranged from 17.2% to 19.0%, with values as follows: Bayanshira – 17.2%, Cabernet Sauvignon – 17.6%, Madrasa – 17.8%, Khyndogny – 18.0%, and Moldova – 19.0%.

Additionally, the amount of dry substance in grape seeds was determined during the study. It was found that the quantity of dry substance in the seeds of grape varieties grown under irrigation conditions ranged from 58.7% to 68.4%. Specifically, the dry substance content in grape seeds grown under irrigation conditions was observed as follows: Merlot – 58.7%, Cabernet Sauvignon – 61.4%, Bayanshira – 62.4%, Doyna – 63.3%, Mahmudu – 63.8%, Genjevi – 64.2%, Khyndogny – 64.4%, Madrasa – 65.0%, Moldova – 66.4%, Ag Kharji – 67.4%, Agadaiyee – 67.8%, and Hana grna – 68.4%. Conversely, the amount of dry substance in the seeds of grape varieties grown under rainfed conditions was lower, ranging from 52.6% to 61.2%, with values as follows: Khyndogny – 52.6%, Cabernet Sauvignon – 54.8%, Madrasa – 58.4%, Bayanshira – 60.4%, and Moldova – 61.2%. Furthermore, the tannin content in the seeds of the twelve grape varieties grown under irrigation conditions was examined. The tannin content was found to range from 3.6% to 4.6%. The tannin content varied among different grape varieties, with values as follows: Ag Kharji – 3.6%, Khyndogny – 3.8%, Agadaiyee – 3.8%, Madrasa – 4.0%, Mahmudu – 4.0%, Hana grna – 4.2%, Cabernet Sauvignon – 4.2%, Moldova – 4.4%, Merlot – 4.4%, Bayanshira – 4.6%, Genjevi – 4.6%, and Doyna – 4.6%. For grape varieties grown under rainfed conditions, the tannin content ranged from 4.0% to 4.8%, with values as follows: Bayanshira – 4.0%, Cabernet Sauvignon – 4.2%, Khyndogny – 4.6%, Madrasa – 4.8%, and Moldova – 4.8%. The oil composition of grape seeds is a crucial factor determining their economic significance. In the study, the percentage of crude oil was determined in the examined seed samples. It was evident that, depending on the cultivation conditions, the oil content in grape seed varieties varied significantly. The oiliness indicators of seeds from varieties grown under irrigation conditions ranged from 11.2% to 18.8%. Specifically, these indicators were as follows: Bayanshira – 11.2%, Madrasa – 11.9%, Merlot – 12.4%, Doyna – 12.6%, Khyndogny – 12.6%, Cabernet Sauvignon – 14.1%, Ag Kharji – 14.6%, Mahmudu – 18.4%, Moldova – 18.6%, Agadaiyee – 18.6%, Genjevi – 18.7%, and Hana grna – 18.8%. In grape varieties grown under rainfed conditions, this indicator ranged from 9.2% to 12.4%, with values as follows: Cabernet Sauvignon – 9.2%, Khyndogny – 9.8%, Bayanshira – 10.4%, Madrasa – 11.4%, and Moldova – 12.4% (Fig. 2).

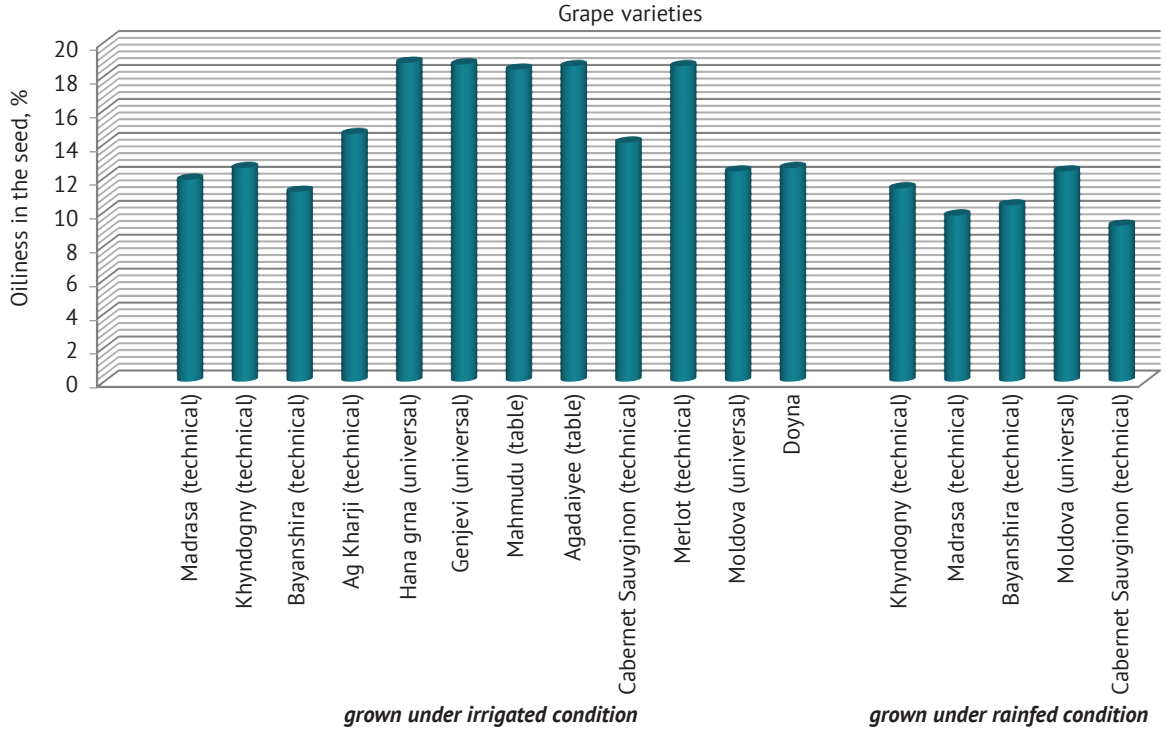

***Figure 2**. Oil extraction from the seeds of grape varieties grown under irrigation and rainfed conditions (using the cold press method)*

***Source:** compiled by the authors*

Based on statistical analysis, it became evident that there is a correlation between certain morphological, technological, and biochemical indicators of grape seeds and the oil extraction process. The study clarified that cultivation conditions exert a significant influence on the morphological, and biochemical indicators of grape seeds, as well as on oil extraction. Furthermore, the factors influencing oil extraction from the seeds were identified. Calculations conducted using the Pearson correlation method determined that the highest correlation with the amount of oil extracted via the cold press method was associated with seed mass, size, and the mass of 100 seeds. Notably, the correlation coefficient ranged between r = 0.72 and 0.80. Specifically, the correlation dependence between the mass of 100 seeds and oil extraction was most pronounced, with a correlation coefficient of r = 0.80 (Fig. 3).

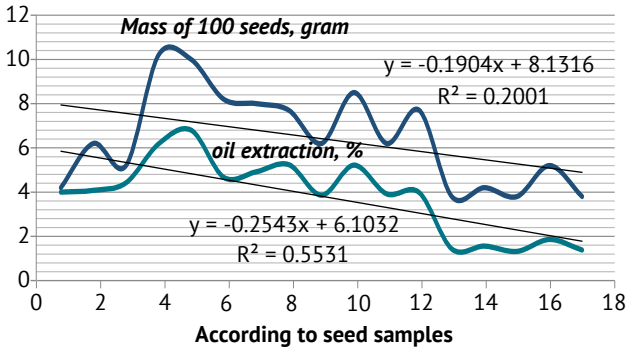

Figure 3. *Correlation dependence between the mass of 100 seeds and oil extraction*
Source: *compiled by the authors*

The morphological and biochemical composition of grape seeds varies depending on the prevailing growing conditions, highlighting the need for a broader scope of research. Improving technologies and updating protocols in the oil extraction process is essential to accommodate the distinct morphological and biochemical compositions of seeds from different grape varieties. Challenges arise in seed supply, storage, analysis, and preparation for oil extraction due to the novelty of these procedures. When using the cold press method to extract oils from seeds of various origins, notable distinctions are observed in the colour, taste, aroma, and overall appearance of the resulting products. However, in conducting biochemical analyses on oils derived from diverse grape varieties and grapes cultivated under differing conditions, the primary focus is on determining fatty acids. Unfortunately, the lack of appropriate devices and equipment remains a significant obstacle in this regard.

This study examines the potential of grape seeds in Azerbaijan, focusing on the impact of irrigation conditions on seed composition, oil content, and extractability using the screw press method. Despite existing research on the cultivation conditions of both local and foreign grape varieties in Azerbaijan, there remains a gap in understanding varietal characteristics, morphological traits of seeds, their sizes, and particularly their biochemical composition, notably the fat content. The Scientific Research Institute of Viticulture and Winemaking has conducted novel research into the biochemical assessment of grape seed varieties cultivated under diverse environmental conditions. This pioneering study included the determination of oil yield and explored the influence of cultivation conditions on oil production. Furthermore, the research analysed the morphological and biochemical composition of the seeds.

The winemaking industry has a long-standing history intertwined with ancient technologies and customs. To ensure its sustained existence, the wine industry must actively incorporate sustainable practices into its operations, acknowledging the critical need for long-term viability amid ongoing environmental and economic shifts (Santini *et al.,* 2013; Demirkol & Tarakci, 2018). A pivotal aspect of sustaining the viticulture sector lies in enhancing the quality of wine. This can be achieved by reducing chemical inputs and embracing responsible practices, thereby fostering long-term viability in business operations. A thorough understanding of the elements influencing soil quality is paramount, given their significant impact on the soil's efficacy in supporting plant growth, biodiversity, water retention, and pollution management. By discerning these factors, measures can be implemented aimed at sustaining soil health and preserving its critical ecosystem services (Cataldo *et al.,* 2021). Furthermore, beyond the adoption of sustainable practices, the preservation of vital natural resources such as soil, water, and biodiversity is essential for sustaining the long-term viability of the wine industry. Among the varied spectrum of grape cultivars native to Azerbaijan and adjacent regions, prominent varieties such as White Shani, Bayanshire, and Madrasa are recognized for their significant contributions to the area's abundant viticultural legacy (Sharifov, 2010). By preserving and promoting indigenous grape varieties that thrive in distinctive local climates, Azerbaijani winemakers both honour their cultural heritage and actively engage in biodiversity preservation efforts.

In the winemaking industry, the foremost drivers of sustainability initiatives include environmental values, individual preferences, and professional satisfaction (Gabzdylova *et al.,* 2009). This comprehensive strategy ensures that winemakers not only excel in producing exceptional wines but also play a pivotal role in advancing a more sustainable and harmonious world. The modern concept of a solar winery requires either the infrastructure or the winemaking procedures to actively utilise solar energy harvested from radiation incidents in the winery (Smyth *et al.,* 2011; Flores, 2018). Solar wineries employ photovoltaic (PV) panels to convert solar energy into electricity, strategically placing them on

winery rooftops, structures within vineyards, or nearby land to maximise sunlight absorption. This eco-friendly method reduces dependence on traditional energy sources, supports environmental preservation by reducing carbon emissions, and promotes the integration of renewable energy in the wine sector. The economic potential of renewable energy sources is estimated at 27 gigawatts, with solar energy constituting 23,000 megawatts of this estimate (AREN, 2024). The areas where this potential is most promising include the central river valleys, as well as the northern and western regions of Azerbaijan, where viticulture has flourished.

CONCLUSIONS

In the primary empirical segment, the investigation elucidates the nuanced interplay between grape variety traits, cultivation environments, and diverse morphological and biochemical features of grape seeds. The results emphasise that both the inherent characteristics of grape varieties and the environmental contexts of cultivation exert notable impacts on the dimensions, weight, fat content, and, consequently, the oil extraction capacity of grape seeds. Comparative analyses of grape seeds from different varieties grown under irrigated and rainfed conditions reveal discernible variations in key parameters. Specifically, grape seeds from vines grown under irrigation demonstrated a broader range of characteristics compared to those from rainfed vines. Seeds from irrigated grapes exhibited larger mass (4.2-10.2 g), greater dimensions (5.8/3.8-7.8/4.8 mm), and a higher oiliness index (11.2-18.8%). Conversely, seeds from rainfed grapes showed diminished values in these indicators, reflecting a reduction of 30-45%. Moreover, the investigation into oil extraction methods highlighted notable distinctions between grapes cultivated under different conditions. Cold pressing of seeds from irrigated grapes yielded oil extraction rates ranging from 3.86% to 6.80%, whereas seeds from rainfed grapes produced lower extraction rates of 1.32% to 1.86%. These findings underscore the distinct profiles of grape varieties cultivated under irrigation versus rainfed conditions, emphasising the nuanced effects of cultivation practices on seed characteristics and oil extraction potential.

In essence, the research underscores the importance of considering both grape variety characteristics and cultivation conditions when assessing the quality and potential utility of grape seeds. Understanding these factors is vital for optimising agricultural practices, refining seed processing techniques, and harnessing the economic potential of grape seeds in various industries. To enhance efficiency and enrich the raw material base for grape seed oil production, further investigation is imperative. This necessitates the resolution of existing challenges and the application of innovative approaches through additional research initiatives.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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Стійкість у виноробній промисловості та оцінка характеристик виноградного насіння під час переробки: докази з Азербайджану

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Анотація. У контексті розвитку виноробства в Азербайджані ця стаття досліджує сталість виноградарства з особливим акцентом на виноградне насіння, яке має важливе значення для розмноження виноградної лози, видобутку олії та загального здоров'я виноградників. Метою дослідження є вивчення морфологічних, технологічних та біохімічних характеристик виноградного насіння для вдосконалення методів виробництва винограду та просування практики сталого виноградарства. Для цього були ретельно зібрані та проаналізовані зразки насіння дванадцяти сортів винограду, як місцевих, так і інтродукованих, за різних умов зрошення, включаючи зрошувані та незрошувані ділянки, що дозволило провести всебічну оцінку. Дослідження виявило значний вплив зрошення на властивості насіння. Зокрема, було виявлено, що насіння зрошуваного винограду було більшим, важчим і багатшим за вмістом олії порівняно з насінням незрошуваного винограду. Детальний аналіз показав, що вміст азоту в насінні коливався від 0,96 % до 1,46 %, вміст целюлози – від 18,8 % до 25,3 %, вміст золи – від 1,9 % до 3,1 %, азотистих сполук – від 5,5 % до 7,2 %, а неазотистих екстрактивних речовин – від 16,6 % до 22,0 %. Важливо відзначити, що були виявлені кореляції між властивостями насіння та ефективністю екстракції олії холодним пресуванням, що дає цінну інформацію. Це дослідження в кінцевому підсумку сприяє просуванню практики сталого виноградарства в Азербайджані, забезпечуючи довгострокове здоров'я та продуктивність виноградників у регіоні

Ключові слова: сільське господарство; виноградарство; виноробство; технологічні характеристики; біохімічний склад

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The dynamics of catching aquatic bioresources in the south of Ukraine: Analysis, challenges and prospects for their solution in the context of sustainable development

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Abstract. Given the significance of fish farming as a promising sector of Ukraine's agriculture, and the Mykolaiv, Odesa, and Kherson regions are characterised by a significant number of natural and artificial water bodies, the study of aquatic bioresource catching indicators in the south is both important and timely. The research aimed to determine trends in aquatic bioresource catching in southern Ukraine during

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the period 2018-2023 and to analyse the factors influencing the extraction of aquatic bioresources. This article presents overall catch statistics, as well as catch data for inland waters of the south and aquaculture conditions over the past six years. It has been established that the catch of aquatic biological resources in southern Ukraine has been declining each year from 2018 to 2023. The negative trends in aquatic bioresource catching, both in aquaculture and natural water bodies, are linked to several factors. In particular, the decline in catches has been influenced by: COVID-19; the unstable military and political situation in Ukraine, associated with Russian military aggression; outdated material and technical base of fishing enterprises; lack of government subsidies and foreign investment in the sector; imperfections in the systems of control and regulation of the extraction of aquatic bioresources; and irrational use of the bioproductive potential of water bodies in southern Ukraine. Based on a scientific analysis of the dynamics of aquatic bioresource extraction in southern Ukraine and the identification of key factors contributing to the decline in catches, a set of measures has been developed to positively impact the fishing industry. These measures include: attracting foreign investment in fish farming; improving the quality of monitoring, regulation, and control over aquatic bioresource catching at local, regional, and state levels; restoring critical fish farming infrastructure damaged by Russian aggression; ensuring sustainable fisheries management; and introducing EU best practices into Ukrainian fish farming. The scientific results obtained from this research can be used in practice to ensure the sustainable development of fisheries in southern Ukraine

Keywords: water bodies; fisheries; sustainable fisheries; aquaculture; inland waters; rational use

INTRODUCTION

Fisheries is a significant sector of the global economy, especially in countries with significant water resources, and Ukraine is no exception. Given that fisheries products provide valuable food for the population and important raw materials for industry, studying trends in the extraction of aquatic bioresources at various territorial levels is highly important and relevant. Aquatic bioresources are highly sensitive components of aquatic ecosystems. Their life processes are influenced by both biotic and abiotic factors of the aquatic environment, which determine the level of fish stock development in water bodies of various origins. According to D.S. Archybisova and V.S. Suslov (2018), and A. Trofymchuk *et al.* (2021), the level of development of aquatic biological resources in water bodies is highly dependent on their ecological status and fluctuations in temperature. The economic efficiency of the Ukrainian fish product market has a significant dependence on demand. Numerous scientific studies indicate that in recent years, Ukrainian consumers have shown a greater preference for foreign fish products over domestic ones, significantly weakening this economic sector in Ukraine (Melnychenko *et al.,* 2021; Melnychenko & Bogadorova, 2023). It should also be noted that according to the research of I.I. Korman (2020), a large amount of high-quality Ukrainian fish products is exported to various countries around the world, while Ukraine, on the contrary, imports fish products at a price several times higher than domestic ones. This trend suggests that Ukrainian fisheries products are highly valued on the international market but, at the same time, are inaccessible to the Ukrainian consumer market.

The level of efficiency of fisheries operations is significantly dependent on the quantity of aquatic bioresources caught. In turn, the quantity of aquatic bioresources in water bodies is significantly influenced by the level of development of their natural food base, ecological factors, human anthropogenic activities, the structure of ichthyocenoses, and artificial feeds used for fish feeding (Okeke-Ogbuafor *et al.,* 2022; Zeng *et al.,* 2022). At the same time, the level of extraction of aquatic bioresources is also dependent on socio-economic and political factors that exert a so-called "external" influence, which has been characteristic of Ukraine for a long time. Given ongoing inflationary processes, armed conflict, revolutions, and COVID-19, the extraction of aquatic bioresources in Ukraine has been declining at an intensive rate since 2020 (Glebova & Shkarupa, 2019).

Ukraine offers a favourable environment for fisheries due to its abundance of water bodies, particularly in the southern regions. Numerous scientific studies indicate that the highest levels of aquatic bioresource extraction occur in Odesa, Mykolaiv, and Kherson regions (Bushuyev & Snihirov, 2020; Chepil *et al.,* 2021). Given the importance of the fisheries sector for food security and economic growth, an analysis of recent trends in aquatic bioresource extraction in southern Ukraine will allow for the identification of existing trends, as well as the factors influencing them, and the proposal of scientifically sound solutions to existing problems. The aim of this study was to analyse the trends and dynamics of aquatic bioresource extraction in Odesa, Mykolaiv, and Kherson regions during 2018-2023 and to identify the factors influencing it.

For the study, statistical data on the dynamics of aquatic bioresource catching in southern Ukraine were collected using informational websites of the territorial divisions of the State Service of Ukraine in the Mykolaiv, Kherson, and Odesa regions (Main Department of Statistics in the Mykolaiv region, 2023; Main

Department of Statistics in Kherson region, 2023; Main Department of Statistics in Odesa Region, 2023), as well as the State Strategy for the Development of the Fisheries Sector until 2030. The theoretical nature of the article involved the use of analysis, generalisation, statistical, graphical, and mathematical analysis methods. Analysis and generalisation allowed for an assessment of the theoretical aspects of fisheries sector development and the key factors influencing it. Statistical data on aquatic bioresource extraction over the past five years were used to identify trends and factors inhibiting industry growth. Based on this and the Strategy for the Development of the Fisheries Sector, measures were developed to improve the state of the sector and increase catch volumes. The mathematical method was used to calculate overall catch indicators, while the graphical method allowed for a visual representation of the dynamics of indicators in the form of histograms from 2018 to 2023, highlighting key trends in aquatic bioresource extraction in southern Ukraine.

REGIONAL ANALYSIS OF THE FISHING SECTOR IN SOUTHERN UKRAINE

Fisheries is a vital sector of the agricultural economy, serving not only as a profitable industry but also playing a significant role in providing the population with high-quality food products. "Fisheries" encompasses the extraction, processing, reproduction, and increase of various species of aquatic bioresources in water bodies of different origins. The fisheries sector provides not only valuable and high-quality food products but also medicinal, feed, and technical products. Currently, in Ukraine, there are two types of fisheries activities: fish farming, which is aimed at the rational reproduction of aquatic bioresources, particularly valuable commercial fish species; and fishing, which primarily aims at the catching of aquatic bioresources.

The southern region of Ukraine, comprising the Mykolaiv, Odesa, and Kherson regions, presents a promising area for analysing the extraction of aquatic bioresources. These regions are very well endowed with natural water resources, but due to the arid and hot climate, a large number of artificial water bodies have been constructed for agricultural purposes. For instance, in the Kherson Region, the total area of water bodies is 467.2 thousand hectares, accounting for approximately 16.4% of the entire region. Regarding natural water resources, the region is traversed by several water arteries, the largest being the Dnipro River and the Inhulets River. Additionally, a significant number of artificial water bodies for various purposes have been constructed within the oblast. As of 2023, there are 1,154 ponds within the region, primarily intended for fish breeding, multi-purpose use, and irrigation of agricultural lands. Furthermore, the region contains 15 small water storages of varying volumes, which, like the ponds, are mainly aimed at comprehensive use and fish breeding.

In the Mykolaiv Region, approximately 6.1% of its area consists of water bodies of various origins, amounting to 150 thousand hectares. The natural water resources in Mykolaiv include rivers such as the Southern Bug, Syniukha, Kodyma, Chornyi Tashlyk, Inhul, Chychykliia, Vysun, and Inhulets. Additionally, the region is home to 1,198 artificial water bodies with various intended purposes. There are 45 small water storages of varying capacities within the region, primarily aimed at irrigation, fish breeding, and comprehensive utilisation. Furthermore, the region has 1,153 ponds, where fishery activities are predominantly conducted.

In the Odesa Region, approximately 8.6% of the territory is occupied by water bodies of both natural and artificial origin, amounting to 286.6 thousand hectares. Odesa Region is home to two major rivers: the Danube and the Dniester. Additionally, the region contains a significant number of medium and small rivers, including the Chychykliia, Kodyma, Kuchurhan, Cogâlnic, and Tylihul. Beyond natural water bodies, the region also has ponds and small water storages, totalling 1,056 water bodies. Compared to other southern oblasts, Odesa has the highest number of small water storages – 64, with a total volume of 2,106.7 million cubic meters. As for ponds, their number in the region reaches 992, with a total volume of 198.0 million m^3. The ponds and small water storages of the Odesa Region, like those in other southern regions of Ukraine, are primarily constructed for irrigation, fish farming, and multi-purpose use. It should be noted that such a large number of natural and artificial water bodies in the Kherson, Odesa, and Mykolaiv regions provide a favourable foundation for the development of the fisheries sector specifically in southern Ukraine.

During the study, statistical indicators regarding the catch of aquatic bioresources in Odesa, Mykolaiv, and Kherson regions were collected and analysed. Statistical materials from the State Statistics Service of Ukraine (Main Department of Statistics in Kherson region, 2023; Main Department of Statistics in the Mykolaiv region, 2023; Main Department of Statistics in Odesa Region, 2023) indicate that the fisheries sector in southern Ukraine has reached a relatively high level of development. For instance, aggregated data on the extraction of aquatic resources in southern Ukraine in 2018 showed that the catch amounted to 37,168.9 tons, a significant figure compared to other regions of the country. Figure 1 shows that the highest extraction of aquatic bioresources in the southern region was observed in 2019 – 49,765.5 tons. However,

from 2020 onwards, a decline in this sector began, attributed to the COVID-19 pandemic. The lowest catch of aquatic bioresources during the studied period was characteristic of 2022, with a catch of only 12,439.5 tons. The main reason that negatively impacted the extraction of aquatic bioresources in 2022 was the Russian invasion of Ukraine and the ongoing active hostilities in the south, which has practically prevented economic entities from accessing water bodies. Starting from 2023, there has been a slight increase in the catch – 16,046.4 tons, associated with an increase in the extraction of aquatic bioresources in inland water bodies of Odesa and Mykolaiv regions.

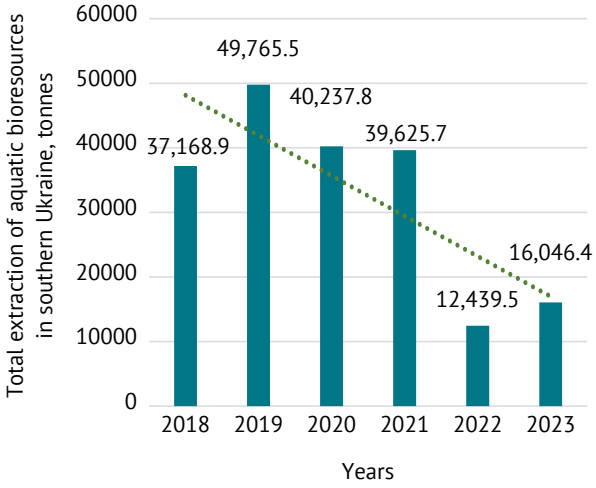

Figure 1. *Dynamics of aquatic bioresource extraction in the south of Ukraine for the period 2018-2023*
Source: *developed by the authors based on the Main Department of Statistics in the Kherson region (2023), Main Department of Statistics in the Mykolaiv region (2023), Main Department of Statistics in the Odesa Region (2023)*

It is important to note that in southern Ukraine, fish farming is also conducted under aquaculture conditions. Fish are primarily cultivated, reared, and bred in small water storages and ponds, as these water bodies possess significant natural bioproduction potential. Furthermore, compared to other regions, the south has a longer growing season, which positively impacts aquaculture overall.

Statistical data indicates that aquaculture is quite widespread in southern Ukraine. Figure 2 graphically depicts the dynamics of aquaculture indicators for the period 2018-2023, where it can be seen that the trends in the extraction of aquatic bioresources during artificial cultivation are similar to natural catches. Thus, in 2018, 676.7 tons of bioresources were caught from artificial water bodies in the south, the highest catch was observed in 2019 – 779.6 tons, and accordingly, the lowest – in 2023 – only 98.5 tons.

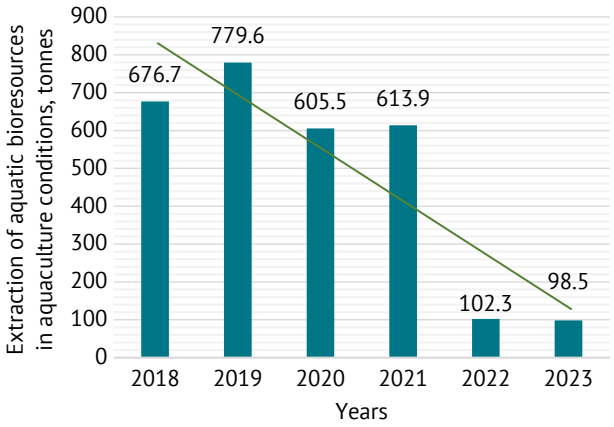

Figure 2. *Dynamics of aquatic bioresources extraction in the south of Ukraine under aquaculture conditions from 2018 to 2023*
Source: *developed by the authors based on the Main Department of Statistics in the Kherson region (2023), Main Department of Statistics in the Mykolaiv region (2023), Main Department of Statistics in the Odesa Region (2023)*

As mentioned above, southern Ukraine is quite rich in inland water bodies, where fishing activities are also actively conducted (Fig. 3). Analysis and graphical representation of statistical indicators regarding the extraction of aquatic bioresources in inland waters of the south showed that during 2018-2023, the highest catch was observed only in 2018 – 17,557.8 tons, and from 2019 onwards, there was a sharp decline in the catch of aquatic bioresources. However, in 2023, the catch of aquatic bioresources in inland waters amounted to 3,776.6 tons, indicating a certain "upturn" in extraction compared to previous years.

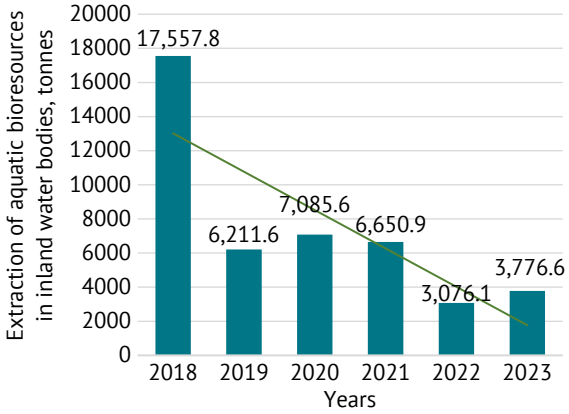

Figure 3. *Dynamics of aquatic bioresources extraction in the south of Ukraine in inland water bodies from 2018 to 2023*
Source: *developed by the authors based on the Main Department of Statistics in the Kherson region (2023), Main Department of Statistics in the Mykolaiv region (2023), Main Department of Statistics in the Odesa Region (2023)*

Therefore, in southern Ukraine during the studied period, there are negative trends in fish farming, except for a slight increase in catch in 2023 due to inland water bodies in Odesa and Mykolaiv regions. Given that Kherson, Mykolaiv, and Odesa regions have all the necessary prerequisites for the development of this sector, and most importantly, favourable climatic conditions and the presence of a large number of water bodies of various origins, fruitful cooperation between the state, scientists, and the public is necessary for the optimal development of this sector of the economy. Starting from 2019, the main factors "destroying" the fisheries sector of southern Ukraine have been the ongoing pandemic and active military aggression from Russia.

EXTRACTION OF AQUATIC BIORESOURCES IN THE SOUTHERN REGIONS OF UKRAINE: INDICATORS, TRENDS AND PROSPECTS

During the research, an analysis was conducted of the indicators for the extraction of aquatic bioresources across the southern regions of Ukraine – Mykolaiv, Odesa, and Kherson (Table 1). It was found that all three regions engage in the extraction of aquatic bioresources. The largest quantities are extracted in the Odesa Region, which is due to the presence of a large number of inland water bodies, marine areas, as well as ponds and small water storages. Smaller quantities, compared to the Odesa Region, are extracted in the Mykolaiv Region, and the smallest quantity is in the Kherson Region.

Table 1. *Dynamics of aquatic bioresource extraction by Odesa, Mykolaiv, and Kherson regions during 2018-2022*

Years	The total volume of extracted aquatic bioresources, tons	Including	
		Aquaculture, tons	Caught in inland waters, tons
Odesa Region			
2018	12,802.5	185.9	9,024.2
2019	17,059.0	268.9	3,923.2
2020	11,313.2	200.0	5,058.5
2021	10,472.9	185.8	4,732.0
2022	3,035.6	-	2,877.9
2023	3,609.2	36	3,546.3
Mykolaiv Region			
2018	18,777.6	-	19,591.4
2019	26,230.8	245.6	9,296.6
2020	23,168.4	193.8	8,839.2
2021	24,862.2	235.6	9,078.6
2022	9,403.9	102.3	14,229.6
2023	12,437.2	62.5	230.3
Kherson Region			
2018	5,589.8	490.8	9,350.2
2019	6,475.7	265.1	7,240.9
2020	5,756.2	211.7	13,952.3
2021	4,290.6	192.5	10,628.9
2022	-	-	-
2023	-	-	-

Note: *there is no data on the extraction of aquatic bioresources within the Kherson region for 2022 and 2023, as it was not carried out due to active hostilities and the ban on access to water bodies in the region*
Source: *developed by the authors based on the Main Department of Statistics in the Kherson region (2023), Main Department of Statistics in the Mykolaiv region (2023), Main Department of Statistics in the Odesa Region (2023)*

Such indicators can be explained by the fact that there are fewer water bodies of both artificial and natural origin in the Kherson and Mykolaiv regions compared to Odesa. Such trends in the extraction of aquatic bioresources are rather disappointing and may in the future lead to several negative consequences, including: given that fishery products are a valuable food product and a product for pharmacology and industry, there is a threat to the country's food security; a decrease in the volume of fish catches leads to Ukraine's import dependence on the global fish products market, and consequently to an increase in prices for fish food products; a decrease in the volume of fish caught can lead to the decline of this industry and the deterioration of economic indicators at both the regional and national levels (Fedchyshyn & Ihnatenko, 2021). Thus, both across Ukraine as a whole and in the south in particular, several factors hinder the development of the fishery sector. In this context, to achieve positive changes in the fisheries of southern Ukraine, the following measures are necessary:

1) at both the national and regional levels, enhance the level and quality of protection, sustainable use, and restoration of "valuable" aquatic bioresources that are popular targets for fish farming (Mugwanya *et al.,* 2022);

2) develop methods that stimulate the growth of the bioproductive potential of artificial aquatic ecosystems, while also employing existing methods such as ichthyomelioration and the application of organic fertilisers. These approaches will significantly increase the natural feed base, regulate the ichthyocenosis in water bodies, and facilitate the cultivation of valuable fish species through natural feeds, resulting in considerable positive economic impacts (Kamali *et al,* 2022);

3) ensure the sustainable development of aquaculture in southern Ukraine, as the region has a large number of small water storages and ponds with complex multi-purpose designs, which are, however, largely underutilised for fish farming (Fedorenko *et al.,* 2020);

4) utilising blockchain technology to obtain comprehensive statistical data regarding the industrial catch of aquatic bioresources, not only in the south but across all regions of Ukraine. This will provide reliable indicators for fishery management and help combat the "shadow" catch of aquatic bioresources (Gladju *et al,* 2022);

5) facilitate the restoration of infrastructure damaged by the Russian invasion that is directly linked to or impacts the fishery sector in the southern region. In this context, the restoration of energy facilities, logistical chains, the demining of water bodies, and support for the return of medium-sized enterprises to the region are of key importance (Starchak, 2023);

6) ensure effective and transparent government oversight of various types of fishery enterprises, which will enhance the efficiency of aquaculture activities in the region;

7) from the government's side, implement measures to stabilise the fishery product market in Ukraine, particularly in the south. Support for domestic fish product manufacturers and the substitution of foreign fish products with Ukrainian alternatives are essential (Sinenok, 2019);

8) foster close collaboration in the field of aquaculture with the European Union and the General Fisheries Commission for the Mediterranean, which will enhance the effectiveness of utilising Ukraine's industrial capabilities (Kovalenko *et al.,* 2022);

9) provide state subsidies and attract foreign investments into the fishery of southern Ukraine, which will help modernise technological processes for cultivating aquatic bioresources and increase their volume.

Such negative trends in the development of the Ukrainian fishing sector are linked to several factors. Thus, an analysis of existing research and statistical materials from the State Statistics Service of Ukraine (Main Department of Statistics in Kherson region, 2023; Main Department of Statistics in the Mykolaiv region, 2023; Main Department of Statistics in Odesa Region, 2023) has enabled the authors to identify significant reasons that have led to a decrease in the volume of aquatic bioresource extraction in southern Ukrainian regions. The following are the significant factors that have negatively impacted the fish farming sector in southern Ukraine: imperfections in the regulatory and legal framework for catching; the onset of war and active hostilities in southern Ukraine; an outdated material and technical base; irrational use of the natural productive capacities of water bodies; an insufficient level of development of innovative, scientific, technical, and breeding activities; and a high level of import dependence.

THE IMPACT OF POLITICAL, ECONOMIC, AND ENVIRONMENTAL FACTORS ON THE DEVELOPMENT OF FISHERIES INDUSTRY IN SOUTHERN UKRAINE: CHALLENGES AND PROSPECTS

The onset of the Russian-Ukrainian war in 2022 had a negative impact on the extraction of aquatic bioresources in southern Ukrainian regions. The unstable military and economic situation led to a significant decrease in the volume of aquatic resource extraction in the Kherson, Mykolaiv, and Odesa regions. Research shows that these territories are the most vulnerable to the ecological and economic impact of the war, which is reflected in the overall economic stability and state of aquaculture systems. In the study by N. Arakkal Thaiparambil and V. Radhakrishnan (2022), the challenges associated with achieving an economically sustainable aquaponics system were analysed. Emphasis was placed on the need for managing environmental resources in the face of international challenges, which include not only economic but also environmental aspects, especially in a conflict zone, as in the case of southern Ukraine.

As of 2023, due to active hostilities in southern Ukraine, a significant decrease in population has been observed due to intensive migration outflow, especially from the southern regions. Statistical data confirm that the largest number of people left these regions, leading to a significant decrease in economic activity and demand for fish products. Research (Yemtsev *et al.,* 2023) confirms this fact, indicating the problems of the functioning of the Ukrainian fishery under war conditions, in particular, the impact of population migration outflow on it. The closure of production facilities and a decrease in the consumption of fish products have become a topical issue for discussion in the context of the current challenges of managing regional development during wartime.

It should be noted that the Ukrainian fishing industry faces significant challenges that limit its development and impact the aquatic bioresources of the southern regions of the country. Active hostilities in large territories and the mining of water bodies hinder the normal functioning of fish farming enterprises. This significantly limits the industry's development opportunities

and contributes to the decline of existing infrastructure. The lack of an effective regulatory framework in the field of fisheries in Ukraine does not provide the necessary regulation and financing of the industry at all levels of management. National, regional, and local initiatives face significant difficulties due to a lack of funds and access to financing, leading to the closure of enterprises and the loss of development opportunities.

Statistical data indicates that 65% of fish farming in Ukraine has an outdated material and technical base, which negatively impacts the quality and volume of their production. This highlights the need for investments in the renewal of technical equipment and infrastructure to support the stable development of the fisheries sector. In comparison to the research of K. Yue and Y. Shen (2022), which examined the prospects of using new technologies in fisheries, the current challenges of the Ukrainian fishing industry point to the need for a comprehensive approach to modernising and supporting the sector to ensure sustainable development under difficult conditions.

In the context of high operational costs in fish farming, a significant portion of water resources remains underutilised. In particular, in southern Ukraine, approximately 85% of water bodies consist of artificial water objects – ponds and small water storages – which have the potential for irrigation and fisheries. However, most of them remain outside the production process due to significant economic costs, leading to the unprofitability of fish production. The irrational use of water bodies for fisheries is another unresolved problem. Regardless of whether they are natural or artificial aquatic ecosystems, southern Ukraine has significant bioproduction potential, determined by climatic conditions and the length of the growing season. However, fish farming often does not utilise the natural food base, or it is minimised in favour of artificial feeds, leading to the irrational use of the potential of water bodies. A comparison of these facts with the research of G.S. Araujo *et al.* (2022) shows that global trends in fisheries management take into account the effective use of water resources and bioproduction potential. The optimisation of these processes can play a significant role in the sustainable development of regional fisheries, including southern Ukraine.

For an extended period, unregulated and "shadow" catching has been occurring in southern Ukraine, leading to the depletion of aquatic ecosystems. This issue is extremely pressing as inadequate control and shortcomings in catching regulations cause significant damage to natural resources. Uncontrolled catching leads to a decrease in biodiversity, and the destruction of natural habitats for fish and other aquatic organisms, which in turn negatively impacts the ecological balance of the region's water bodies. The very low level of scientific support for the fisheries sector, especially selective breeding work in aquaculture, further exacerbates this problem. The lack of innovative research and modern approaches to fisheries management creates conditions for the degradation of aquatic ecosystems and a decrease in fisheries productivity. Selective breeding, which is the foundation for the development of aquaculture, requires significant investments in scientific research and innovation to ensure the sustainable development of the industry.

The research by V.V. Shekhovtsov and T.V. Yermolayeva (2021) highlights the theoretical and practical problems of rational use of aquatic bioresources in the context of Ukraine's sustainable development. In their research, they note that insufficient legal provisions and shortcomings in legislation lead to ineffective management of aquatic bioresources. They emphasise the importance of integrating scientific achievements into practical applications to improve the efficiency of natural resource use. In particular, A. Falola *et al.* (2022) stress the need to improve the legislative framework for regulating the catch of fish and other aquatic bioresources, as well as implementing modern methods of management and control. They also draw attention to the importance of developing research programs aimed at optimising selective breeding and introducing innovations in aquaculture, which can contribute to the sustainable and economically viable development of the fisheries sector.

Ukraine's high level of import dependency on the global fish products market is a pressing issue for the national economy. According to data from 2022, the Ukrainian population consumed 547.7 thousand tonnes of fish products, of which 84.1% were imported, and only 15.9% were domestically produced. This indicates a reliance of Ukrainian consumers on foreign fish products, which are imported into the country in significant volumes. For comparison, the research of N.M. Vdovenko *et al.* (2019) highlighted the issue of the competitiveness of the fisheries and aquaculture sectors in Ukraine, which is a key factor in the efficiency of the national economy. Their study analyses the state of the fisheries, identifies the factors influencing its development, and proposes ways to increase the sector's competitiveness.

According to the research, one of the main factors contributing to the low competitiveness of domestic fish products is the insufficient level of government support and investment in the fisheries. This leads to low productivity and limited production volumes, preventing Ukrainian producers from competing with imported products. Additionally, the absence of modern technologies and innovations in the fishing industry also acts as a barrier to the sector's development. Therefore, it can be stated that to reduce import dependency and increase the share of domestic fish products in the Ukrainian commodity market, it is necessary to focus on the development of fisheries and aquaculture in Ukraine.

CONCLUSIONS

Thus, the dynamics of aquatic bioresource extraction in southern Ukraine during the period 2018-2023 has a negative trend, caused by factors such as the COVID-19 pandemic; Russia's military aggression; an outdated material and technical base; the absence of state subsidies and foreign investment, as well as imperfections in the systems of control and regulation of aquatic bioresource extraction. It has been found that fisheries are an important sector of the agricultural complex of southern Ukraine and play a significant role in ensuring food security for the population and the ecological sustainability of aquatic ecosystems. Over the period 2018-2022, a negative trend in the extraction of aquatic bioresources was observed. In 2018, the total catch amounted to 37,169.9 tons, in 2019 – 49,765.5 tons, in 2020 – 40,237.8 tons, in 2021 – 39,625.7 tons, in 2022 – 12,439.5 tons, and in 2023 – 16,046.4 tons.

It has been established that to overcome negative trends in fish farming, it is necessary to implement measures such as: attracting foreign investment; improving the quality of monitoring, regulation, and control of aquatic bioresource extraction; restoring infrastructure, ensuring rational fisheries management, and implementing EU best practices. Key trends and factors influencing the development of the fisheries sector are considered, including the impact of military actions and the pandemic. Negative factors also relate to the outdated material and technical base of fisheries enterprises, the lack of state subsidies and foreign investment, as well as the irrational use of the water bodies' bioproduction potential.

Existing trends in the extraction of aquatic bioresources have been analysed using a graphical method, allowing for the visual representation of the collected statistical information and highlighting the trends present during the study period. Graphical methods revealed significant fluctuations in the catch of aquatic bioresources, including a decrease in 2020, which coincided with the COVID-19 pandemic, and a gradual recovery in 2021-2022, despite the impact of military actions. Thus, the results of the study indicate that to ensure the sustainable development of the fisheries in southern Ukraine, it is necessary to introduce comprehensive measures aimed at overcoming negative trends and utilising the available bioproduction potential of water bodies. The prospects for further scientific research on this topic lie in the study of the dynamics of the catch of aquatic bioresources within specific water bodies of individual regions of southern Ukraine, which will subsequently allow for the development of comprehensive, scientifically-based measures to improve the state of the fisheries sector.

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CONFLICT OF INTEREST

None.

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Динаміка вилову водних біоресурсів на півдні України: аналіз, проблеми та перспективи їх вирішення в контексті сталого розвитку

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Анотація. З огляду на те, що рибництво є однією з перспективних галузей сільського господарства України, а Миколаївська, Одеська та Херсонська область характеризуються наявністю великої кількості водних об'єктів природного та штучного походження, дослідження показників вилову водних біоресурсів на півдні є доволі важливим та актуальним. Мета дослідження полягала у визначенні тенденцій вилову водних біоресурсів на півдні України за період 2018-2023 рр. та аналізі чинників впливу на видобуток водних біоресурсів. У статті наведено загальні показники вилову водних біоресурсів, а також показники видобутку в розрізі внутрішніх водойм півдня та в умовах аквакультури за останні шість років. Встановлено, що упродовж 2018-2023 років на півдні України з кожним роком скорочувався видобуток водних біоресурсів. Виявлено, що негативні тенденції у вилові водних біоресурсів як в умовах аквакультури, так і в природних водоймах пов'язані з цілою низкою чинників. Зокрема, на спад у видобутку водних біоресурсів вплинули: Covid – 19; нестабільна військово-політична ситуація в Україні, яка пов'язана з російською воєнною агресією; застаріла матеріально-технічна база рибогосподарських підприємств; відсутність державних дотацій та іноземних інвестицій в галузь; недосконаліть систем контролю та регулювання видобутку водних біоресурсів; нераціональне використання біопродукційного потенціалу водойм півдня України. На основі проведеного наукового аналізу динаміки видобутку водних біоресурсів в межах півдня України, а також визначенні ключових чинників, які сприяли зменшенню кількості видобутку, було розроблено заходи, які мали б позитивний вплив на рибницьку галузь. До таких заходів, віднесено: залучення іноземних інвестицій в рибництво; покращення якості моніторингу, регулювання та контролю за виловом водних біоресурсів на локальному, регіональному та державному рівнях; відновлення критичної для рибництва інфраструктури, яка постраждала від російської агресії; забезпечення раціонального ведення рибного господарства; впровадження у рибництво України найкращих практик його ведення у ЄС. Отримані наукові результати досліджень можна використовувати на практиці з метою забезпечення сталого розвитку рибного господарства півдня України

Ключові слова: водні об'єкти; водойми; стале рибне господарство; аквакультура; внутрішні водойми; раціональне використання

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